U.S.
NAVAL ORDNANCE

A TEXT-BOOK

OF

NAVAL ORDNANCE AND GUNNERY.

PREPARED FOR THE

USE OF THE CADET MIDSHIPMEN

AT THE

UNITED STATES NAVAL ACADEMY.

BY

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PREFACE.

This work was undertaken by the Instructors in the Department of Ordnance and Gunnery at the Naval Academy, to supply a deficiency which has long been felt, and to render available, as far as possible, in a single volume the course of instruction hitherto pursued by the Cadet Midshipmen; thus relieving them from the necessity which at present exists, of copying manuscript notes on the subject.

The unsettled condition of various questions relating to ordnance, makes it necessary to prepare suitable text-books for to-day, which should be revised as often as the progressive development of the subject seems to require. Explosive-agents, rifled ordnance, gun-carriages, and many other branches of the subject, are in a state of transition, and it is impossible at the present moment to produce a complete and entirely satisfactory treatise on these subjects.

It is thought that no intelligent progress can be made in the subject of the manufacture of cannon, and of many of the stores used in their service, without some preliminary knowledge of the metallurgy of iron, and of the means of producing the metals employed. As this subject is not taught in any other department of the Academy it is given a place here.

A sufficient knowledge of mathematics, physics and chemistry, is attained by the students in their previous course, to enable them to grasp all the subjects treated in this work.

The subject of Field Fortifications was formerly taught in this department, but for want of time and an appropriate text-book it was taken out of the course. The last chapter, entitled "Naval Operations on Shore," has been arranged with a view of covering briefly the necessary ground in this branch.

In the compilation of the material employed, the writer is greatly indebted to Lieut.-Commanders C. W. Tracy, G. W. Coffin, N. Ludlow, and C. F. Goodrich, to Lieut. J. C. Soley, and to Professors J. M. Rice and D. Fisher. The advice, assistance, and manuscript notes of many other officers have likewise aided materially in the preparation of this work.

Department of Ordnance and Gunnery,
U. S. Naval Academy, Annapolis,
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THE FOLLOWING IS A LIST OF THE PRINCIPAL BOOKS AND DOCUMENTS WHICH HAVE BEEN CONSULTED OR QUOTED IN THIS VOLUME

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NAVAL ORDNANCE AND GUNNERY.

CHAPTER I.

CANNON METALS.

Section I.—Metallurgy of Iron.

1. Metallurgy of Iron * is the art of extracting iron from its ores. This metal is used in the manufacture of most of the engines of destruction that modern science has introduced into the art of war. In its pure state it is rarely found in nature, but its ores exist in great abundance in all parts of the world.

The natural compounds of iron which are available as ores of the metal, are chiefly oxides and carbonates. These scarcely ever occur in a state of purity, but associated with clay and other silicious minerals, or with limestone, which substances are useful as slag-forming components; and also with compounds of sulphur and phosphorus, which are deleterious impurities.

2. PREPARATION OF IRON ORES.—The ironstone, or ores of iron, when extracted from the mines, being in a very rough state, and intermixed with earthy substances, it is first necessary to prepare them for the *blast* or *smelting furnace.*

Ores are subjected to different treatment in different countries and at different mines, depending upon their value and quality.

3. Dressing.—Some ores are not subjected to any particular dressing, while others are separated from a portion of the intermingled clay and sand by sifting, crushing, stamping and washing.

* Bauerman.

These processes are usually accomplished by breaking-machinery and roller-crushing-mills. The machinery used for washing the ores generally consists of a horizontal staff armed with projecting knives or paddles, revolving in a cylindrical trough, through which a stream of water is kept flowing. The rough ore, after being well mixed up with the water by the action of the paddles, is carried by the stream into a settling-pit, where the heavier masses of clean ore deposit, while the finely divided earthy matter is carried off with the waste water.

Washing of ores is rarely practised, except in countries where labor is very cheap, or facilities for washing very great.

4. Weathering.—At some mines the ores are exposed to the action of the air for some time. Superficial oxydation takes place, the adherent fragments of foreign substances disintegrate, and can be readily removed; and impurities are also partially removed by rain.

5. Ironstone Breakers.—In order to attain the greatest regularity in the process of smelting, it is advisable that all charges of ores and fluxes should be reduced to fragments of nearly uniform dimensions. The size of the fragments should be proportioned to the height of the furnace and the greater or less susceptibility to reduction of the ore, varying from cubes of one to two inches in the side, to as much as four to six inches in the side. The limits are determined by the conditions required: the larger masses being only adapted for tall furnaces, when by the slow descent of the charges, sufficient time is allowed for the heat to penetrate to the interior, at the same time that a free passage is afforded to the upper current of the gas. Smaller pieces, on the other hand, although exposing a greater surface to the action of the reducing gases, pack closer together and offer greater resistance to the blast.

The reduction in size is effected by various mechanical means of breaking, the most advantageous of which are *crushing-rollers* and lever-machines called *breakers*. The material operated upon is sometimes raw ore and sometimes washed ore.

6. Roasting or Calcination of Iron Ores.—In this country roasting of ores is much less practised than in England and on the Continent; partly on account of the higher price of labor here, but chiefly because our principal ores—*hematites* and *magnetites*—are anhydrous.

The object of roasting is to expel the water, sulphur, arsenic and other impurities with which the ores are combined: all volatile matters are thus removed, the amount of iron is concentrated into a smaller weight, and as the fragments of mineral retain their form they are rendered porous and more readily susceptible of being changed in the subsequent operations in the smelting-furnace. The roasting is effected in various ways, which may be classified generally under two different heads.

7. *First. Roasting in the Open Air.*—This is done by distributing the ore in alternate layers with waste coal, wood or charcoal, and the pile thus formed is ignited and burned. This method is used in localities where fuel is cheap, when compared with labor, but is in many respects disadvantageous on account of the waste of fuel and the imperfect distribution of the heat, the interior of the pile often being heated to excess, with a partial fusion of the ore, when the outer parts have only attained the proper temperature.

8. *Second. Roasting in Furnaces or Kilns.*—This method is generally to be preferred when economy of fuel is of importance, as the heat of combustion is more perfectly applied, and a more uniform product is obtained, than is the case with the more rude method of roasting in the air.

The construction of the kilns in different localities varies considerably, but the principle of working is, in the main, the same everywhere.

The ore is piled above a thin bed of fuel at the bottom of the kiln shaft, which may be conical, cylindrical, barrel or wedge shaped, and when ignited is covered with layers of ore and fuel alternately until the shaft is full to the top or throat.

The ore roasted by the combustion of the fuel at the bottom, where the air has access to the kiln, is withdrawn, and the next layer falls; the deficiency being made good by fresh charges at the top. (Fig. 1.)

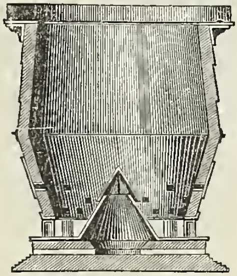


Fig. 1.

9. SMELTING is the process by which the iron is reduced to the metallic state, and separated from the refractory substances with which it is combined in the ore.

It consists in raising the ore to a high heat, in contact with carbon and a suitable *flux*, in the blast or smelting furnace. The *flux* unites with the earthy matter of the ore, forming a glassy substance called *slag* or *cinder*, and the carbon as carbonic oxide unites with the oxygen of the ore, setting the iron free; which in turn unites with a portion of the carbon and forms a fusible compound called pig or cast-iron.

10. FLUXES USED IN IRON-SMELTING.—In practice, very few ores are found to contain earthy ingredients in proportions sufficient to form readily fusible slags alone, and it therefore becomes necessary to supply the deficiency. This may be done, either by mixing ores of dissimilar composition in such quantities as shall yield slags of the desired composition, or by the addition of calcareous or aluminous minerals not containing iron.

The first of these methods is certainly to be preferred, as by it the slag is formed without unnecessarily reducing the percentage of iron in the charge or burden, taken as a whole: whereas, the addition of fluxes increases the weight of material to be passed through the furnace for the same produce of metal; but it can only be carried out in localities having a large and varied command of minerals. Usually, therefore, a combination of both methods is used, the best mixture of ores obtainable being supplemented by the addition of earthy minerals.

11. DIFFICULTY OF OBTAINING PURE METAL.—The reduction of iron ores can be effected practically only by carbon or carbonic oxide.

The principal flux employed in iron smelting is carbonate of lime in the form of limestone. As a very high temperature is necessary to effect the reduction, the metal almost always combines with a greater or less proportion of the reducing agent, as well as of other elementary substances; such as silicon, sulphur and phosphorus, that may be present either in the ore, the fuel or the flux; so that the ultimate result is never a pure metal, but a compound of iron with carbon, silicon, sulphur, phosphorus and sometimes manganese, and occasionally traces of other baser elements, as titanium, etc.

Small traces of foreign elements exert a very marked influence on the metal, and it is these small and in many cases unnoticed differences of composition, that render so many points in the chemistry and practical working of iron obscure and difficult to be understood.

12. COMPOSITION OF FLUXES.—The composition of the limestone to be used is of considerable importance, and depends upon the kind of ores employed. Chemical analysis alone can determine to which class a particular limestone belongs, as there is often nothing in the external appearance by which a pure limestone may be distinguished from one containing forty or fifty per cent. of foreign matter. Magnesium limestone is especially to be avoided as producing a very refractory slag.

The addition of fluxes to the blast-furnace is regulated by several considerations. When the ores are of good quality, the chief point to be considered is the production of the most fusible slag, with the smallest addition of non-ferriferous matters; this is more especially the case with charcoal-furnaces. When mineral fuel is used, however, it is necessary to form a slag that is capable of absorbing sulphur, which would otherwise be taken up by the iron ; and, for this purpose, a larger quantity of flux is used than that indicated by theory, as giving the most fusible product. The quality of the iron produced, depends greatly upon the kind of flux employed.

13. Slag is the vitreous mass which covers the fused metal in the smelting-hearth. It is commonly called *cinder*.

The physical character of slag, such as color, texture, fluidity, etc., varies with the composition and the working condition of the furnace, so that it is not possible from inspection alone, to determine the character of the metal produced, except after considerable experience of the individual furnace; and the relation between the slag and metal in one locality may be totally different in another.

14. Fuel. — The fuel used in iron-smelting varies in different localities and with the purposes for which the iron is intended. Charcoal is said to make the most superior iron, and is always used in the manufacture of iron for ordnance purposes. Coke is very generally used, and bituminous and anthracite coals are also employed.

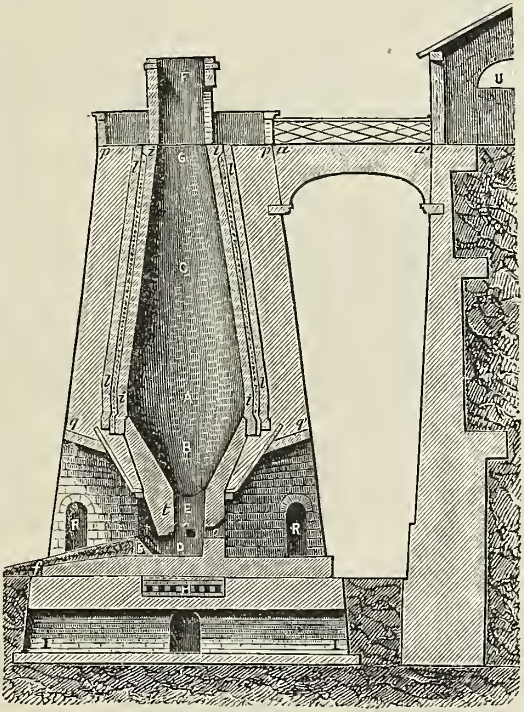


Fig. 2.—Blast-furnace for Smelting Iron Ores.

15. THE BLAST-FURNACE.—The means of reducing iron ore now almost universally in use, is the blast or smelting furnace. (Fig. 2.)

CONSTRUCTION.—This consists mainly of a tall shaft of brick and stone or of iron, and generally of the form of a truncated pyramid, but sometimes cylindrical or rectangular.

The construction of blast-furnaces varies considerably in different localities in regard to size and proportions of parts to each other, as well as material employed.

The height and dimensions vary with the nature of the ores and fuel used.

16. *The Stack.*—The interior has the form of two truncated cones, united at their bases. The upper one, C, which is the larger and more acute, is placed upright; it constitutes the furnace proper, and is known as the *stack.*

17. *The Boshes.*—The lower cone, B, which is inverted, is shorter and more obtuse than the other; their line of junction forming the widest part of the furnace, A, is called the *boshes*, and it terminates below in a space called the *hearth*, E.

18. *The Hearth.*—The hearth, properly speaking, is that part of the furnace only which receives the fluid metal and cinder as they fall below the level of the twyers, *o.*

Three of the sides of the hearth descend to the bottom of the furnace, or to the *hearth-stone*, while the fourth side, called the *tymp*, *t*, does not go all the way down, but leaves an opening, and is supported by an arch or by strong bars of iron let into the sides of the furnace.

19. *Furnace-lining.*—The interior of the furnace has a double lining of fire-brick, *i*, *l*, the space between them being filled with sand or broken slag to prevent injury to the outer wall by the expansion of the lining from the heat. The hearth and hearth-stone and boshes are built of refractory material because of the great heat which they have to endure.

20. DETAILS OF THE LOWER PART OF THE FURNACE.—Arched openings are built on each side of the shaft at the bottom, three of which are called the *twyer-arches*, and the other the *tymp-arch.*

21. *The Twyers*, or blast-pipes, are the ends of the pipes through which the blast is admitted to the hearth, and as they are exposed to a high temperature, they are cast so as to enclose a coil of wrought-iron tubes, through which a stream of cold water continually circulates. Fig. 3 represents a section of a twyer-nozzle thus protected, the cold water en-

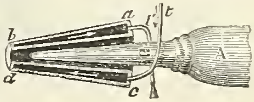


FIG. 3.

tering the casing by the tube *t*, and the hot water running off by the tube *t′*.

22. *Twyer-holes.*—Passages for the introduction of these pipes are perforated through the wall of the hearth, *o*, a short distance above the hearth-stone. These are known as *twyer-holes*, and vary in number.

The smaller charcoal-furnaces have often only two, placed on opposite sides of the hearth. Three is a more usual number, one being placed at the back, opposite to the tymp, and the others at the sides of the hearth. When a larger number is used they are generally placed at equal intervals all around the hearth.

23. *The Fore-hearth* is the front or working side of the hearth. This side is constructed differently from the others, its upper part being formed by a heavy block of stone, *g* (Fig. 4), called the *tymp-stone*, which is supported by a cast-iron *tymp-plate*, *p*, built into the masonry of the furnace; while the lower part is enclosed by the *dam-stone*, *b*, faced externally by a thick cast-iron *dam-plate*, *m*. That portion of the hearth which is shut in by the dam-stone is called the *crucible*, for it is here that the cast-iron produced in the furnace accumulates in a melted state covered with slag.

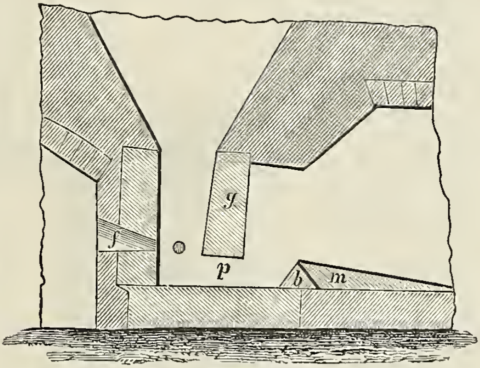


Fig. 4.

24. *The Cinder-notch.*—A semi-circular furrow in the top edge of the dam, known as the *cinder-notch*, forms a passage for the slag. In charcoal and other small furnaces the front of the dam is generally formed into a gently sloping, inclined plane, or *cinder-fall*, where the slag, as it runs out, solidifies in a comparatively thin layer, and may be broken up and removed by hand.

25. *Tap-hole.*—The tap-hole for withdrawing the molten iron from the hearth is a narrow vertical slit pierced through the dam, and extending from the hearth-stone upwards. During the time that the hearth is filling it is stopped by a packing of sand, rammed in tight, which can be easily perforated by a pointed bar at the time of casting.

26. *Tymp-stopping.*—The space between the top of the

dam and the tymp-stone is also stopped with sand or brick, a small passage being left for the escape of slag; this is called the *tymp-stopping.*

27. Details of the Top of the Furnace.—The top, or throat, of the furnace is surrounded by a platform for the convenience of charging, and is in many cases covered with a short cylindrical chimney which leads off the flame escaping at the throat, F. (Fig. 2.)

28. *Throat, Cup, and Cone.*—When it is desired to collect the gases given off at the top of the furnace, it is necessary to work with a closed throat.

The most simple contrivance for this purpose, and that most generally used, is known as the *cup* and *cone.* (Fig. 5.) It consists of an inverted, conical cast-iron funnel, A, fixed to the top of the furnace, whose lower aperture is of about one-half the diameter of the throat.

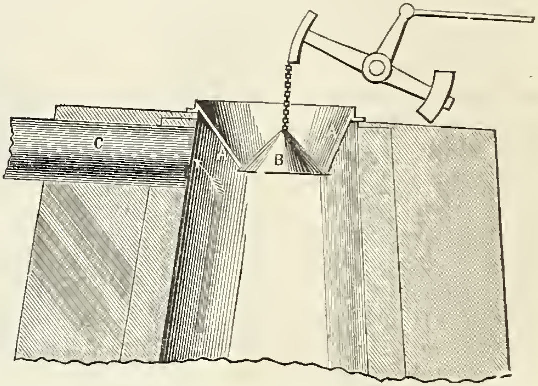


Fig. 5.—Cup and Cone for closing the Blast-furnace, in order that the waste gases may pass into the lateral flue, as shown by the arrow.

An upright cast-iron cone, B, is placed in the furnace below the cup; it is suspended by a chain attached to its apex, so that it may be raised or lowered at pleasure. In the former position it bears against the bottom of the cup and forms an air-tight stopper, preventing the escape of gas from the top of the furnace; which then finds its way out by the proper passage through the wall of the furnace, C.

29. *How suspended.*—The cone is suspended by an arch-headed lever, carrying a *counter-balance* at the end of the opposite arm.

The raising or lowering is effected by a pinion moved by a hand-wheel gearing into a ratchet attached to the counter-balance weight. The gas passes through a lateral flue into a wrought-iron main-pipe, which distributes it to the various pipes feeding the boiler fires and hot-blast stoves.

30. Charging.—The charges are thrown into the space enclosed by the cup, then by lowering the cone, it allows the charges in the cup to be dropped into the furnace and at the same time acts as a distributer; only the small amount of gas that is lost during the time of charging is allowed to escape, and as the operation is very quickly performed the current through the main-pipe is kept up with great regularity.

31. The Blast, or draft, in the furnace is introduced through the twyers, and is maintained by means of blowing-engines of various constructions.

32. *Pressure of Blast.*—The working-limits of blast-pressure vary with the nature of the fuel employed, and the burden of the furnace, etc.

A steady current in the furnace is accomplished by arrangements for equalizing the pressure, and its amount and force are indicated by means of gauges.

33. Temperature of Blast.—*How Determined.*—In practice the temperature of the blast is generally determined by its power of fusing metals, mercurial thermometers not being reliable for temperatures much above 400° or 500° F., owing to the irregular expansion of the mercury when near its boiling-point. This is done by exposing a thin rod of the metal to the current in the twyer, a hole being made for the purpose in the elbow of the branch-pipe connecting the twyer with the main blast-pipe.

34. The following table, from "*Bloxam on Metals*," contains the melting points of various metals:

TABLE OF FUSIBILITY.

Tin	melts at	442° F.
Cadmium	" "	442° "
Bismuth	" "	507° "
Lead	" "	617° "
Zinc	" "	773° "
Antimony *	" "	1,150° "
Silver	" "	1,800° "
Copper	" "	1,990° "
Gold	" "	2,000° "
Cast-iron	" "	2,780° "
Steel	" "	4,000° "
Wrought-iron	" above	4,000° "

* Estimates of temperature above the fusing-point of zinc cannot be regarded as exact, on account of the difficulty of ascertaining them.

35. Hot-blast.—When the stream of air forced through a furnace is heated above 300° or 400° F., it is called a hot-blast.

36. *Effects of Hot-blast.*—Whenever a forced stream of air is employed for combustion, the resulting temperature must evidently be impaired by the coldness of the air injected upon the fuel; fires fed with hot air should, with the same fuel, rise to a higher temperature than fire fed with common cold air.

Furnaces blown with heated air exert greater reductive power than those in which a cold-blast is used. This has led, since the introduction of hot-blast, to the extensive use in iron-smelting of refractory ores not formerly smelted; a large part of which have been ores of a class calculated to produce inferior iron; and it is to the use of ores of this nature, far more than from any deterioration in quality, arising from a heated blast, that the frequent inferiority of hot-blast iron is to be ascribed.

As the fusing metal is brought in contact with less fuel, and as less air is passed through the furnace, the chemical reactions are probably somewhat modified, but it is thought the quality of the product is not injured.

37. *Excessive Heat of Furnace.*—An excessive temperature in the furnace is injurious, because unnecessary heat of fusion injures the quality of the metal produced: dark-gray graphitic iron resulting always from intensity of heat.

But this can be regulated as well with the hot-blast as with the cold: since it depends on the fuel employed, the burden of ore, and the pressure of the blast, as well as its temperature.

38. Advantages of Hot-blast.—With fuels difficult of ignition, and with refractory ores, the advantages of the hot-blast are most marked. It effects a saving of heat, and accomplishes the reduction of the most refractory ores in less time and with a less expenditure of fuel than the cold-blast.

It is therefore employed at the present day almost to the exclusion of cold-blast, the latter being retained only for certain special makes, such as for gun-founding, which command an extra price, and may therefore be produced without strict regard to economy.

39. Warm-blast.—Even for purposes where it is desirable to produce the best possible quality of iron without regard to cost it is now customary to use a *warm-blast* rather than the cold; that is to say, a blast varying from 100° to 200° F., so as to obtain uniformity of temperature at all seasons of the year; which is not possible when using a blast absolutely cold.

40. Some of the latest experiments upon the comparative strengths of hot-blast and cold-blast irons appear to warrant the

conclusion, that so far as the temperature of the blast only is concerned, the hot-blast tends slightly to injure the quality of the softer (gray) irons, whilst it improves, sometimes in a very remarkable degree, the character of the harder (white) cast-irons.

41. Method of Heating the Blast.—The combustible gases from the stack are generally used to heat the air. For this purpose a kind of oven is built near the stack, and the inflammable gases are drawn off from the top and passed through it. In this oven are series of pipes through which the air is forced before it enters the stack; sometimes this oven is heated independently of the stack.

42. The amount to which the temperature of the blast may be raised with advantage does not appear to have any practical limit, except that arising from the necessity of keeping the apparatus tight, and avoiding its rapid destruction by excessive heat. Yet, Bell says 1,000° F. should be the limit even in the largest furnaces. (Art. 45.)

43. Blowing in is the operation of starting the furnace.

In manufacturing gun-iron charcoal is used with limestone as a flux.

To commence blowing in, first put a quantity of good dry wood in the bottom, raising it to a height of three or four feet, and then several tons of charcoal; over this are introduced regular layers of charcoal, flux, and a very light burden of ore. When the furnace is thus filled, to about one-third its height, the wood at the bottom is ignited. When the upper layers become incandescent the charging is resumed until the furnace is two-thirds full, the burden of ore being gradually increased, up to that necessary for producing gray iron of the proper quality in the ordinary working. When the fire reaches the top of the minerals the furnace is filled up to the top, and the blast turned on to about two-thirds its full force.

This continues for a time, when the blast is turned full on, and the charging goes on regularly.

The weight of the charges as well as the temperature and pressure of blast must be gradually increased so as to get to the proper burden by degrees.

44. Working of the Furnace.—When the furnace is at work or in blast it is kept filled to the top or throat, with alternate layers of fuel, ore and flux, the latter being mixed in proper proportions, to produce the most fusible combination of the earthy matters; a constant stream of air being maintained through the twyers, at a sufficient pressure to pass freely through the contents of the furnace.

45. Chemical Action in the Furnace.*—The oxygen of the blast coming in contact with a great excess of incandescent fuel is saturated, so to speak, at once with carbon, and carbonic oxide is formed. The heat thus generated, though not the maximum which the fuel would produce if burnt with excess of air, suffices to fuse the carburetted iron, and the silicious compounds descending from above; and they fall into the hearth when they separate by liquation into metal and slag. The latter, being specifically lighter, rises to the surface, and protects the former from the decarbonizing action of the blast.

The carbonic oxide produced, together with the inert nitrogen, rises through the incandescent materials of the furnace and at a certain height, within ten or fiften feet of the top of a fifty or sixty-five feet stack, where the temperature is comparatively low (probably not exceeding the melting-point of zinc), the reduction of the oxide of iron takes place. The reaction may be approximately expressed thus:—$Fe_2O_3 + 3CO = 2Fe + 3CO_2$.

The CO_2 formed reacts immediately on the hot coal, and is converted again to CO, and this reduces more iron oxide, and thus the interaction continues until certain proportions of CO and CO_2 obtain, when the reducing action of CO becomes less powerful than the tendency of CO_2 to oxydize the newly formed metal.

The power of CO_2 to oxydize iron over that of CO to reduce it increases with the temperature. At a high heat, too, an excess of CO is produced, as carbon reduces CO_2 better at high temperatures.

These facts, according to Bell, set a limit to the degree of heat at which the blast can be advantageously used.

The escaping gases searcely ever contain more than forty parts of CO_2 to one hundred CO by volume, and this is diluted with about two hundred parts of nitrogen.

It follows that only one-fifth of the carbon is wholly consumed in the blast-furnace.

Another important reaction takes place below the reducing-zone, depending on the fact that carbonic oxide is itself reduced with the elimination of carbon, or decomposed according to the formula $2CO = C + CO_2$ in the presence of metallic iron, and the lower oxides of iron at a certain temperature somewhat higher than that most favorable for the reduction of the iron oxide.

The spongy metallie iron, probably not wholly reduced,

* Bell's Chemical Phenomenon of Iron-smelting.

descends unmelted into the bottom portions of the furnace where the reduction is perfected, probably by the finely divided carbon resulting from the reaction described above. At the zone of fusion, just above the twyers, the iron combining with a portion of this carbon, and with varying quantities of silicon, etc., melts and falls into the hearth below as cast-iron.

46. PRODUCTION OF GUN-IRON.—It is very necessary that this should be of uniform strength and density. In order to produce the best quality of iron the greatest care is required.

All the materials which enter the furnace should be of the best and purest quality, and kept dry; regularly and uniformly mixed, and supplied to the furnace at regular intervals.

The temperature of the blast should be kept as nearly uniform as possible, without using what is termed the *hot-blast*, which is on no account to be used.

47. TAPPING.—The molten metal accumulating in the hearth of the furnace is removed at regular intervals by tapping, or piercing a hole through the lower part of the dam, and allowing the metal to flow into sand or cast-iron moulds placed in front of the furnace.

Before tapping, the blast is shut off and the tymp-stopping removed.

The tap-hole is opened by driving in the point of a wrought-iron bar, which is held by one man while another strikes the end with a sledge-hammer if necessary.

48. The molds, or pig-beds, usually consist of a series of furrows in the sand of the casting-floor, molded by a wooden core having the name or mark of the foundry attached to it.

The molds are arranged in parallel series on either side of a central feeder, known as a *sow;* and as soon as one series is filled the current is allowed to flow into the next, and so on, until the cast is completed. For gun-iron sand-molds should be used.

When this operation ceases the tap-hole is again secured, and the work proceeds as before. In this manner a furnace may be kept continually going night and day for years, until repairs render *blowing out* necessary.

49. PILING PIGS.—Each pig of any one run should be placed in a separate pile, and each of these piles should be kept separate in transportation, and be re-piled in the foundry yard in the same order as at the smelting-furnace.

These precautions are necessary in order to have an accurate history of the metal of which each gun is made.

Section II.—Cast-Iron.

50. Composition of Cast-Iron.*—The only substance with which iron is invariably and indispensably associated in cast-iron is carbon. By fusing finely divided iron with charcoal until the metal has taken up as much carbon as it will dissolve, a dark-gray mass is obtained, which is so brittle that it may be powdered in a mortar.

That carbon forms any definite compound with iron is very doubtful.

Iron seems to have the power of dissolving carbon at a high temperature, and on slow cooling the carbon is separated in distinct graphitic scales. If the cooling is very slow large crystals one-half to three-fourths of an inch long are formed, and graphite may be readily removed from the faces with a knife. On chilling gray iron the carbon is retained in a more intimate state of combination or solution, and cannot be separated.

As to whether the carbon is chemically combined, or whether it is carbon in another form than graphite simply dissolved in the iron, different opinions exist.

The percentage of carbon in the best varieties of pig-iron varies from three to rather over four per cent., except, perhaps, in the variety of iron known as *spiegeleisen*, which sometimes contains nearly five per cent.

51. Varieties of Cast-Iron.—On examining the fractures of freshly broken pieces of cast-iron, it will be found that some specimens have a silvery-white and others a gray color, caused by the presence of very minute particles of carbon, which are interspersed among the lighter-colored particles of the metal.

When the gray samples of cast-iron are acted upon by acid (diluted sulphuric or hydrochloric) the iron is dissolved, but the black particles of carbon are left, and these are found to possess the same properties as the natural variety of carbon, known as black-lead, or *graphite*, of which pencils are made.

When the white cast-iron is dissolved in acids very little black residue of carbon is left, because the greater part of the carbon, being intimately combined with the iron, is dissolved by the acid, or eliminated as gaseous hydro-carbons, and very little is presented in the form of graphite.

52. When a sample of gray cast-iron is melted, the particles of the free carbon are dissolved by the liquid metal becoming intimately combined with the iron; and if the melted mass be

* Bloxam.

suddenly chilled by throwing water upon it, or by running it when near its point of solidification into a thick iron mould, the carbon does not separate again, so that a mass of white cast-iron is thus produced.

53. It is more difficult to convert the white into the gray variety of cast-iron, but this can be done by exposing the melted metal to a high temperature, and allowing it to cool down very slowly, when a portion of the carbon separates from the iron, and the gray variety of cast-iron is produced.

The relative grayness or whiteness of pig-iron furnishes no real standard of quality as compared with the produce of other localities, but is rather an indication of the working condition of the furnace.

54. The variable qualities of ore, fuel, and limestone may exercise such an influence on the resulting crude iron as to render a low denomination of one manufacture of greater commercial value than a higher denomination of other makes. Other things being equal white cast-iron can be more readily and cheaply produced than gray, as the same amount of fuel is made to carry a larger burden of ore, and the charges are driven more rapidly. As, however, it can only be used for forge purposes, while the more expensive gray metal is available for making castings or malleable iron, it is usually sought to diminish its production as much as possible, except in special cases, where quantity of make or an extreme economy of fuel is desired.

55. Gray Cast-iron.—Since in gray cast-iron a smaller proportion of the iron is in combination with carbon, and more of it in the true metallic state, this variety would be expected to exhibit more of the properties of metallic iron. Accordingly the gray cast-iron is much softer and less brittle than white iron; it is in a slight degree malleable and flexible. The larger proportion of metallic iron contained in the gray cast-iron causes it to require a higher degree of heat before it begins to show signs of fusion, but it is capable of becoming very liquid at a sufficiently high temperature, so as to be easily run into molds. It becomes more fluid and preserves its fluidity longer than white iron; it expands on becoming solid so as to be capable of filling up the smallest cavities and depressions of a mold.

Gray cast-iron is about one-twentieth lighter than the white variety; its average specific gravity is 7.1. The gray iron rusts more easily in air and is more readily acted upon with acids than white iron, which may be ascribed partly to its containing more iron in an uncombined form, and partly to the acceleration of chemical action caused by the voltaic disturbance excited by the contact of the particles of graphite with the particles of iron in the presence of the acid; in the case of air, carbonic acid. This variety of iron is used for ordnance purposes

56. White Cast-iron.—Since in white cast-iron a considerable proportion of the iron is in intimate combination with carbon, this variety would be expected to present the characters of the compound of carbon with iron, described above (Art. 50); accordingly the white cast-iron is very brittle and extremely hard, so that a file will scarcely touch it, whereas gray iron is much softer, and admits of being filed and turned.

White cast-iron is softened at a lower temperature than gray, but becomes less perfectly fluid; in cooling it passes through the pasty or semi-fluid state, and contracts very considerably on solidification. It *scintillates* or throws off sparks, as it runs from the furnace, to a much greater extent than gray iron.

Its average specific gravity is 7.5.

White iron usually, but by no means invariably, contains less total carbon than gray iron. Its qualities generally are the reverse of those of gray iron, and it is therefore unsuitable for ordnance purposes.

57. There are two distinct kinds of white iron. *First*, That obtained from ores containing a larger proportion of *manganese* crystallizing in large plates; this variety, called *spiegeleisen*, is highly prized for making steel; and *Second*, That resulting from a heavy mineral burden of the furnace, or from a general derangement of its working, and that caused from the rapid chilling of fused gray iron.

58. Mottled Cast-iron is composed of a mixture of the white and the gray varieties in varying proportions, the gray iron sometimes appearing in specks, like minute flowers upon a white ground, whilst in other specimens the mass is composed of gray iron and the white iron appears in spots. Fine gray mottled iron from its great tenacity is known to be the best fitted for large castings where great strength is required, and is employed for gun-founding. It may be made by mixing white and gray iron, or by continuing gray iron in fusion for some time, until it gets the proper color. The kind of mottle will depend much upon the size of the castings. (Art. 364.)

59. Classification of Pig-iron.—Generally a medium-sized grain, light-gray color, lively aspect, fracture sharp to the touch, and a close, compact texture indicate a good quality of iron; while a grain either very large or very small, a dull earthy aspect, loose texture, dissimilar crystals mixed together indicate an inferior quality.

The produce of the blast-furnace is divisible into several qualities, which for practical purposes are determined by the appearance presented by a freshly fractured surface—a number of pigs taken from each cast being broken for the purpose.

The numerous gradations in the scale are mainly dependent on color or degree of grayness, texture or size of crystals, and their uniformity and lustre. The largest-grained, brilliant, and graphitic dark-gray metal is known as No. 1 pig, while the smaller-grained varieties, with diminishing lustre and color, are designated by the higher numbers as far as No. 4.

Beyond this point, when the metal ceases to be gray, it is usual to omit the numerical scale, and denominate the remaining qualities by their color, as *mottled*, *weak* and *strong mottled*, and *white*, the last being the lowest.

This classification is subjected to variations in different localities.

The gray numbers as far as No. 3, are also called *melting* or *foundry-pigs;* the lower qualities, which are only adapted for conversion into malleable iron, coming into the class of *forge-pigs.*

60. VARIATIONS IN COMPOSITION OF CAST-IRON.—Although carbon appears to be the only substance indispensably associated with the metal in cast-iron, the commercial varieties of this material always contain *silicon*, *phosphorus*, *sulphur*, and *manganese*, which are often present in considerable proportion, and are known to exercise an influence upon the character of the cast-iron; other substances, such as *titanium*, *cobalt*, *nickel*, *chromium*, *copper*, *vanadium*, *calcium*, *magnesium* and *arsenic* may also be discovered by a careful analysis of considerable quantities of cast-iron, but they are generally present in very small proportion, and are not known to produce any effect on the metal.

The following table illustrates the general composition of the three principal varieties of cast-iron:

	Gray.	Mottled.	White.
Iron	90.24	89.31	89.86
Combined carbon	1.02	1.79	2.46
Graphite	2.64	1.11	0.87
Silicon	3.06	2.17	1.12
Sulphur	1.14	1.48	2.52
Phosphorus	0.93	1.17	0.91
Manganese	0.83	1.60	2.72
	99.86	98.63	100.46

61. The difficulties attending the chemical analysis of cast-

iron are very great on account of the large quantity of iron which has to be separated from small quantities of the other constituents, so that, although numerous analyses are recorded, their results do not exhibit that agreement which is necessary in order that the composition of this material may be considered to be thoroughly established.

There appears to be little knowledge of a thoroughly satisfactory character with respect to the effect of different proportions of foreign matter upon the quality of iron, for the exact analysis of this material is tedious and difficult; and those who are competent to execute it in a trustworthy manner have rarely the opportunity of becoming practically acquainted with the behavior of the metal.

62. Silicon.—Next to carbon silicon, or *silicum*, is the commonest and most abundant constituent of cast-iron; its effect is very similar to that of carbon, and its tendency is to reduce the percentage of carbon. It is an element that is always present in every form of iron, although at times its quantity is very minute; the proportion of silicon being higher in the gray than in the white variety, and the greater the quantity of graphite in the crude iron, the larger the amount of silicon.

The best common iron contains from one to one and one-fourth per cent. of silicon. Such iron has a smoother face than inferior pig, and when struck with a hammer rings; it is brittle and crystalline; whereas inferior pig contains only two to four-tenths of silicon, is rough on the face or surface, breaks with less ease than the crystalline pig, and when struck sounds dead like lead, without ringing at all.

Silicon exists in cast-iron sometimes combined and sometimes separate, and is derived from silica in the ore or in the fuel; silica is a combination of silicon with oxygen, and when the latter is abstracted by the carbon at the high temperature of the blast-furnace, the silicon enters into combination with the iron.

The presence of a large proportion of silicon in cast-iron is generally considered injurious to its quality, the strongest cast-irons being those which contain a small quantity of that element.

Iron which has been smelted with coke contains a larger proportion of silicon than that smelted with charcoal, and hot-blast iron commonly contains more than that smelted by cold-blast.

The presence of silicon in pig-iron affects in a remarkable degree the yield as well as the strength of the bar-iron produced therefrom. It is necessary that this element should be removed as much as possible by a refining process, before the crude iron is submitted to the puddling process; but as this involves a great waste of material and trouble, it becomes an object of much practical importance to prevent, as far as possible, the presence of this element in the crude iron.

In refining iron the silicon is oxydized before the carbon, and in some cases the silicon is separated completely from the metal, existing only as traces. The time required to refine iron seems to depend upon the amount of silicon present in the pig; thus, gray iron requires much longer time than white, and when very silicious white iron or glazed gray pig is used, it is almost impossible to refine it.

It has always been the general impression that any amount of silicon in steel reduces its quality and seriously impairs its strength; good steel may, however, contain two per cent. of silicon, and its presence makes steel castings more solid.*

63. Manganese is seldom if ever absent from cast-iron, for it is a metal which very nearly resembles iron in its chemical properties, and is commonly found in iron ores, so that the same operation which reduces the iron in the blast-furnace also reduces the manganese, and this metal becomes alloyed or closely mixed with the melted iron.

The manganese has been found in the large proportion of one-sixteenth of the weight of the cast-iron, but it seldom exceeds one-fortieth.

The influence exerted by the manganese upon the character of the cast-iron is very decided, tending to the production of the white variety, the manganese diminishing the tendency of the carbon to separate in the form of graphite.

White cast-iron, therefore, is found to contain the largest proportion of manganese.

The spathic iron ores yield a cast-iron containing a particularly large quantity of manganese, sometimes exceeding one-tenth of the weight of the cast-iron. Such an iron is capable of containing upwards of one twenty-fifth of its weight of carbon in combination with it, and the compound thus formed crystallizes in large and shining plates, whence it is named by the Germans *spiegeleisen*, or *mirror-iron*. It is largely employed in the manufacture of Bessemer steel.

It has been asserted that the presence of manganese in iron ores encourages the passage of phosphorus, sulphur, and silicon into the slag, thus reducing the proportion of those injurious impurities in the metal.

* Riley.

64. Phosphorus is one of the most unwelcome ingredients in iron ores, from the ease with which it passes into the metal during the smelting process, producing the most injurious effects, if present in more than a very small proportion.

Practically speaking, all the phosphorus in the ore and in the fuel passes into the pig-iron made; like silicon it makes pig-iron weak, although it is thought that when the amount is not more than one-half to three-fourths per cent., the strength of the pig-iron is not materially affected by it.

Phosphorus occasionally forms between one-fiftieth and one-sixtieth part of the weight of cast-iron, but about one-hundredth part is a more common proportion of phosphorus. It exists in combination with a portion of the metal as *phosphide* of iron, and is derived either from phosphate of iron contained in the ore, or from phosphate of lime, which is frequently present in the limestone employed as a flux, and in minute quantity in the coal. These phosphates contain phosphorus in a state of combination with oxygen, which is abstracted by the carbon of the fuel in the blast-furnace, and the phosphorus thus set free enters into combination with the iron. So completely is the phosphorus taken up by the metal, that only traces of that element in the form of phosphates are usually found in the slag from the blast-furnace.

The effects of phosphorus are to harden cast-iron, decrease its strength, and increase its fusibility. Iron made from ores containing much phosphorus is always *cold-short*, or incapable of being wrought cold under the hammer without breaking.

65. Sulphur, though almost invariably contained in cast-iron, rarely forms as much as one-fiftieth of its weight. It is chiefly derived from *ironpyrites*, which is the yellow substance, of metallic appearance, so common in lumps of coal, and may be found in rusty globular masses on the sea-beach.

It is composed of iron combined with sulphur in nearly equal proportions, and since crystals of ironpyrites are found in many iron ores, it is the chief source of the sulphur, which is the most objectionable impurity in iron.

The most prejudicial form in which sulphur can exist in the blast-furnace is when it occurs as sulphide of iron; it has no prejudicial effect when it exists as sulphide of calcium.

Large quantities of sulphur may be present as a sulphate of an alkaline earth without having any effect on the quality of the iron produced.

The white varieties of cast-iron contain a larger proportion of sulphur than the gray, and it will make gray iron white. It is thought that slightly different amounts of it may modify the pig-iron, and produce the difference we find in it, for practically there is a very great difference in the working of the different grades of iron, when chemically speaking there may be no difference apparent.

The percentage of sulphur usually increases as the quality of the pig decreases, and its presence tends to *red-shortness* in bar-iron, rendering it incapable of being worked at a red heat under the hammer. This element also imparts to crude iron the property of becoming viscid and of solidifying quickly with cavities and air-bubbles.

Iron may be both red-short and cold-short at the same time. Such iron is the worst possible iron, and is made from ores containing a high percentage of sulphur and phosphorus.

Section III.—Wrought-Iron.

66. Wrought or Malleable Iron.*—This is the nearest approach to the chemically pure metal that can be obtained on the large scale, and may be almost absolutely free from carbon. It never contains more than one-fourth per cent.

67. It is a soft, malleable, and extremely tenacious substance, infusible except at extreme temperatures obtainable in furnaces of special construction, but capable of being agglomerated by pressure, when at a white heat, to a compact state by the process of welding.

68. How Produced.—It may be produced either directly from the ore, or by the conversion of pig-iron.

Varieties.—The varieties of malleable iron are distinguished by many different names, but they have reference rather to form and destination than to difference of composition.

69. Conversion of Crude into Malleable Iron.—This is effected by one or more operations, which are necessarily of an oxydizing nature, the object being to eliminate from the cast-iron the carbon in the form of carbonic oxide gas, and the silicon, sulphur, phosphorus, and other foreign bodies in the form of oxydized products which pass either partially or wholly into slag or cinders.

70. Various Processes.—The numerous processes employed in the production of malleable from cast-iron are divisible into two classes, according to the nature of the furnaces employed.

First. The *open-fire*, or *hearth-furnaces*, where the pig-iron

* Bauerman.

is melted and decarbonized in a shallow hearth before the blast of an inclined twyer.

Secondly. The *puddling-furnaces*, where the same operation is performed on the bed of a reverberatory furnace.

71. Chemical Reactions.—The reactions going on during the process are similar in either case.

The carbon, if it exist originally as graphite, first passes into the combined state, and is then converted into carbonic oxide either by the oxygen of the blast directly, or indirectly by the oxide of iron dissolved in the slag.

Oxydizing agents for the indirect conversion may be derived from the pig-iron under treatment, which is always oxydized to a certain extent under the influence of the blast during the melting, or they may be added in the form of ore, forge-scales, or slags.

According to the relative importance of the parts played by these agents, the process is divided into *dry* and *wet* puddling, the former being dependent mainly on the exposure of the metal to the action of the air, while in the latter, which is more generally known as the *pig-boiling* process, the slag and oxide of iron added are the most important oxydizing agents.

The removal of the foreign matter in combination with the iron takes place in the following order:—first, silicon, then manganese, then phosphorus, and lastly sulphur, the latter element being most difficult of removal.

In the treatment of gray pig-iron, the graphitic carbon is transformed into the combined condition after the removal of the silicon during the melting of the charge.

72. Kind of Iron most suitable for Conversion.—White cast-iron is more suitable for conversion into malleable iron than gray, as in it the whole of the carbon in combined with the iron, and it does not, when raised to a high temperature, pass immediately from the solid to the liquid state, but assumes, when near its melting point, an intermediate or pasty condition favorable to the more effectual action of the air or other agents employed in the removal of the combined carbon. Gray metal, on the other hand, though requiring a higher temperature for fusion, becomes very liquid, and in a deep hearth sinks below the level of the blast, and, becoming covered with a coating of slag, is completely protected against the action of the air, unless it is brought under the influence of the blast by stirring or lifting with an iron bar, an operation which involves great labor and delay, as well as an increased expenditure of fuel and waste of iron.

No sensible amount of decarburation takes place until the whole of the graphitic carbon has entered into combination with the iron, or, what amounts to the same thing, until the metal has passed from the gray to the white state; and this conversion is an essential preliminary in all refining processes where the air is introduced above the surface of the melted metal.

73. Refining.—Gray pig-iron is often subjected, as a first step in the process of making malleable iron, to a preliminary decarburation in the oxydizing *blast-hearth*, or *refinery;* this process is called refining.

74. The Puddling Furnace is of the reverberatory form, one in which the flame is made to pass over a bridge and then beat down again or reverberate upon a hearth or surface on which the materials to be heated are placed.

It consists of an oblong casing of iron plates (Fig. 6), firmly bound together by iron tie-bars, and lined with fire-brick.

The fireplace, F, is separated from the hearth, A, by a *fire-bridge* over which the heated products of combustion with a surplus of oxygen play upon the surface of the molten metal, effecting its conversion, and thence pass through the flue to a

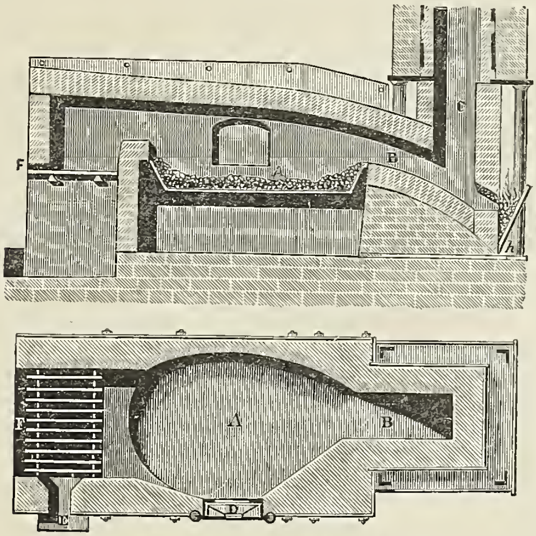


Fig. 6.—Puddling Furnace.

lofty chimney, C, in which is suspended a metal damper-plate, by which the draught can be regulated.

The Fireplace varies in depth with the nature of the fuel employed, being greatest with the hard kinds of coal.

The fire-grate is made of plain wrought-iron bars. A forced draught, produced by blowing air in below the grate, is sometimes used. The surface of the grate should be between one-half and one-third of that of the bed or hearth.

The charging or fire hole is about a foot above the grate.

The hearth.—The bottom of the bed is formed of cast-iron hearth-plates resting upon cast-iron beams.

The hearth is covered with cinders or sand, and is terminated at either end by a straight wall or bridge, called respectively the *fire-bridge* and the *flue-bridge.*

The Flue.—The roof of the furnace is curved to a flat arch, and is generally made to slope at a small angle towards the flue, which slopes towards the stack.

The sectional area of the flue varies with the nature of the fuel, being larger for soft coal.

The main working-door, D, is made of brick set in a cast-iron frame; it may be readily lifted and lowered by means of a lever. It is only opened during the introduction of the charge and the removal of the puddled balls. The sill of the door is about a foot above the level of the bed. There is sometimes a second working-door near the flue for introducing the cast-iron, so that it may soften slowly till it be ready for drawing towards the bridge.

The Stopper-hole.—A small rectangular or arched notch, called the stopper-hole, is cut out of the lower edge of the door for the introduction of the tool used in stirring the metal, and through which the workman can observe the state of the furnace. It may be closed air-tight.

The Tap-hole, through which the slag, or tap-cinder, is withdrawn from the hearth, is placed below the door-sill. It is plugged up with sand. A portion of the cinder also overflows the flue-bridge, and runs down the inclined surface of the flue to the bottom of the stack, *h*.

75. Process of Puddling.—Although the process of puddling is susceptible of considerable modification according to the nature of the pig-metal employed and that of the iron which it is desired to produce, it may be generally stated to include the following operations:

1st. Melting down of the charge with or without the previous heating.

2d. Incorporation of oxydizing fluxes with the charge at a low heat.

3d. Elimination of carbon by stirring the contents of the furnace at a high temperature.

4th. Consolidation of the reduced iron to masses or balls fit for hammering.

76. Charging the Furnace.—Pieces of metal are successively introduced with a long shovel, and laid one over another on the sides of the hearth in the form of piles rising to the roof, the middle being left open for puddling the metal as it is successively fused. The piles are kept separate to give free circulation of air round the metal. The working-door of the furnace is now closed, fuel is laid on the grate, and the mouth of the fireplace is filled up with coal; at the same time the damper is entirely opened.

In puddling refined metal, or in dry puddling, the furnace is charged with metal alone, but in puddling gray metal, that is, in wet puddling, or boiling, as it is termed, *forge-cinder* is charged along with the metal, and the temperature rises much higher.

77. Puddling-tools.—The tools employed are principally of two kinds, namely, long, straight, chisel-edged bars, or paddles, and hooked bars with similar flat ends, called *rabbles*. The number of tools used in the working of one charge depends on the quality of the iron, and may vary from four to eight, according to the amount of work required. When withdrawn from the furnace, the points are coated with molten cinder, which is removed by quenching the bar in a cistern of cold water.

78. In order to lessen the great amount of labor involved in working the charge, various mechanical appliances have been proposed in substitution for manual puddling, but these as yet have not been adopted to any great extent. They may be generally classified under two heads, namely, those imitating the motions of hand-stirring, and those using rotating or oscillating hearths.

Dank's rotatory puddling-furnace is the most successful of these, and is being introduced quite extensively. It produces a better quality of iron with much less labor, and in less time than is possible by hand-puddling.

79. Manipulation of the Molten Iron.—When the metal begins to soften, the workman or puddler introduces the rabble through the stopper-hole for the purpose of working the metal. The amount of handling required in this part of the process depends upon the nature of the iron operated upon.

80. *White or Refined Iron.*—When this is used it requires a continuous operation, which calls for much care and skill on the part of the workman. The pieces of metal that begin to melt are detached from the piles with the rabble, and new surfaces opposed to the action of the heat; as it softens it is removed from the vicinity of the fire-bridge, to prevent the metal from running together.

When the whole of the metal is reduced to a pasty condition, the temperature of the furnace is lowered to prevent its becoming more fluid. The puddler now works about with his rabble the clotty metal, which swells up exhibiting a kind of fermentation, occasioned by the discharge of carbonic oxide, burning with a blue flame as if the bath were on fire. The metal becomes finer by degrees and less fusible, or, in the language of the workman, it begins to *dry*. The disengagement of carbonic oxide diminishes and soon stops. The workman continues meanwhile to puddle the metal till the whole charge is reduced to the state of incoherent sand; the damper is then progressively opened. With the return of heat the particles of metal begin to agglutinate, the charge becomes more difficult to raise, or, in the language of the workman, it works *heavy*.

The refining is now finished, and nothing remains but to gather the iron into balls.

81. *Gray Pig-iron.*—With this variety of iron, which requires a higher temperature for fusion, but which runs very liquid, the fragments may be melted down without being moved, if the furnace is sufficiently hot.

Oxydizing agents are charged with the iron. In order to bring about the reaction of the slag upon the melted metal it is necessary to incorporate the whole contents of the furnace well together after melting. For this purpose the temperature is lowered by checking the draught or even throwing water upon the metal, the charge being stirred at the same time.

The slag is also reduced to a more basic condition by the addition of *scale*, or *mill-cinder*, to compensate for the silica produced from the oxydation of silicon in the pig.

When the mixture is complete and the mass somewhat stiffened, the reaction of the oxide and silicate of iron upon the combined carbon is apparent by the escape of blue flames of carbonic oxide, and as the temperature is increased by opening the damper the whole surface commences to boil, from the rapid escape of gas, and at the same time a portion of the molten slag flows out. The action is facilitated by constant stirring with the rabble.

As the carbon diminishes the ebullition becomes less violent, and the bath from its reduced fusibility in spite of the high temperature begins to stiffen, and malleable iron separates, or, as it is called, *comes to nature*.

At this point of the process the whole contents of the furnace require to be well stirred and broken up, so that every part may be brought under the influence of the high temperature. The reduced mass is subject to a final heat in order to facilitate the separation of the cinder by rendering it perfectly fluid.

82. The Puddle Balls.—The last operation consists in forming up the balls, which is done by detaching from the reduced iron masses from sixty to eighty pounds weight each, and pressing them together with the tool until they are sufficiently coherent to be moved without falling to pieces. This may be done either by pressing against the bottom and sides of the furnace, or by a rolling motion, the iron being gathered up around a small nucleus like a snow-ball.

As soon as a ball is made, it is placed close against the fire-bridge to keep it hot and out of the draught of air between the working-door and the flue; the second is proceeded with until the whole of the charge has been balled up; the stopper-hole is then closed, and the final heat is given to facilitate the operation of *shingling.*

The removal of the balls, which are of a roughly spherical form, after they are drawn to the working-door with the tool, is effected by means of a long pair of tongs with curved jaws. They are first lifted to the iron table in front of the working-door, and afterwards either dragged along the floor or carried on a wrought-iron truck to the hammer, or such other machine as may be employed for shingling.

83. Shingling, or Blooming, is the process of converting the puddle balls into malleable stuff by hammering or compressing.

A Bloom is a rough lump or bar of wrought-iron which results from the shingling process.

84. *Shingling Machines.*—The machines used in the compression and welding of the rough balls of malleable iron into blooms are of two different kinds, namely, *hammers* and *squeezers,* the former acting by percussion, and the latter by compression. In addition to these, it is usual to reduce the blooms so obtained to short rough bars by passing them at the same heat through a rolling-mill.

85. The Finished Bar.—The rough bars, or slabs, of malleable iron obtained in the process of puddling and shingling, require to be subjected to other treatment in order to produce finished, or merchant iron.

For this purpose they are cut into short lengths, which are made into nearly cubical packets or *piles* and subjected to a further consolidation by hammering and rolling, at a welding-heat, until a bar with a uniformly smooth surface, free from flaws or cracks, is obtained.

86. Rolling-mills.—These are used in the production of finished iron from the blooms. In its simplest form a rolling-mill consists of two cast-iron cylinders placed with their axes

horizontally one above the other, and connected by spur-gearing, so as to revolve at the same velocity. (Fig. 7.)

The surface of the rolls may be either smooth, as is the case in the plate-mills, or grooved into various patterns, as in those used for the production of merchant bars. (Fig. 7.)

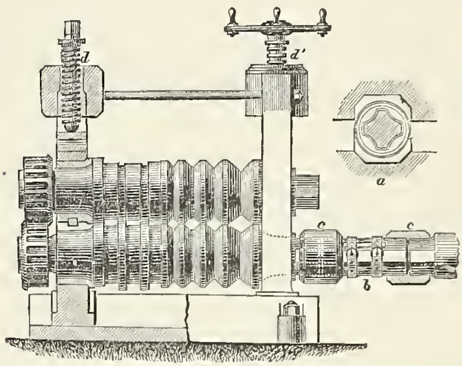


Fig. 7.

The reduction in the size of the bloom is effected by regulating the vertical distance between the two rolls, by the use of grooves diminishing regularly in size, or by a combination of both methods.

As the direction of rotation of the rolls is constant under ordinary circumstances, it is necessary after the bar has passed through one groove, to return it by lifting it over the top roll, in order to bring it in position to pass through the next smaller one, and so on in succession. This may be easily done with blooms of small size, but it is attended with considerable difficulty when it is required to handle large masses of iron, and in any case gives rise to a certain loss of time and consequent waste of iron by scaling, from exposure to the atmosphere in a highly heated condition for a longer time than is absolutely required.

Very heavy mills, such as are used for armor-plates, require to be reversed at each passage of the pile, the distance between the rolls being diminished each time.

87. Reheating.—The operation of reheating may be performed in several different ways. The plan most generally adopted is in a reverberatory furnace known as the *mill-furnace*, not unlike in external appearance to that used in puddling. The bed is made of fire-brick covered with a thick coating of sand. On it the piles are placed, and brought rapidly up to a welding-heat, for rolling.

When the dimensions of the pile are such as to require several passages through the rolling-mill, in order to reduce it to the proper section, it is often necessary to subject it to a second heating.

In this process loss by oxydation consequent upon unnecessary exposure must be prevented as much as possible. Oxide of iron in the form of scales forms very rapidly when a heated bar is exposed to the air.

Those produced in the rolling-mill are called *mill*, or *forge*, *cinders*, and are much used in puddling by the wet way, or pig-boiling.

88. Piling.—The amount of work put into bar-iron varies with the quality. For the common kinds, puddled bars, or No. 1 iron, cut into lengths, are piled, and when brought to a welding-heat, are rolled off, either with or without first being worked into a bloom under the hammer. More usually, however, the iron of second-rolling, or No. 2, is employed at the top and bottom plates of the piles when making finished No. 3, or best iron. Beyond this, if further piled and welded, the iron is distinguished as *best-best* and *treble-best*, according to the number of heatings and weldings to which it has been subjected. (Fig. 8.)

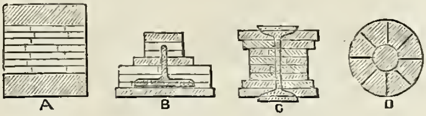


Fig. 8.—Sections of piles for finished iron.

The harder and more granular kinds of iron are worked almost exclusively under the hammer, the rolling-mill being only used in giving the proper figure to the bar at the finishing stage.

The piles for the heavier classes of plates are built up of layers of bars, placed alternately across each other, instead of having their longer sides parallel, as in the case of ordinary bar-iron, and the covering slabs, or top and bottom plates, are flat bars of greater width than the intermediate layers.

89. *Examples of Piling.*—The following examples, from *Bauerman*, give the details of manipulation in rolling bars.

For bars of one inch square the pile was made up of six bars, each three-quarters of an inch thick, and four inches wide. When at a proper welding-heat it was passed eleven times through the rolls.

The loss on the weight of the pile was about fifteen per cent., caused by oxydation, and in *crop-ends* and waste in rolling.

Crop-ends.—The waste material, or scraps, produced by shearing in finishing bar-iron is called *crop-ends*. They are reworked or utilized in many ways.

For boiler-plates measuring six feet long by three feet broad and three-sixteenths inch thick, the pile was made twenty inches long, six to seven inches high, and twelve inches broad.

The whole of the work was done at one heat, the pile reduced to a roughly squared bloom by passing lengthways through three grooves in the blooming-rolls, then four times through the plate-roughing rolls, in the direction of the breadth, which draws it into a thick squared plate, and finally three times lengthways through the finishing-rolls.

The difference in weight between the finished plate and the rough bars taken for the pile is about twenty per cent., which includes the waste in reheating and scraps produced in shearing the edges to the proper size.

90. *Rolled Armor-plates* are put together as follows: The balls from the puddling-furnace are shingled, and rolled to slabs about twelve inches broad, thirty inches long, and one inch thick. Five or six of these slabs are in a second heat rolled to a slab about four feet square. At the third piling five or six slabs of the second heat are welded and rolled into a plate about eight feet long, four and one-half feet broad, and two and one-half inches thick, weighing rather more than 30 cwt., and made up of between twenty-five and thirty-six original inch-slabs of No. 1 iron.

For the finished plates of four and one-half or five and one-half inches in thickness four of the large 30 cwt. plates are piled together and reheated.

The door of the furnace is placed parallel to the axis of the rolling-mill, and the pile, when sufficiently heated, is drawn forward with tongs, and received on a truck which runs upon a railway directly to the rolls. A similar truck is placed on the opposite side of the mill, their surfaces being supplied with friction-rollers, so that the pile may be easily pushed between the rolls, through which it is passed forwards and backwards, by reversing the rolls, until it is reduced to the proper thickness.

It will be seen that the finished plate consists of between 100 and 144 slabs, compressed to about one-twentieth or one-thirtieth of their original thickness.

91. Peculiarities.—By the processes described, the cast-iron has been converted from a fusible, hard, and brittle substance into a tough and elastic bar. It has been rendered *malleable*, which is the property of extending or spreading under the hammer without cracking; *ductile*, a property similar to malleability, whereby it may be drawn out into wire without breaking, and its *tenacity* has been increased, a property which enables it to sustain a very great pressure or force without crushing or breaking.

In a cold state it is hard and stubborn, but at a red heat it is soft and pliable, and, at a white or sparkling heat it may be welded to itself or to steel, which is one of its greatest advantages.

92. The great improvement in the strength of malleable iron by the processes of fagoting and rolling has been more satisfactorily established by experience than explained by theory.* One obvious effect of the violent compression between the rollers is the squeezing out of slag, which is liable to become entangled in the iron during hammering and rolling of the balls taken from the puddling-furnace. The occurrence of small masses of slag in malleable iron is not an uncommon cause of weakness, each particle of slag giving rise to a flaw in the metal. In the process of reheating the bars this slag is melted, and may then be squeezed out by the action of the rollers.

A marked diminution in the proportions of carbon and silicon present in the iron is also effected during the process, as shown by the following results of chemical analysis:

In 100 parts.	Carbon.	Silicon.
Puddled bar................	0.296	0.120
Best bar....................	0.111	0.088

This may be explained by the action of the oxide of iron formed upon the surface of the bar during exposure to air at a welding-heat.

The rolling of several bars into a single bar would render the structure of the metal uniform, so that the bar would be equally strong throughout.

During the operation of fagoting and rolling the iron acquires a remarkable fibrous structure, so that if a bar of the best iron be notched with a chisel, and broken across by a steady pressure, the fracture will present a stringy appearance, resembling that of a green stick; whilst a puddled bar thus treated would exhibit a crystalline, shining fracture, not unlike that of cast-iron. That this *nerve*, or reed, as the fibrous structure is sometimes called, should materially increase the resistance of a bar to any transverse strain, can readily be believed, for such a bar resembles a bundle of wires firmly bound together, whilst a crystalline bar must be regarded as composed of a number of particles of iron stuck together in a confused manner.

93. But with our present imperfect acquaintance with the mutual relations and movements of the individual particles composing a solid mass, it is not easy to give a satisfactory explanation of the production of the fibrous structure by rolling the softened bars in the direction of their length.

Much less can we explain the circumstance, which appears

* Bloxam.

to have been satisfactorily established, that this fibrous structure is liable to reconversion into the crystalline structure if the iron be subjected to a long succession of powerful vibrations.

The deterioration in the strength of bar-iron by often repeated forging under the hammer is commonly explained as resulting from this change in structure, and axles, girders, etc., originally made of fibrous iron, are said to have snapped unexpectedly, exhibiting a crystalline structure. Hence, in cases where the iron is to be exposed to much vibration, a fine-grained wrought-iron, richer in carbon, is preferred to a fibrous iron.

94. In drawing any inference as to the quality of wrought-iron from the character of its fracture, it is most important that the mode of breaking it should be taken into account, for it is found that a bar or plate which exhibits a fine fibrous structure, when broken by bending, appears crystalline when suddenly snapped, or when broken by a blow from a shot; and it is probable that a want of attention to this has given rise to many of the contradictory statements with respect to alterations in the structure of wrought-iron under various conditions.

95. Variation in Quality.—Forged, or wrought-iron, like cast-iron, varies greatly in quality according to purity and treatment in its manufacture.

It may be divided generally into four different kinds.

First. Iron which is tough and malleable at all temperatures. This is the best and most useful, as it may be bent in any direction without breaking, both when it is hot and when it is cold.

It may be known generally by the equable surface of the forged bar, which is free from cross fissures, or cracks, in the edges, and by a clear, white, small grain, or rather fibrous texture. The best and toughest iron is that which has the best welding properties, and which bears the highest heat without injury, and which has most fibrous texture, and is of a clear grayish color.

Second. The next best iron is that which has a texture consisting of clear whitish small grains intermixed with fibres. It is tough and malleable at all temperatures, bears a moderately high degree of heat without injury, and has good welding properties.

Third. Another kind of iron is tough when heated, but brittle when it is cold, so brittle that it will sometimes break with a single blow of the hammer, or by a sudden jerk, which makes it unfit for several kinds of work where life and property are dependent upon it; but for some kinds of work that are to be exposed to the weather it is very useful, as it will resist the action of the atmosphere better than the other kinds. It may generally be distinguished by a texture consisting of large shining plates, without any fibres, and is called *cold-short iron.*

Fourth. Hot-short, or *red-short*, *iron.* This is extremely brittle when hot, and malleable when cold. It will not bear bending without breaking, or piercing without splitting, and it is never used for superior kinds of work.

But owing to its being much cheaper than the superior kinds, and being very tough and ductile in its cold state, for many purposes it is a very useful iron.

On the surface and edges of the bars of this kind of iron cracks or fissures may be seen, and its internal appearance is earthy, dull, and dark.

96. WELDING is that operation by which pieces of iron, or steel, or steel and iron, are heated nearly to a state of fusion, and appearing to be covered with a strong glaze, or varnish, are brought together, and united by repeated blows of the hammer, or under pressure, and the union not to be perceived.

The heat required for welding iron varies in some degree with the purity of the iron. Pure fibrous iron will bear almost any degree of heat without much injury, if not too long exposed to the heat, while impure iron bears but a moderate degree of heat without being melted or burnt.

97. *Porter-bar.* When a mass is too large to be handled conveniently with the tongs, a large iron rod is welded to it, to serve as a porter, or guide-rod. Sometimes a part of the porter-bar is made to form the core of the forging, and the slabs of iron which form the forging are welded and built upon the bar. When the mass of iron is too large to be handled by the forge-man, it is supported by a crane, which serves to swing it from the fire to the hammer.

98. *Upsetting.*—When it is required to thicken any part of a bar of iron without welding, it is done by the operation called "*upsetting.*" This consists in giving it the welding-heat at the part to be thickened, and while one end rests upon the anvil hammering at the other till the required size is produced. When the bar is large, if it be lifted and jumped upon the anvil its own weight will supply the required force for upsetting. When it is required to weld two bars of iron together the ends are first *upset*, or made thicker.

99. *Scarfing.*—Each end is then bevelled off to a thin edge, called *scarfing ;* the two ends are then placed in the fire, and raised to a welding-heat, or nearly to a state of fusion ; care is required that both arrive at the proper heat at the same time.

The bars may in part be prevented from wasting by taking care to supply them at the heated part with powdered glass or sand just before they arrive at the welding-heat. The sand or other material melts on the surface of the iron, and serves to form a flux, or fluid glass, which protects the iron from the impurities of the fuel, and defends it from the air, at the same time uniting with and removing the oxide which may have been formed on the heated scarfs.

When the bars have obtained the welding-heat they are removed from the fire with the utmost dispatch, and struck across the anvil to remove as far as possible all scales and dirt which would hinder their uniting; they are then placed in contact at the heated part and hammered, the superfluous cinder is squeezed out as the clear parts are brought together, and the hammering continued until no visible seam or fissure remains.

100. In welding large pieces the process is more difficult. Several minutes must sometimes elapse before the parts can be brought together; meanwhile thick scales are forming on the exposed heated surfaces.

The rapidity with which iron at a welding-heat becomes oxydized is strikingly illustrated in the operation of "patting" the Armstrong tubes after they are welded end to end. (Art. 654.)

The scales that form on the inside of the tube are jarred off at every stroke of the hammer upon the outside, thus exposing fresh surfaces to oxydation. At the end of the process the scales form a pile in the tube several inches in depth.

Section IV.—Steel.

101. Peculiarities.—Those varieties of iron in which the amount of carbon is above the maximum of malleable and below the minimum of cast-metal, are known as *steel*. The distinguishing property of this class of products is the capability of being hardened or softened at pleasure by sudden or slow cooling by the process known as *tempering*.

Being intermediate in position between wrought and cast-iron, steel is both fusible and malleable, but requires a higher temperature for fusion than cast-iron, and greater compressing power, owing to its lower welding temperature, than malleable iron.

102. Steel is a combination, or alloy, of iron that will forge, harden, and temper.

There are various kinds of steel, such as *Carbon Cast-steel*, *Tungstein Cast-steel*, *Chrome Cast-steel*, *Cyanogen Cast-steel*, and *Titanium Cast-steel;* and several other metals have been alloyed with Iron to make Steel.

There is also *Blistered Steel*, which is made from malleable bar-iron, by a process called *Cementation ; German Steel*, which is made directly from the ore, and sometimes from Pig-iron, in the Catalan forge ; and steel which is made by other processes.

103. The line between Cast-iron and Steel is: when it is capable of being forged, it is Steel; and when it will not forge, it is Cast-iron. And the line between Malleable Iron and Steel is: when it will harden and temper, it is Steel; and when it will not harden and temper, it is Malleable Iron.

Cast-steel will harden slightly when it contains from 0.25 per cent. to 0.30 per cent. of carbon, and ceases to be capable of forging if it contains much more that 1.75 per cent. of carbon.

104. *High and Low Steel.*—Those varieties that are the richest in carbon are the hardest and most fusible, and are known as *high steels*, or *strong steels*, while those that are nearer malleable iron in composition are distinguished as *low steels*, or *mild steels*, or *homogeneous* metals.

105. How Obtained.—Steel may be obtained by a variety of processes, of greater or less complexity, from either cast or wrought-iron. These processes are directly opposed to each other.

First, by working pig-iron which contains too much carbon, in a suitable furnace until such carbon is reduced to that quantity required to constitute steel; or, *second*, by heating bar-iron, in contact with charcoal, until it has absorbed that quantity of carbon which may be necessary.

The progress made within the past few years in the manufacture of steel, has been such as to indicate that in a very short time it may be produced as cheaply, if not cheaper, than wrought-iron is at present. In fact, steel is already taking the place of iron, for various industrial purposes, to a very great extent; and inventions of new processes and apparatus for its manufacture, and improvements in those already in use, have become so common as to attract but little attention.

106. Classification.—Steel may be classed into three kinds:

First. Natural Steel, which is manufactured from pig-iron direct.

Second. Cemented Steel, or converted steel, which is produced by the carbonization of wrought-iron.

Third. Cast-steel, which is produced by the fusion of either natural or converted steel.

107. Puddled Steel.—This is a *natural steel*, made in the puddling-furnace by a modification of the puddling process.

The process of making puddled steel may be described in a general way as follows: Cast-iron contains from three to five per cent. of carbon; ordinary steel contains from three-fourths to one per cent. of carbon; while wrought-iron contains but a trace. In changing from cast to wrought-iron in a puddling-furnace, the pig-metal passes through the state of steel, that is to say, it is steel before it is wrought-iron. Now making puddled steel is simply stopping the common puddling process, just at the moment when the decarbonizing mass under treatment is in the state of steel.

Several modifications in furnaces and processes have been patented, and various fluxes, especially manganese, are differently used, by different manufacturers.

108. Cemented Steel.—The production of steel by cementation consists essentially in the exposure of bars of malleable iron, in close contact with charcoal, to a high and long-continued heat, the air being excluded.

109. Converting-furnace.—The furnace in which iron is cemented and converted into steel, is called a *Converting-furnace.* (Fig. 9.) It has the form of a large oven, constructed so as to form in the interior of the oven two large and long cases, commonly called *pots*, and built of good fire-brick.

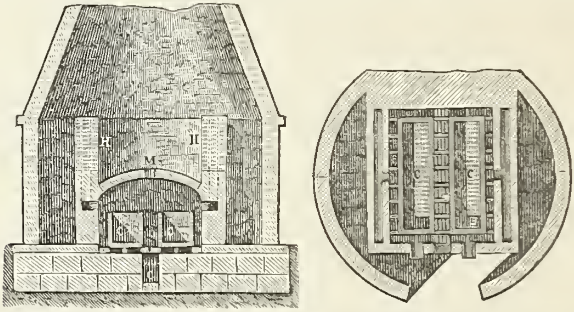


Fig. 9.—Cementation Furnace for converting Bar-iron into Steel.

110. *Packing the Pots.*—Into each of these pots layers of the purest malleable-iron bars and layers of powdered charcoal are packed horizontally, one upon the other, to a proper height and quantity, according to the size of the pots, leaving room every way for the expansion of the metal when it becomes heated. The bars are cut to certain lengths, according to the lengths of the pots.

Three or four of the bars are placed in such a manner that they can be drawn out at any period of the process, through a small hole in the end of the pot, and examined. After the packing of the pots is completed, the tops are covered with a bed of sand or clay, to confine the carbon and exclude the air.

111. *Process of Cementation.*—All the open spaces of the furnace are then closed, and the fire kindled; the flame passes between, under, and around these pots on every side, and the whole is raised to a considerable intensity of heat. This heat is kept up for eight or ten days, according to the degree of hardness required, the hardest quality for melting purposes requiring the longest time.

The progress of the conversion is determined by the appearance of the trial bar; the first is taken out after about a week's firing. When there is no longer an unaltered kernel of soft iron apparent in the centre, the conversion is considered to be complete, the fire is allowed to go down, the furnace is left to cool, and the cemented bars are then after several days withdrawn.

112. The physical properties of the iron are considerably modified by conversion: the color of the fractured surface changes from the original bluish tinge of malleable iron to a somewhat reddish-white, and the lustre is considerably diminished; the texture, which was originally fibrous, has become granular, and is in all cases scaly-crystalline.

The finer the grain, and the darker the color, as a general rule, the more highly carbonized, or harder, will be the steel produced; at the same time both specific gravity and tenacity are reduced.

113. Blister-steel.—A more decided peculiarity of the converted bars is the blistering of the external surface, whence the term *blister-steel* is derived. When the blisters are small and tolerably regularly distributed, the steel is of good quality; but when large, and only occurring along particular lines, they may be considered as indicative of defective composition or want of homogeniety in the iron employed.

Blister-steel bars are generally subjected to one or more reheatings in packets, or fagots, and weldings by hammering or rolling, whereby the texture becomes more uniform, and strength and elasticity are increased, but with a progressive diminution of hardness.

114. Spring-steel, or *tilted steel*, is produced by heating blistered bars at an orange-red heat, and drawing them down either under the hammer, or by rolling.

115. Shear-steel is a better quality obtained by drawing out the original bars, which are piled together in fagots, and

welded. The product of this operation is known as *single shear.*

It may be further refined by doubling the bars, and repeating the process of heating and welding, making *double shear-steel.*

Shear-steel breaks with a finer fracture, is tougher, and capable of receiving a finer and firmer edge and a higher polish than blistered or spring-steel.

116. CAST-STEEL.—The best and most uniform quality of steel can only be obtained by fusion.

That obtained by cementation is, as a rule, very unequal in quality; and uniformity can only be attained by repeated fagoting and welding, steps which are necessarily attended with a loss of carbon and consequent reduction of hardness.

The requisite uniformity of composition may, however, be obtained by breaking up the crude bars produced in the forge or by cementation, and exposing them to a strong heat in crucibles out of contact with the air. The product, when melted, is poured out into cast-iron molds forming ingots of *cast-steel*, which are much more regular in composition and texture than the original material.

117. PROCESS OF MANUFACTURE.—Crucibles of the most refractory fire-clay, mixed with plumbago, varying in capacity from thirty to fifty and a hundred pounds, or more, in weight, are charged with fragments of blister or shear-steel, and placed in furnaces. (Fig. 10.) The furnaces are furnished with covers, *b*, and a chimney, *a*, to increase the draught of air, and the crucibles, *c*, are furnished with lids of clay to exclude the air. The furnaces containing the crucibles are filled with fuel; and for the perfect fusion of the steel the most intense heat is kept up for two or three hours. When the steel is thoroughly melted the crucibles are removed, either by hand or machinery, and their contents poured, in the liquid state, into ingot-moulds of the shape and size required.

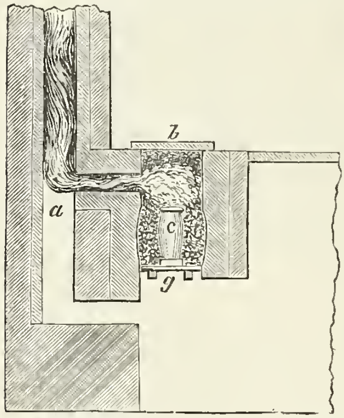


FIG. 10.—Furnace and Pot for melting Steel. *g*, Grate. *c*, Crucible. *b*, Cover of Furnace. *a*, Chimney.

118. STEEL INGOTS.—Although steel may be cast into ingots, it is too imperfectly fluid to be cast into very small articles.

When the crucibles are emptied, if sound, they are returned to the furnace again and charged. The ingots of steel are taken to the forge or rolling-mill, and prepared by hammering or rolling into shape in the same manner as other steel, but with less heat and with more precaution.

The great secret of the manufacture is in the selection and mixture of irons, and in the pouring of sound ingots.

Large castings are made by emptying a sufficient number of large crucibles into an immense ladle placed over the mould; the ladle is then tapped from the bottom.

Great skill in melting and pouring the metal, and particularly in heating and forging such great masses, without burning them on the outside, or failing to condense them to the core, is of obvious importance.

119. Steel, like iron, is improved by hammering and rolling; consequently when a large cast-steel block is required of great tenacity for a particular purpose, the metal is not run into a mold of the shape and size of the required finished dimensions, but it is cast into a short, thick ingot, and then hammered and drawn to the required finished dimensions, or it is rolled to the required shape between the rollers.

The drawing down of a heavy ingot requires: *First*, a uniform heat throughout the mass; and to soften the centre of such a casting without burning the outside requires a moderate and steady temperature maintained for several days. *Second.* The effect of the hammer must be felt at the centre of the mass, instead of being confined to the outside. A light blow would be absorbed in changing the figure of the surface-metal, and in breaking and distorting the grain, while a great weight falling from a moderate height would be resisted by the whole mass of the forging, and thus felt at its centre.

The heaviest hammers, however, are found to produce too much local and exterior, and too little distributed and interior, compression upon large masses of steel; therefore hydraulic pressures are much used for drawing and shaping large ingots.

120. Bessemer Process.—This is one of the simplest methods of producing cast-steel in large quantities. It combines the action of the puddling and ordinary steel-melting furnace into one operation. The essence of the process consists in injecting large quantities of air into a bath of molten cast-iron through a large number of small orifices situated in the bottom of the converting-vessel in order that the combustion of the carbon, and other matters in combination, may take place rapidly and uniformly.

By this means a very high temperature is developed in the converting-vessel, the heat being sufficient to melt the decarbonized malleable iron instead of producing it in a pasty, weldable condition, as is the case in the puddling-furnace.

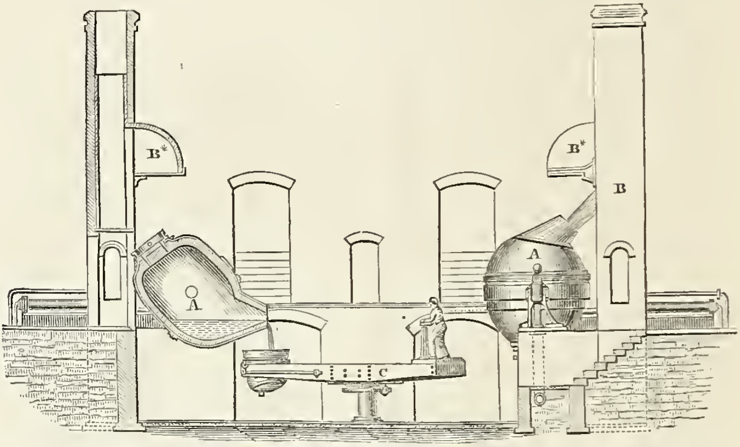


FIG. 11.—Bessemer's process. A, Converting-vessel. B*, Hood for carrying the carbonic oxide gas into the chimney, B. C, Crane for swinging the ladle under the converter.

This great increase of temperature is obviously due to the rapidity of combustion owing to the intimate contact of the air with the molten metal, instead of being merely in contact with its surface as in puddling.

121. TO PRODUCE BESSEMER STEEL.—Steel may be produced by this process by interrupting the blowing after partial decarbonization of the charge, the proper moment for stopping the operation being determined by the time employed and the appearance of the flame issuing from the mouth of the converting-vessel; or the metal may be completely decarbonized, and then brought back to the composition of steel by the addition of highly carbonized melted pig-iron, in sufficient quantity to restore the necessary amount of carbon.

122. THE CONVERTER, or furnace, consists of an egg or pear shaped vessel suspended upon trunnions, and provided with appropriate moving mechanism, whereby it may be rotated vertically through an angle of about 180°. The outer casing, or shell, is made of wrought-iron plates riveted together, the interior lining of the most refractory material obtainable.

The Trunnions.—The suspension is effected by means of a stout hoop of wrought-iron shrunk on to the body of the converter, and carrying two trunnions, which run in bearings supported by cast-iron standards.

One of these trunnions is solid, while the other is hollow, forming a passage for the blast. (Fig. 12.)

The Twyer-box.—The bottom of the converter is flat, and contains the *twyer-box*, E, which is a cylindrical chamber, connected by a curved pipe with the hollow trunnion.

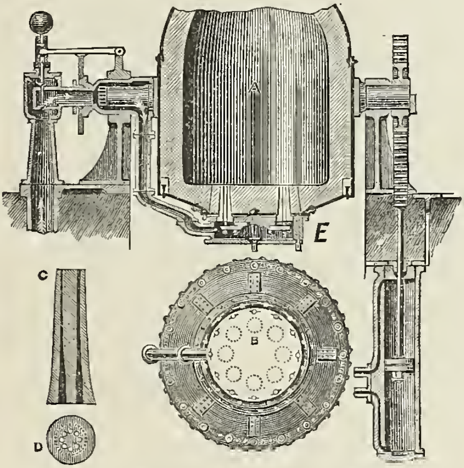


Fig. 12.—Bessemer's steel converter.
A. Transverse section through trunnions.
B. Bottom plan.
C. Section of twyer brick. D. Plan of ditto.

The Twyers are cylindrical, or slightly tapered, fire-bricks, C, each perforated by seven parallel holes, about half an inch in diameter. Usually five to seven of these bricks are used, which are arranged vertically, and at equal distances apart in the lining of the bottom of the converter, their lower ends communicating with the twyer-box.

123. Charging the Converter.—The charge of pig-iron, which may be of any weight from one to ten tons, or more, according to the size of the vessel, is melted in a reverberatory or other furnace. The converter is turned to a horizontal position (Fig. 11), to receive the charge of molten metal, which is run in through a movable gutter of wrought-iron lined with sand.

124. *The Blast.*—After the converter is charged the blast must be admitted before it is turned back to the vertical position, otherwise the molten metal would run down through the twyers.

A pressure of from five to six pounds per square inch is required to overcome the hydraulic head of the liquid column of metal, and from nine to fourteen pounds more to force the air through at the proper velocity, or from fifteen to twenty pounds per square inch total pressure.

After the blast is turned on the converter is slowly brought back to the vertical position.

125. Process of Conversion.—During this period, lasting from four to six minutes, the action going on is similar to that in the refinery in the first stage of puddling—the conversion of graphite into combined carbon, and the oxydation of silicon with the formation of a silicate of iron and manganese.

In the second or boiling period, when the oxygen of the blast begins to attack the carbon, the action becomes very violent, and the flame increases in brilliancy. This lasts for about six or eight minutes longer.

In some establishments the process is stopped here, the required decarbonization being determined by the time of its duration, and by the color of the flames; but a far more exact method of ascertaining when the requisite amount of carbon has been removed, consists in viewing the flame through the *spectroscope*, which enables the observer to detect a certain line in the spectrum or image of the flame, the disappearance of which marks, to within a few seconds, the conclusion of the process. In others it is continued until from the sudden dropping of the flame, the iron is known to be quite decarbonized. When the converter is turned back to the horizontal position, and the proper quantity of molten pig-iron of known quality is run in.

126. Casting the Ingots.—The vessel is turned on its trunnions until the fluid steel will run out into the *casting-ladle* (Fig. 11), which is attached to the arm of a hydraulic crane, C, so as to be brought readily over the molds.

The ladle is provided with a fire-clay plug at the bottom, the raising of which by means of a suitable lever, allows the fluid steel to descend in a clear vertical stream into the molds.

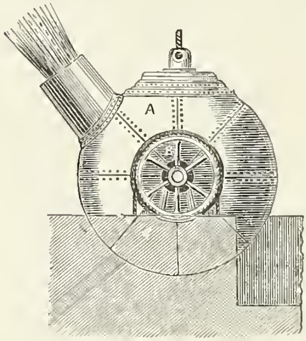


Fig. 13.

As soon as the first mold is filled the plug-valve is depressed, and the metal prevented from flowing until the casting-ladle is moved over the next mold. To pour a heavy ingot several converting vessels are emptied into one mold.

The molds usually employed are made of cast-iron, and arranged in a semicircle on the floor of the casting-pit.

127. *Hammering the Ingots.*—When drawn from the molds the ingots, like those obtained from steel melted in crucibles, are always more or less unsound, and require to be compacted by hammering after reheating. If this is done before the interior has

solidified much fuel is saved, and the core is certain to be thoroughly heated.

128. *Another and more recent Form of Converter*, suggested by Bessemer, shown in Figs. 13 and 14, has a globular form, and is seven feet in diameter, the air-blast introduced through a single twyer passed through the top of the converter, and made of circular fire-bricks, D (Fig. 14), strengthened by a stout iron rod passing down the centre, and terminating in a kind of rosette with numerous apertures, through which the air is projected into the liquid iron.

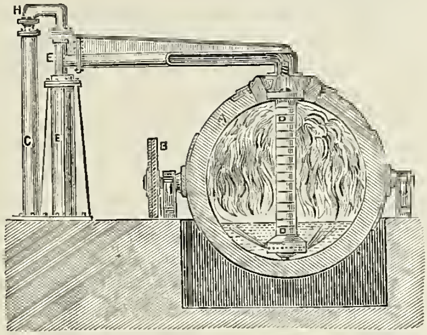


Fig. 14.—Section of Bessemer's globular Converting-vessel. A, The converter. B, Pulley wheel for tipping the converter, connected by a wire rope with a hydraulic ram. G, Pipe conveying the blast. H, Elbow-pipe with telescopic joint.

When the conversion is finished the twyer is lifted out by an ingenious hydraulic crane, E, and the converter tipped by the action of a hydraulic ram in order to discharge its contents into the casting-ladle.

In the Bessemer methods, and in others, air passes through iron, thus endowing the latter with the carbon, whose addition makes the difference between iron and steel. A greater or less proportion of this air remains in the substance, and occasions holes and flaws. These, of course, weaken the steel, and make it liable to break up.

129. Whitworth Metal.—In order to procure a more dense metal than forged steel, Whitworth has resorted to the expedient of compressing the steel while in a liquid state. He has applied a pressure of twenty-five tons to the square inch, but estimates that eight tons are sufficient to expel air-bubbles, and that then, reheating the ingot, the metal may be compressed by hammering, thus producing a resulting metal which may be regarded with certainty as free from air-cells, and as superior to all other steels.

130. Annealing is a process applied to the manufacture of metals to prevent the particles arranging themselves in that condition which produces a brittle quality.

The texture of a metal depends greatly upon whether it has been gradually or suddenly cooled; and this influences many of its most important mechanical properties: as, for instance, its hardness or brittleness, or its softness and malleability. The former qualities are given by cooling it rapidly, the latter by cooling it slowly.

When cast-iron has, by too rapid cooling, acquired the quality of hardness, it may in some degree be taken from it again by heating it a second time and cooling it gradually. This process is called *annealing.*

Steel is most hardened when it is raised to the highest temperature which it can receive, and then suddenly cooled by being plunged in mercury or an acid, or into a mass of lead; if instead of these substances, water or oil be used to cool it, the temper obtained is not so hard.

131. Corresponding to every different degree of heat to which the metal is raised, there is a different hardness, but as these are all different degrees of red heat, which it is very difficult to distinguish from one another, it is customary to make use of a remarkable property by which the metal can be made to lose to any degree, the hardening which it has acquired, by heating it again to an inferior degree and allowing it to cool gradually. This is the process called *tempering*, communicating in the first place to the steel a hardness above that required, then heating it again over charcoal and cooling it gradually.

This process is facilitated by certain remarkable changes of color which appear in the steel as it undergoes the second heating. These colors are: *straw-color*, *yellow*, *purple*, *red*, *violet-blue*, *blue*, and *clear-watery-blue*, and they indicate the point at which the second heating should be arrested to obtain the temper or degree of hardness required for different purposes.

132. Tempering Steel in Oil.—Oil is used as a bath for toughening large tubes of mild cast-steel, calculated to be used as barrels for heavy built-up-guns, because of the high temperature required to convert it to the vaporous state, and its imperfect conducting quality, which causes the steel to part with its heat slowly. This slow rate of cooling is necessary to form a uniform degree of contraction, thus giving the steel a longer time for the re-arrangement of its particles and making the strain more uniform throughout the mass. Heavy masses or thick lumps of highly carbonized steel, whether tempered in oil or water, cannot be hardened without becoming fractured either internally or externally.

The process.—A tube of mild cast-steel is lifted by a powerful crane and placed in a perpendicular position in an upright furnace, which has been previously heated with wood to a red-heat. It rests on an iron-shoe placed on the grate-bars to prevent the cold air from coming in contact with its extreme end.

Great care is taken to heat the mass uniformly, fuel being added gradually until the whole tube is entirely surrounded with wood, thrown in at the top of the furnace.

Wood is used because of its purity; it is not so liable to degrade the steel as other fuels.

The amount of heat received by the steel is judged by eye and by long practice and attention. The more uniform the temperature, the straighter the block will keep, and the more even its temper. After the steel has acquired the proper uniform temperature throughout, the travelling crane is brought over the furnace, its top removed, and the large iron tongs, pendant from the crane, fasten themselves to the steel tube; a small collar being upon its end to prevent the tongs slipping.

The Oil-bath.—The tube of steel is now drawn out of the furnace and sunk into a large iron tank about twenty feet deep, containing several hundred gallons of oil. The heated steel in passing into the oil will sometimes cause the surface-oil to take fire, which is extinguished by closing the top of the tank.

A covering of coal is also formed round the steel by the burned oil, which greatly retards transmission of heat.

The tank has a water-space surrounding it, and as the steel parts with its heat, raising the temperature of the oil, the temperature of the water is also raised. The water, as it is heated, is drawn off by an escape-pipe, and a supply of cold water is continually running in, thus the heat is gradually taken from the mass. Exceeding toughness is the result of the operation; the tensile strength of the steel is made higher, and it is harder and more elastic.

Section V.—Bronze.

133. Bronze for Cannon, consists of ninety parts of pure copper and ten parts of tin, allowing a variation of one part of tin, more or less. When the mixture is well made the metal is homogeneous; the fracture is of a uniform yellow color with an even grain. The specific gravity of bronze is about 8.750, being greater than the mean of the specific gravities of copper and tin.

134. *Pure copper* is of a red color, inclining to yellow; it has a fine metallic lustre. The fracture of cast-copper is even grained; that of the forged bar exhibits a short, even, close grain of a silky appearance, it is strong, very ductile, and very

malleable. The greater the purity of the copper, the more malleable it is and the finer the grain. Its specific gravity varies from 8.600 to 9.000.

The copper of commerce is impure, frequently containing oxygen, silicon, iron, lead, tin, zinc, antimony, and arsenic. It should be rejected for the manufacture of guns, if it contains sulphur in an appreciable degree, more than one-thousandth of ansenic and antimony united, more than about three-thousandths of lead, iron, or oxygen, or five-thousandths of other substances all together.

135. *Pure Tin* is of a white color, a little darker than silver; it is very malleable and susceptible of being rolled into thin sheets; it is not very ductile; it is soft, and when in rods or bars it is bent backwards and forwards gives a peculiar crackling sound, the distinctness of which is in proportion to the purity of the tin. Its specific gravity is from 7.290 to 7.320. Tin for gun metal should be rejected if, when run into drops, it has not a smooth and reflecting surface, without any considerable sign of rough spots; if when analyzed it contains one-thousandth of arsenic and antimony united, three-thousandths of lead or iron, or four-thousandths of foreign substances.

All bronze ought to be rejected which contains sulphur in an appreciable amount, .001 arsenic and antimony, .003 lead, iron, or zinc, or in all more than .005 of foreign substances.

The fracture of bronze may give indications sufficient to authorize the rejection of certain bronzes full of sulphur or oxydes.

136. *Management of Bronze.*—The circumstances of chief difficulty and importance in the manipulation of bronze, as affecting the production of cannon, are:—*

First. The chemical constitution of the alloy as influencing the balance of its hardness and tenacity.

Second. Its chemical constitution and what other conditions influence the segregation of the cooling mass of the gun, when cast, into two or more alloys of different and often variable constitutions.

Third. The effect of rapid and of slow cooling, and of the temperature at which the metal is fused and poured.

Fourth. The effects due to repeated fusions and to foreign constituents in minute proportions entering into the alloy.

In bronze, as in every other material for cannon, while sufficient hardness must be secured to resist longest the abrasion of projectiles, and the deflagration of the powder along with the

* Mallet.

greatest ultimate tenacity, there must be a certain rigidity and ductility, with ultimate cohesion.

The hardness and rigidity increase with the proportion of tin; the ductility and tenacity with that of copper, but not in any direct ratio in either case. The specific gravity increases with the copper. The fusibility is always greater than that of copper, and less than that of tin. The ultimate cohesion is always less than that of tough copper, but greater than that of tin. The ductility less than that of copper and greater than that of tin. The hardness is always greater than that of either.

137. In common with the great majority of metallic alloys, bronze is held so loosely in combination, that very slight forces are sufficient to induce its segregation into two or more different alloys, which on cooling are found to occupy different portions of the mass.

Thus, in a gun cast vertically, the external portions which cool first have a determinate constitution different from that assigned by the proportions of the metals, as fixed for fusion. The interior of the gun which cools last has another constitution different from either, and always richer in tin. But when the whole gun has become solid, and portions are examined from the extreme lowest, middle, and highest parts of the previously fluid column of metal, it is found that these again differ from each other, and that this difference varies, in the vertical or exterior, or crust alloy, which has cooled first, and for the interior column of alloy that has cooled last; so that, in fact of any gun, no two adjacent portions have strictly the same chemical constitution; the maximum of copper being found in the exterior and breech of the gun, and the maximum of tin in the interior and highest part of the metallic column.

138. The constitution of the alloy changes, not only in cooling, but in melting by oxydation; resulting in the continual reduction of the quantity of tin, which oxydizes much faster than copper, though the latter be present in so much greater mass. The oftener the alloys are melted the more difficult it is to produce solid castings with them.

139. The difficulty of making sound castings from old and often remelted alloys, arises from oxydation, which in bronze takes place in such proportions that for one part by weight of tin oxydized, there are from three to four of copper. A part of this oxygen is absorbed or combined and given up again by one or both metals, at the moment of consolidation, and its evolution causes the dissemination of minute air-vesicles through the mass which is the cause of imperfect castings.

These are seldom known to occur in such abundance in new, or not frequently, fused metals.

140. In consequence of the difference in the fusibility of tin and copper, the perfection of the alloy depends much on the nature of the furnace and the treatment of the melted metal. By these means alone, the tenacity of bronze has been carried at the Washington Navy Yard Foundry, as high as 60,000 lbs.

141. OTHER ALLOYS.—For many years experiments have been made for the improvement of alloys used in the fabrication of cannon, and trials have been instituted to ascertain the modifications produced in the resistance of bronze for cannon, by different compositions and various modes of manufacture.*

142. *Phosphorus Bronze.*—By the addition of about two per cent. of phosphorus to ordinary bronze, and casting the metal in ingot-molds for the purpose of rapid cooling, a metal has been attained having a hardness approaching that of steel; an elastic and absolute resistance varying between sixty and 175 per cent. above ordinary bronze, a composition more homogeneous than that of bronze, and consequently resisting better the effects of the combustion of gun powder.

143. It is thought by some that the best gun will eventually be constructed with some extremely dense and homogeneous alloy, cast and used without being drawn under the hammer.

144. If a gun is made of an alloy possessing great density, the detonating force of the powder will be resisted by a greater quantity of the metal employed, than it can be by making use of one with greater elasticity.

145. No theoretical trials of any extent, specially designed to ascertain the truth concerning this point, have ever been made; and it is impossible, in the absence of further experiments, to predict either great success or failure for the alloys.

Although the alloying of copper, especially for cannon, has been practised for more than five hundred years, it is yet much undeveloped.

146. While certain alloys of both iron and copper have one important feature in common hemogeneity, due to fusibility at practicable temperatures, the alloys of iron have this grand advantage, iron is everywhere cheap and abundant; and the other necessary ingredients and fluxes—carbon, manganese,

* *Essay on the use of various Alloys, especially of Phosphorus Bronze, for the Founding of Cannon.* By C. Montefiore-Levy, and C. Kunkel. Brussels, 1870. Translated by John D. Brandt, Navy Dapartment, Ordnance Bureau. Washington: Government Printing Office, 1872.

zinc, and silicium—are equally abundant, and, in some localities, already mixed, although perhaps not in the proper proportions.

Section VI.—General Qualities.

147. Requirements.—The qualities necessary in cannon-metals, are: strength to resist the explosion, weight to overcome the severe recoil, and hardness to endure the wear in the bore.

148. The selection of a suitable material is a very important consideration in the construction of cannon, in consequence of the difficulty of obtaining any ore that possesses all the qualities required of it.

149. Properties of Metals.—It is necessary to a clear understanding of the subject, briefly to consider the various properties of metals which affect their value for cannon construction.

150. Density is a term used synonymously with specific gravity, to denote the quantity of matter which a body contains under a given or determinate surface; for example, a cubic foot.

The quantity of matter in any body is called its mass, and is measured by the weight of the body to which it is always proportioned. Hence, the density of any body is great in proportion as its weight is great and its volume small; or the density of bodies is directly as their mass, and inversely as their volume. It follows also from the definition, that if two bodies have the same volume, their densities are directly as their masses, or weights; and, that if two bodies have the same mass, or weight, their densities are respectively in the inverse ratio of their volumes.

151. Hardness is the condition of the force of cohesion in solids, which enables their constituent particles to retain their relative position and resist any physical force which tends to alter the figure of the body. Hardness is entirely different from density, for although gold is denser than glass, yet glass is harder than gold. Iron is lighter but harder than gold.

Some metals are rendered hard with great readiness. This is of inestimable value in the manufacture of steel, which can be varied in hardness by heating, suddenly cooling, and then tempering. Hardness is often accompanied by brittleness; but this can be generally overcome by heating and slow cooling; this process, however, often takes away from the hardness.

In the production of alloys this useful property is frequently developed; copper and tin, neither of which are remarkable for hardness, possess this quality when combined. Without a certain degree of hardness, the shape of the bore in cannon will be rapidly altered by the action of the projectile, and the gases resulting from the combustion of the charge.

152. BRITTLENESS is a property of bodies which, although solid, yet are so weakly bound together that a very small mechanical force suffices to separate their particles.

153. TENACITY is that quality of bodies which keeps them from parting without considerable force.

154. TENSILE STRENGTH, is the degree of stretching which a body can endure by drawing it in the direction of its length.

155. POROSITY.—All bodies have between the elementary particles, or atoms, interstices through which *heat* penetrates into them, and into some of them *air*, *water*, and other fluids. These last are said to be *porous*.

That metals are porous has often been proved by submitting metallic vessels containing water to great pressure, by which the water was made to weep through the pores in the surface. That all metals are more or less porous sufficiently accounts for the fact that they are also more or less compressible.

156. ELASTICITY is the inherent property of certain bodies by which they recover their former figure, or state, after external pressure, tension, or distortion.

The force with which metals, when extended or compressed, tend to recover their form, that is, the force necessary to keep them extended, or compressed, is proportional to the amount of the extension, or compression, they have received.

The property of the elasticity of metals is of the greatest moment in connection with their use in gun construction, as they are subjected to various degrees of pressure, and it becomes a matter of importance to know how far they will lengthen themselves under a given *thrust;* also, how far these may be carried without rupture.

A bar of metal is said to suffer a *strain* when the forces which act upon it tend to lengthen it, and a *thrust* when they tend to compress it.

All metals used for cannon have an appreciable elasticity, but the range of this elasticity, that is, the extent to which they may be elongated by pressure, before permanently changing their figure, is very diverse for different metals, and very indefinitely determined for all.

The use of elasticity is, that it allows space for the power to act in without permanently stretching, and thus injuring the metal. Upon application of any force, metal having no elasticity would either permanently stretch, or instantly break.

157. *Limit of Elasticity.*—The displacement of the particles of a body must be confined within certain infinitely minute limits, in order that they may return to the position they before occupied in it. If those limits be passed, the displaced particle may be wholly separated from the rest of the body in the direction from which it has been moved, and thus a partial rupture may take place; or other particles of the body occupying the space which it has left, and through which it has moved, it may take up its position under a new arrangement of particles exactly as it did under the preceding, and enter into precisely the same relation with them as before; so that in every respect, the qualities of the body shall remain unaltered under this new arrangement of its particles.

158. PERMANENT SET.—In this last case it is said to have taken a *set*, and the phenomenon described under this name includes all that we understand by ductility and malleability, which terms but imply different ways in which the same property of taking a set, is called into operation.

Experiments prove that the elasticity of the body is not injured when a set is given to it. When beams of iron are so loaded in the middle as to cause them to take a permanent deflection, or *set*, their elasticity is found to be unimpaired by it; so that when again loaded, they tend to recover themselves with forces which are, as before, proportional to the deflection.

While some portions of the substance of a metallic body are made to take a *set*, others may be ruptured. Its elasticity may still remain, but its extensibility will be greater, and its strength impaired.

159. ELASTICITY OF TORSION.—If a wire be twisted it will tend to recover its natural state with a certain force, which is called its *elasticity of torsion.* The law of this force is that it is always proportional to the angle through which the body has been twisted. While a piece of wire of small diameter may be in a degree homogeneous, this quality is not to be expected in a bar, therefore, the conditions of torsion in a bar become complicated and anomalous.

160. MALLEABILITY.—The surface of a body always yields to an impact, however slight.

If a metallic surface thus yields beyond the limits of elasticity, it takes a *set.*

This property, by which a *set* is given to metals by impact, is called *malleability.*

There are certain metals, and certain states of the same metals, in which this property of malleability exists in a greater degree than in others. Thus, for instance, cast-iron is not perceptibly malleable except in a slight degree, when *annealed* it flies in pieces under the hammer; but when converted into wrought-iron it becomes perfectly malleable.

161. Ductility is the power possessed by certain bodies, and especially by the metals, in virtue of which they are capable of being drawn out in length while their diameter is diminished without fracture, or separation. Among the metals it may be called the property of being drawn out into wires.

The order of the metals which are ductile is almost similar to the order of those which are malleable.

The ductility of metals is most effectually called into operation by rolling them. It is thus that iron plates and bars are made. Some metals, and especially soft wrought-iron, may be considerably and permanently stretched without rupture. After stretching they appear to assume a new arrangement of particles and a new limit of elasticity, until close to the point of rupture. Wrought-iron increases in tenacity when drawn into bars, or wire, or rolled into plates. Such parts as have been so reduced have a greater tenacity per square inch, than when in the previous named condition.

162. Rupture.—When the parts of a body are by any external cause separated beyond the limits of ductility, the separation becomes permanent, and if it extend far enough, this separation constitutes a rupture of the mass. The rupture of a bar of metal may take place either by a strain, or tension, in the direction of its length, to which is opposed its *tenacity*; or by a thrust or compressing force in the direction of its length, to which is opposed its power of resistance to the *crushing* of its material, or each of these powers of resistance may oppose themselves to its rupture; the one being called into operation on one side of it, and the other on the other side, as in the case of *transverse strain*; or, lastly, the bar may be ruptured by torsion.

163. Tables of Strength of Materials.—It is important to know to which of these forces a material will first yield, and in what proportion it will yield differently to these causes of rupture.

Tables are prepared from experiments with the forces reduced to the square inch, which are necessary to tear asunder the materials enumerated, and to crush them.*

164. Qualities of Cast-Iron.†—*Comparative Strength.*—The chief argument against cast-iron as a material for an entire gun, made without regulated initial tension, is its comparative weakness. Cast-iron, having a tensile strength of nearly

* Barlow's Strength of Materials. † Holley.

50,000 pounds per square inch, has been applied to cannon founding. Assuming a sufficient supply of such iron of uniform quality, and that its contraction when cooling and its elastic limit are favorable for cannon making, it is still a weak material when compared with steel at 100,000 to 150,000 pounds—twice to three times as much. But cast-iron does not average 50,000, nor even 40,000 pounds tensile strength. The average of the highest quality is not over about 30,000 pounds, and this is considerably above the strength of the greater proportion of the cast-iron of commerce.

It is further proved that the strongest iron does not always make the most enduring gun. Several experiments mentioned by Captain Rodman* illustrate the general experience in this direction.

This inferiority of the strongest iron for guns is attributed to its greater contraction in cooling; and in the examples cited, the best guns were stated to have been made of low, soft, gray iron of moderate tenacity and small shrinkage; while the poorest were made of high, hard, close-grained, strong iron, having the greatest contraction of .10 to .15 inch more in the diameter of the gun than lower irons.

165. *Want of Uniformity.*—Cast-iron is far from being uniform; we do not by any means know what qualities of cast-iron are necessary to make the best gun; nor if we did, do we know absolutely how, from any of its ores, constantly to produce cast-iron which shall possess those qualities.

The difference in the strength of the highest and lowest gun-iron tested during a series of years (Art. 347), is stated at about 37,000 pounds, which is about equal to the highest cast-iron of commerce.

This want of uniformity must always be risked, because it cannot positively be remedied. Long experience, however, enables founders to mix iron with a great degree of certainty as to the intended product, but no two charges in the smelting-furnace, or pigs broken for remelting, can be relied upon as being exactly alike.

166. Identity of chemical composition may coexist in different specimens of cast-iron with great variation of physical properties; therefore chemical identity does not involve uniformity in the mechanical properties of cast-iron. So that, however desirable it may be to ascertain the chemical qualities, practical men are very far from accepting them as indices of its tensile strength.

* Experiments on Metals for Cannon, etc., 1861.

167. *Cost.*—The principal argument in favor of cast-iron as a material for guns, is its cheapness and the facility with which it can be produced compared with wrought-iron or steel. To convert and shape the latter, at a great expenditure of fuel and labor, wear of machinery and loss of machinery, costs in England, where prices are lowest, twenty to forty cents per pound; the cost of large guns increasing faster than their weight; melting cast-iron, preparing the molds, and dressing the surfaces already shaped, can be done from seven to thirteen cents per pound, which is about half the cost of wrought-iron for a given calibre. But calibre is not always a measure of work.

168. QUALITIES OF WROUGHT-IRON.—*Strength.*—Wrought-iron being comparatively refined is not necessarily so various in quality as cast-iron, and is very much stronger. Its permanent yielding-point is higher than the breaking-point of cast-iron, and its breaking-point is double that of its yielding-point. The average tensile strength of the best qualities of wrought-iron is about 60,000 pounds per square inch, or about double that of the best qualities of cast gun-iron.

169. *Uniformity.*—Although there is a wide range of strength between the highest and lowest specimens of wrought-iron, it is practically much more uniform than cast-iron; that is to say, the iron for a given service can be selected with much more certainty. The wrought-iron from any particular maker, who is careful in the manufacture, is found to be nearly uniform.

170. *Detection of Weakness.*—Unmistakable evidences of failure when it approaches, is obviously an important quality in any cannon metal. The detection of the coming fracture of cast-iron guns may undoubtedly be determined from minute cracks in the bore, and from close inspection of the gradual enlargement of the vent. But from the fact that cast-iron breaks in the testing-machine at the instant of perceptible elongation, these evidences must be more or less vague.

Wrought-iron continues to stretch after the point of permanent elongation, and the margin which lies between the point of yielding permanently and the point of ultimate rupture is of great importance as a condition of safety.

171. *Resistance to Compression and Wear.*—Another important quality of cannon metal is that the material shall be sufficiently hard so that the surface of the interior of the bore shall not in any way be indented or bruised, or otherwise acted upon by the powder or the projectile, or even by the premature fracture or explosion of a shell within the bore.

The bores of wrought-iron guns have been permanently indented by moderate firing. This is a great objection to wrought-iron, and it becomes a serious defect under the high pressures which heavy guns have to endure.

The hardness of metals, their resistance to abrasion, such as the wear of projectiles, approximates to their resistance to compression. The average hardness of steel is highest, and that of wrought-iron lowest. Cast-iron is well adapted for this purpose.

172. *Want of Homogeniety.*—The grand defect of wrought-iron is, that it is not homogeneous. The puddling process, by which it is produced, the piling process, by which large masses are aggregated, and the welding process, by which all parts, large and small, are united, are all the means of interposing strata of impurities and planes of weakness.

In fabricating guns, the first necessity is the production of a large mass of material. While melted cast-iron and steel run into castings of any size by their own gravity, wrought-iron is not melted at a practicable heat, so that another process must be resorted to. If the gun is forged solid, the process consists in adding a little at a time under the hammer, and trimming off a great deal of scrap. Many weeks are occupied in forging a heavy gun. If the gun is *built-up*, small pieces are fitted together with tools at a still greater cost. When all this is done it is not homogeneous.

173. QUALITIES OF STEEL.—*High Steel.*—Its distinguishing properties are extreme ultimate tenacity, hardness, and capability of extension without permanent change of figure; but its extensibility beyond the elastic limit is small, and it is therefore brittle under concussion. It will harden when heated and immersed in water; it is with difficulty welded, because it deteriorates under high heat, and because its welding heat is very near its melting point, and it is melted at a low temperature compared with wrought-iron.

Its obvious defect for cannon is its brittleness, but if so large a mass is used that its elastic limit will never be exceeded, or if it is jacketed with a less extensible metal, this defect is remedied or modified.

174. *Low steel* is a more suitable metal for cannon. It can be welded without difficulty, although over-heating deteriorates it, and it more nearly resembles wrought-iron in all its properties, although it has much greater hardness and ultimate tenacity, and a lower range of ductility, depending on its proportion of carbon. It has less extensibility within the elastic limit than high steel, but greater extensibility beyond it, that is to say, greater ductility.

175. The grand advantage of low steel over wrought-iron, for nearly all purposes, is, that it can be melted at a practicable heat and run into large masses; thus avoiding the serious defect of wrought-iron in large masses—want of soundness and homogeniety.

Its other important advantages for cannon are: greater elasticity, tenacity, and hardness.

If steel, or any metal requiring the highest attainable effort of force in motion to stretch it within its elastic limit, could also be made to have a great range of ductility beyond it, the safest and most perfect cannon metal would be obtained. But unfortunately as the one property increases the other decreases.

Elasticity is an indispensable quality in hoops, especially when the inner barrel is of cast-iron or a slightly ductile metal. If hoops change their figure permanently, their usefulness is in a great degree destroyed. For a given elongation without permanent change of figure high-steel requires more "work done" than any other metal.

176. *Strength.*—The tensile strength of steel ranges all the way from 50,000 to 200,000 pounds.

The strength of low steel, adapted to cannon-making, averages about 90,000 pounds, or three times that of the best cast-iron. The superiority of steel as regards hardness is too evident to require comment, and, considering the friction of rifle projectiles and the enormous pressure that modern cannon are required to stand, this is by no means an unimportant quality.

177. Bronze.—The work done in stretching to the elastic limit, and the point of fracture, is less for ordinary bronze than for wrought-iron of maximum ductility, and for low steel. This defect, added to the costliness of bronze, to the various embarrassments experienced in the casting of large masses, its softness and consequently rapid wear and compression, and to its injury by heat, has not warranted its employment for large calibres and high charges.

178. The mean ultimate cohesion of bronze, according to European authorities and the experiments of the United States government is about 33,000 pounds per square inch.

179. Rifled bronze-guns would be naturally more liable to rapid deterioration than smooth bores, as the weights of projectile and charge are much greater in the former in comparison to the area acted upon, and consequently the local heating at the seat of the charge is much more intense, thus tending to separate the copper and tin, more or less, from each other, forming those tin spots and porous patches which injure the strength of the material. The reduction of windage also, in the rifle-gun, would

tend to increase this local heating, and it must be remembered that bronze becomes hot very easily, and tin melts very soon (442° F.); moreover, the grooves in a rifle-gun open out many tin spots which would remain unexposed in a smooth-bore.

180. Conclusions.—The fitness of metals for cannon depends chiefly on the amount of their elongation within the elastic limit and the amount of pressure required to produce this elongation, that is to say, upon their elasticity.

It also depends, if the least possible weight is to be combined with the greatest possible preventive against explosive bursting, upon the amount of elongation, and the corresponding pressure, beyond the elastic limit; that is to say, upon the ductility of the metal.

Hardness to resist compression and wear is the other most important quality.

181. Cast-iron has the least ultimate tenacity, elasticity, and ductility; but it is harder than bronze or wrought-iron, and more uniform and trustworthy than wrought-iron, because it is homogeneous.

The unequal cooling of solid castings leaves them under initial rupturing strains; but hollow casting and cooling from within remedies this defect and other minor defects.

182. Wrought-iron has the advantage of a considerable amount of elasticity, a high degree of ductility, and a greater ultimate tenacity, than cast-iron; but as large masses must be welded up from small pieces, this tenacity cannot be depended upon; this defect, however, is more in the process of fabrication than in the material, and may be modified by improved processes. Another serious defect of wrought-iron is its softness and consequent yielding under pressure and friction.

183. Low cast-steel has the greatest ultimate tenacity and hardness; and what is more important, with an equal degree of ductility it has the highest elasticity.

It has the great advantage over wrought-iron of homogeniety in masses of any size.

It is, unlike the other metals, capable of great variation in density, by the simple processes of hardening and annealing, and, therefore, of being adapted to the different degrees of elongation that it is subjected to, in either solid or built-up guns.

184. Bronze has greater ultimate tenacity than cast-iron, but it has little more elasticity and less homogeniety; it has a high degree of ductility, but it is the softest of cannon-metals, and is injuriously affected by the heat of high charges.

185. In view of the duty demanded of modern guns, it

would seem that simple cast-iron is too weak, although it can be used to advantage for jackets over steel tubes. And, although cast-iron barrels, hooped with the best high wrought-iron, and with low-steel, cannot fulfil all the theoretical conditions of strength, and do not endure the highest charges, they have thus far proved trustworthy and efficient.

Wrought-iron in large masses cannot be trusted, and is in all cases too soft.

Bronze is impractically soft, and destructible by heat.

Low-steel is, therefore, by reason of the associated qualities, which may be called strength and toughness, probably the only material from which we can hope to maintain resistance to the high pressures demanded in modern warfare.

186. The necessity for strength in any gun construction depends upon the amount of strain that is brought upon it, and this strain is affected by the method and rate at which the gases are evolved in the burning of the powder-charge, and the rate at which the powder-space behind the projectile is enlarged by the gradual movement of the projectile through the bore.

It is evident that if by any proper manipulation of the powder in manufacture, the size, form, and density of the grain can be so determined and adjusted as to confine the strain within certain limits, the strength of the gun to resist such a strain need not reach the maximum requirements of steel, but may be found within the well-known capabilities of our best cast-iron.

CHAPTER II.

GENERAL DESCRIPTION OF ORDNANCE.

Section I.—Terms and Definition.

187. Ordnance.—The term Ordnance includes artillery of all kinds in its most comprehensive signification.

Classification.—Ordnance is divided into three general classes, viz.: *guns*, *mortars*, and *howitzers*.

188. GUNS.—In a technical sense, a gun is a heavy cannon. Guns are used for firing projectiles at very low angles, with large charges, to obtain high initial velocity.

They are distinguished as *rifle* and *smooth-bore* cannon, as *cast* and *built-up* cannon, and as *breech-loading* and *muzzle-loading* cannon.

Smooth-bore cannon are of two kinds, *solid-shot-guns* and *shell-guns*.

Solid-shot-guns are distinguished by the weight of the projectiles, and shell-guns by the diameter of the bore.

Shell-guns possess the advantage of being lighter pieces, and yet firing shells of as large diameter.

189. A gun of ordinary construction is cylindro-conical in general form. As the strain upon the piece, when discharged, decreases from breech to muzzle, the thickness of metal may be proportionately reduced, and advantage thus gained of lessening the weight of the gun without impairing its efficiency.

The greater part of the effect of the charge is sustained by the heavy cylindrical portion, the other part of the gun being principally a directing tube.

190. NOMENCLATURE.—Guns may generally be divided into five principal parts, viz.: *Breech*, *Cylinder*, *Curve*, *Chase*, and *Muzzle*. (Figs. 15 and 16.)

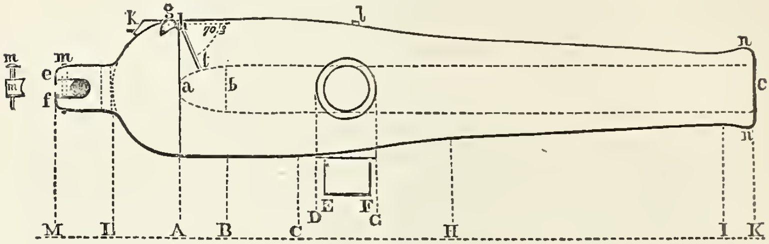
191. *The Breech* is the mass of solid metal in rear of the bottom of the bore.

The thickness of metal in the prolongation of the axis of the bore is of superior importance, for if a gun be weak there, strength in other parts will not save it from explosion.

The thickness is usually somewhat greater than the greatest thickness of metal in the cylinder.

In the Dahlgren pattern the hemispherical portion in rear of the base-line is struck from a centre at the bottom of the chamber, with a radius equal to the greatest semi-diameter of the piece.

FIG. 15.—Dahlgren Shell-gun.



Scale of 1869.

Length of gun, A K.	Cylinder, A C.	Base line, A.
Breech, A M, including— hemisphere or base of breech, } A L. cascabel, L M. jaws, *e f*. block and pin, *m m*.	Curve, C H.	Trunnion, E F.
	Chase, H I.	Rim base, D G.
	Muzzle, I K, { *n*, swell of muzzle. *c*, face of piece.	Breech sight mass, *k*.
		Front sight mass, *l*.
	Bore, *a c*, { cylinder, *b c*. gomer chamber, *a b*.	Locklugs, *g*.
		Vent, *h t*.

192. *The Cylinder* is that portion between the breech and trunnions, including the seat of charge and the point where the greatest strain is exerted upon the gun.

A thickness of one calibre, or the diameter of the bore, was formerly the general rule, but it has been found insufficient for heavy cast-iron cannons. The results of experiments show that for the larger calibre, the thickness of the cylinder should not be less than one and a quarter times the diameter of the bore, while no important increase in resistance is obtained by increasing the thickness of the metal beyond one and a half calibres. (Art. 223.)

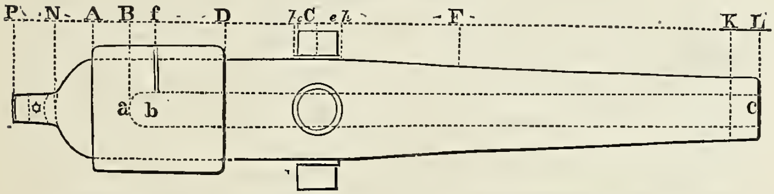
193. *The Curve* is the truncated cone connecting the cylinder with the chase. It is made somewhat thicker than necessary to resist the pressure of the powder, in order to serve as a proper point of support for the trunnions, and to compensate for certain defects of metal liable to occur in the vicinity of the trunnion of all cast cannon arising from the crystalline arrangement and unequal cooling of the different parts. (Art. 366.)

194. *The Chase* is the long, tapering portion of the gun extending from the curve to the muzzle. The principal injury to

which the chase is liable arising from the striking or balloting of the projectile against the side of the bore, in smooth-bored cannon; and the thickness of metal should be sufficient to resist it. In pieces of soft iron or bronze the indentation thus made may increase to the extent of bursting the piece; but in cast-iron cannon, where they are always very slight, the taper of the

FIG. 16.—Parrott Rifle-gun.

Scale of 1869.



B L, length of gun.
A D, reinforce band.
A C, cylinder.
C F. curve.
F K, chase.

K L, muzzle.
B P, breech.
A N, base of breech.
N P, cascabel.
a c, bore.

a b, (hemispherical) bottom of bore.
f, vent.
e e, trunnion.
h h, rim base.

C K is straight in eight-inch guns.

chase can be made more rapid, or, with the same weight of metal, larger than in bronze guns.

195. *The Muzzle* is the increased thickness of metal which terminates the chase. Inasmuch as the metal situated immediately at the muzzle is supported only in rear, it has been usually considered necessary to increase its thickness to enable it to resist the action of the projectile at this point, but in late cannon designed to fire through embrasures, the *swell of the muzzle* has been omitted. The swell strengthens a part liable to be impaired by an enemy's fire, and affords, also, a good position for a notch or sight.

196. THE TRUNNIONS are two cylindrical arms attached to the sides of a cannon, for the purpose of supporting it on its carriage. They are placed on opposite sides of the piece, with their axes in the same line, and at right angles to its axis.

197. *Size.*—The size of the trunnions depends on the recoil of the piece, and the material of which they are made.

The resistance which a cylinder opposes to rupture, is proportional to the cube of its diameter; on the supposition that the strain is proportional to the weight of the charge, it is usual to make the diameter of the trunnions equal to the diameter of the bore.

198. *Position.*—The position of the trunnions, with reference to the axis of the bore, influences the amount of recoil and the endurance of the carriage. By reference to Fig. 17, it will be seen that if the axis of the trunnions be placed below the axis of the piece, the resultant of the force of the charge, which acts against the bottom of the bore, will act to turn the piece around its trunnion, and cause the breech to press upon the head of the elevating-screw, with a force proportioned to the length of the lever-arm, or distance between the axes.

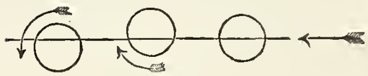


Fig. 17.

The effect will be to throw an additional strain on the carriage by pressing down the rear part of it, and checking the recoil.

If the trunnions be placed above the axis of the piece, rotation will take place in the opposite direction, and the effect of the discharge upon the carriage and recoil will be reversed. By placing the two axes in the same plane, the force of the charge will be communicated directly to the trunnions, without increasing or diminishing its effect on the carriage or recoil; this position is given to them in all cannon of the United States service.

199. *Preponderance.*—The unequal distribution of the weight of a cannon, with reference to the axis of the trunnions, is called the preponderance.

It is the pressure which the breech portion of the gun, when horizontal, exerts on the elevating arrangement. To ascertain the preponderance practically, support the gun at the trunnions as freely as possible, and bring it horizontal by means of a long hand-spike in the bore. Place a platform scales under the breech, and fix a block of wood on it, touching the gun underneath at the elevating-point. The hand-spike being then removed from the bore, the pressure on the block is indicated on the arm of the scales, and is the preponderance of the gun. (Art. 318.)

200. *The Rim-bases* are two larger cylinders placed concentrically around the trunnions, for the purpose of strengthening them at their junction with the piece, and by forming shoulders, to prevent the piece from moving sideways in the trunnion-beds. The ends of the rim-bases, or the *shoulders of the trunnions*, are planes perpendicular to the axis of the trunnions.

201. INTERIOR FORM.—Calibre.—The diameter of the bore is termed the calibre of the gun; this should be so regulated that there may be no waste of powder, and that the

force of the gas may be expended in giving velocity to the projectile with as little strain as possible on the metal of the gun.

The calibre of a piece of ordnance depends upon the form and nature of the projectile; the general form of projectiles being that of a sphere, or cylinder (pointed), it is obvious that the bore of a gun should be cylindrical in shape, except when modified to a certain extent by a chamber, or rifling.

A rifled gun requires a less calibre than a smooth-bored piece, if both are intended to fire projectiles of equal weight, for with the former elongated projectiles can be used, but with the latter only spherical.

A gun intended only for shell firing has a large calibre in proportion to its weight, capacity of shell for bursting charge being requisite.

202. The calibre must also be suited to the charge. As the diameter of the bore is decreased, so with a given charge, must the length of the cartridge be increased, and the conversion of the powder into gas be retarded unless the cartridge be pierced like a tube; with the longer cartridge the strain will be thrown more forward.

In two guns of different calibres, the useful effect of a given charge is probably the greatest in the bore of the higher calibre, as regards the initial velocity of the projectile, for as the gas exerts a certain pressure per square inch on the base of the projectile, the one with the larger bore will receive the most pressure.

As the calibre of the gun is increased, so will the bottom of the bore receive a greater, and the metal surrounding the charge a less proportional strain for a given pressure per square inch; but the pressure will probably increase with the calibre, until the diameter of the cartridge is about equal to its length, on account of the more rapid conversion of the charge into gas.

203. Length of Bore.—The length of the bore of a piece of ordnance, must be such as to allow of the decomposition of its whole charge, a certain time being necessary for its complete combustion. If the bore be not of sufficient length for this purpose, a considerable portion of the charge will be blown out unfired, and therefore wasted.

The initial velocity of the projectile increases with the length of bore up to a certain point, viz.: when the retarding forces of the friction of the ball against the sides of the bore, and the resistance of the column of air in front of the projectile (which increases with the velocity), are equal to the accelerating force of the gas, it follows that after the projectile passes this point, its velocity decreases until it is finally brought to a state of rest.

204. Experiments have been made with smooth-bore guns at different times, to determine the influence the length of the piece exercises on the velocity of its projectile, and they show that the velocity increases with the length of the bore in a variable ratio, the increase of velocity for the short lengths being much greater than those for the long lengths.

Experiments made by Major Mordecai, U.S.A., on a piece of light calibre, show that the velocity increases with the length of the bore up to twenty-five calibres, but that the entire gain beyond sixteen calibres, or an addition of more than one-half to the length of the gun, gives an increase of only one-eighteenth to the effect of a charge of four pounds.

The length of the bore is always limited by several other practical considerations, such as the weight of the piece, and the space it will have to occupy.

205. The proper length of bore for a rifle cannon, has not been satisfactorily determined, so many different points requiring numerous and careful experiments, in order to furnish sufficient data for the proper consideration of the subject. However the length of the bore of a rifled piece, intended to fire a given charge and weight of projectile, should depend upon the calibre and system of rifling adopted; if two rifled guns are required to fire equal charges, but one has a less calibre than the other, the same amount of work will not probably be done upon the projectiles in the two bores, unless the respective lengths of the latter are nearly proportional to the lengths of the cartridges and so equal expansion is allowed to the gas in both bores.

In some systems of rifling a greater force is required to move the projectile than in others, and, consequently, more of the powder is converted into gas before the shot starts; also, in most of the breech-loading rifled guns, there is no windage, and, there being no loss of gas, greater force is exerted in a given space than where there is windage.

206. Windage is the space left between the bore of the piece and its projectile, and is measured by the difference of their diameters.

The windage is strictly the difference between the area of a section of the bore at right-angles to its axis, and the area of its great circle of the projectile, but the linear windage is given in all official tables of ordnance.

207. The objects of windage being to facilitate loading, and to diminish the danger of bursting the piece, it is rendered necessary in all muzzle-loading cannon, by the mechanical impossibility of making every projectile of the proper size and shape, by the unyielding nature of the material of which large pro-

jectiles are made, by the foulness which collects in the bore after each discharge, and by the use of hot and strapped projectiles.

208. Windage diminishes the accuracy of fire, weakens the effect of the charge by allowing an escape of gas, and is the principal cause of deterioration in cannon. It is therefore of importance to make the windage as small as possible, compatible with ease and efficiency in loading.

209. The velocity of projectile and recoil of gun are considerably less as the windage is increased; experiments indicate that the loss of velocity by windage in smooth-bore guns, is proportional to the windage, but this point has not been determined for rifle guns.

210. The amount of gas which is lost will depend upon the form of the projectile, and the resistance which it offers to motion. The greater the force required to move the projectile, the longer the time for the escape of gas, so that the waste should increase with the weight of projectile, and there should be a greater loss in rifled than in smooth-bored cannon, if the calibre and windages are alike, but the elongated form of a projectile will tend to confine the gas as it escapes within narrow limits, and by retarding its motion diminish its waste.

211. Seat of the Charge.—The form of that part of the bore which contains the powder, will have an effect on the force of the charge, and the strength of the piece to resist it.

Chamber.—The chamber of a gun is the contraction, or cavity, at the bottom of the bore to receive the charge of powder. It is generally conceded that chambers are not advantageous except with charges less than would fill a cylinder, whose length is equal to the diameter of the bore.

212. When a light piece is used to throw a projectile of large diameter and great weight, it is advantageous to employ a small charge of powder. If such a charge was made into a form to fit the bore, its length would be less than its diameter, and being ignited at the top a considerable portion of the gas generated in the first instant of inflammation, would pass through the windage, and a part of the force of the charge would be lost. To obviate this defect, and to give the cartridge a more manageable form in loading, as well as to strengthen the gun, the diameter of this part of the bore is decreased so as to form a *chamber*.

213. *Shape.*—The necessity for a chamber being assumed, and its capacity decided upon, the determination of its proper form will be governed by several conditions. *First.* The chamber must be deep enough to receive a cartridge manage-

able in length. *Second.* As the tendency to transverse rupture varies directly as the square of the length of the bore subjected to maximum pressure—and as the chamber adds materially to this length, it must evidently be no deeper than the service of the gun renders necessary. *Third.* It should contain no angles,

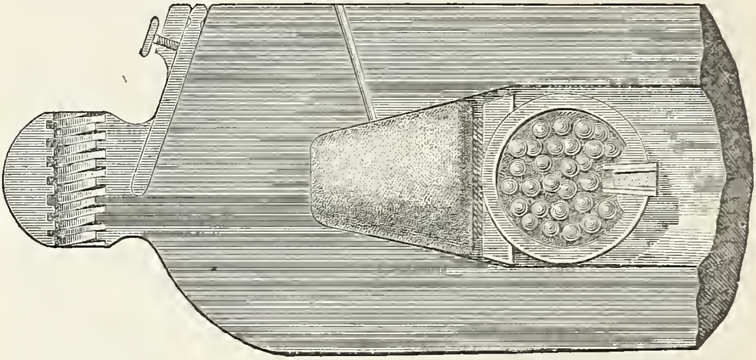


Fig. 18.

on account of the well-known tendency of a split to begin at an angle; hence, the bore should terminate in a curve, the hemisphere, semi-ellipsoid, paraboloid, and ogival, being those most frequently used.

214. The shape of the chamber generally in use is conical. The particular kind of chamber, represented in Fig. 18, is called a *Gomer Chamber* after its inventor. Its principal advantages are, that of distributing the force of the charge over a large portion of the surface of the projectile, thereby rendering it less liable to break if it be hollow, and that of destroying the windage when the projectile is driven down to its proper place.

There are two forms of chambers adapted in the service. The cylindrical and the conical, or *gomer*. The first is nearly obsolete.

215. The Vent is the channel passing through the metal, from the exterior of the breech into the bore, by means of which the gun is fired.

The size of the vent should be as small as possible in order to diminish the escape of gas and the erosion of the metal, which results from it. In Naval Ordnance vents are constructed two-tenths of an inch in diameter.

216. In bronze pieces the heat of the inflamed gases would be sufficient to melt the tin, and rapidly enlarge its diameter.

For this reason they are *bouched* by screwing in a perforated piece of pure wrought-copper, called the *vent-piece.* (Fig. 19.) This arrangement allows the vent to be renewed when too much enlarged by continued use. Copper vent-pieces are especially necessary in rifle-guns, in consequence of the prolonged action of the gas arising from the resistance of the projectile. In the largest calibre the interior orifice is lined with *platinum.* The upper portion of the copper is replaced by steel to obtain a harder surface for receiving the blow of the hammer.

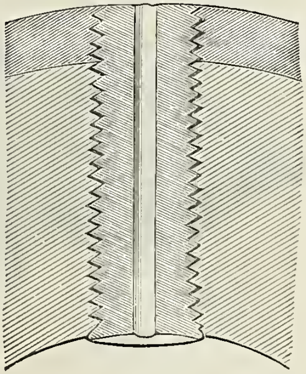


Fig. 19.

217. *Position.*—All smooth-bore guns of the Dahlgren pattern have two unbouched vents, situated on opposite sides of the axis of the bore, and inclined at an angle of 70° with that axis. (Fig. 76.)

The one on the right side is bored entirely through; the other is simply initiated to give it direction.

When the open vent is too much enlarged by wear for further use it is closed with melted zinc, and the other is bored out. Each vent should endure about five hundred service rounds. (Art. 603.)

In smooth-bore cast-guns the vent enters the bore very near the bottom; the vents of heavy built-up guns are usually bored vertically, and in such a position as to strike the cartridge at about four-tenths of its length from the bottom of the bore, it having been ascertained by experiment that the ignition of the charge at about this point realizes the greatest projectile force that can be produced by a given charge.

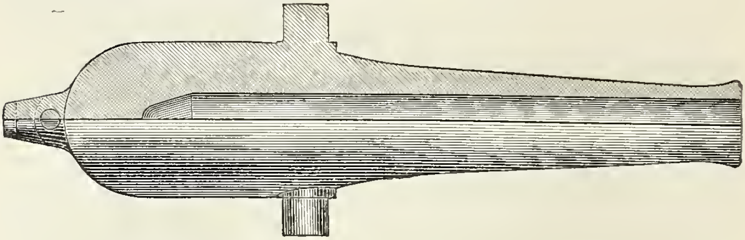
Experiment shows that the actual loss of force by the escape of gas through the vent, as compared to that of the entire charge, is inconsiderable, and may be neglected in practice.

218. Exterior Form.—In designing a gun it is necessary in the first place to endeavor to determine what thickness of metal is required for that part of the gun surrounding the seat of the charge, for it is here where the greatest strain from the explosion of the charge is exerted. No precise rules can be laid down for the regulation of this thickness in various kinds of ordnance, as so much depends upon the physical properties of the material used. The general results of experience, or of experiments, car-

ried on for the purpose of establishing this point, can alone furnish us with the requisite data. (Art. 221.)

The amount of metal in a gun must depend upon the charge,

Fig. 20.—IX-in. Dahlgren.



the weight, and form of the projectile, the material used, and the method of construction.

219. Force to be restrained.—When a charge of gunpowder is ignited in the bore of a gun, the gas exerts equal pressures in all directions, and therefore neglecting windage, the pressure in the bottom of the bore is equal to that on the base of the projectile, and the pressures on the top and bottom as well as those on the sides of the bore balance each other.

220. The metal of a gun is subjected to two principal strains (Art. 308), one, a *transverse* or *tangential*, which tends to rend the metal lengthwise, or from end to end, through A, B (Fig. 21), and the other, a *longitudinal*, tending to fracture the gun across, as through C, D (Fig. 21), or to drive out the breech.

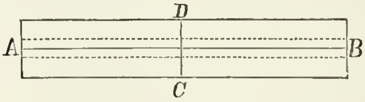


Fig. 21.

As the projectile moves towards the muzzle so will the space in which the gas is confined be increased, and the pressure be decreased; the portion of metal surrounding the space originally occupied by the cartridge, and a little in front of it, is that upon which the *maximum pressure* from the gas is exerted.

The maximum pressure will be influenced by the nature of the powder, the resistance offered by the projectile to motion, and by the absence or amount of windage.

221. Experiments.—Many experiments have been made to determine the gradual decrease of strain upon the metal of a piece of ordnance, from breech to muzzle. The first were

accomplished by perforating a gun in several places from the exterior to the bore, at right angles with the bore, and successively screwing a pistol-barrel, containing a steel ball, into each perforation, and discharging the gun with the pistol-barrel at the differ-

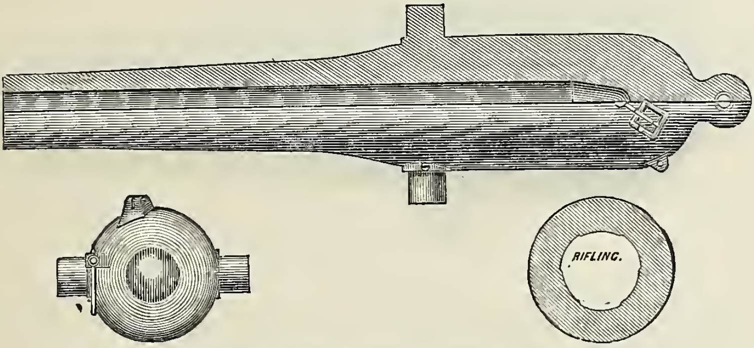


FIG. 22.—Heavy Twenty-Pounder Bronze Rifle, 1,950 lbs.

ent perforations, the relative velocities with which the pistol-ball (received by a pendulum) is forced out at these different positions indicate the force exerted there to burst the gun; and consequently the relative strength of metal necessary in the various parts to resist explosion.

The results of these experiments are relatively as follows, in decimal parts:

At a calibre in rear of centre of projectile......	.98
" centre of projectile........................	1.
" one calibre in front of projectile.........	.81
" two " " "	.68
" three " " "	.62
" five " " "	.53
" seven " " "	.44
" nine " " "	.40
" eleven " " "	.37
" fifteen " " "	.29

These decimals show the relative strength necessary at different parts to resist explosion.

The dimensions here given are intended to apply to cast-iron ordnance, which it was assumed should have a thickness of one calibre round the seat of the charge where the greatest strain is exerted.

222. Other experiments have been made by using Rodman's pressure gauge (Art. 1332) in the holes instead of a pistol-barrel,

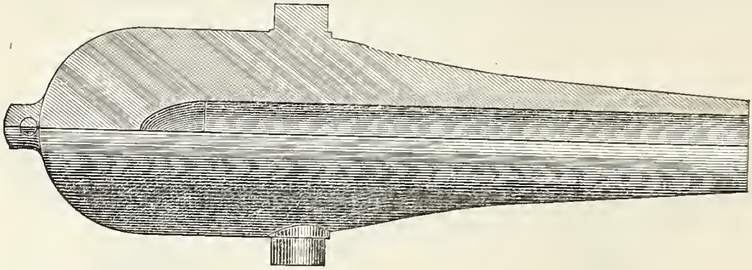


Fig. 23.—Navy XV-inch.

also using electricity by connecting a *chronoscope* with wires in plugs fitted in the holes of the gun. (Art. 1302.)

223. In cast-iron guns of more recent construction the metal is distributed on different principles, viz.: in giving a greater thickness of metal, and consequently more strength about the seat of the charge, while the amount of metal in the chase is diminished, this part having to sustain but a small proportion of the strain from the discharge of the piece; also, in increasing the proportional thickness of metal, as the calibre of the gun is greater. (Art. 311.)

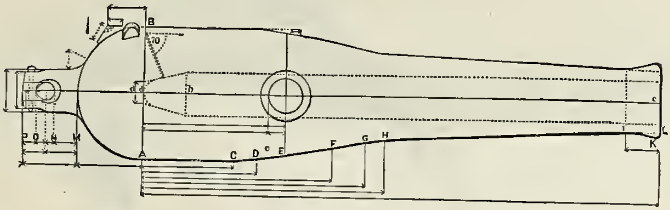
224. Improvements.—Gun-making is no longer the simple matter which it continued to be while the world was content with wooden ships and round shot. There are now almost as many ways of making a gun as of making a steam engine. Ingenuity has been exercised upon the material, the construction, the rifling, and the mounting of the gun, as also in regard to the kind of powder with which it is to be loaded, the structure of the projectile which is to be fired, and the appliances by which the gun is to be worked. Everything is changed since the days when simple smooth-bores and cannon-balls were deemed sufficiently formidable and destructive.

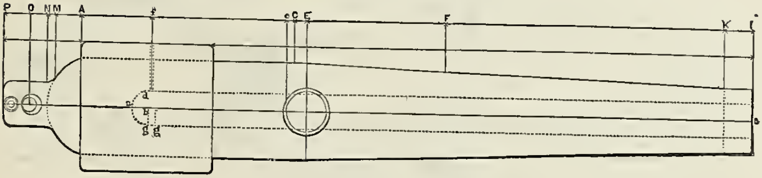
After many years of experiment and millions of expenditure foreign powers have established two or three systems of rifled ordnance as worthy of confidence. These are the German system (Art. 704), the French system (Art. 679), and the English system (Art. 661).

In our country appropriations have been made for carrying on experiments with a view to establishing the best system of heavy rifled ordnance. The Army has been entrusted with this important duty, and experimental guns on different plans are now in course of construction.

225. Devices.—Formerly cannon were highly ornamented with figures representing some fanciful design, together with the national coat-of-arms and cypher of the reigning monarch. Each

Fig. 24.—Dahlgren Shell Gun.





Parrott Rifle Gun, 1864.

piece also bore a particular name, borrowed from some animal or passion; and sometimes mottoes were inscribed upon them. The most recent models are characterized by an entire absence of molding or ornaments, and by the utmost simplicity of figure.

226. (See Table facing page 71, and marked 71*.)

227. MORTARS.—Mortars are short pieces of ordnance with large bores, used to throw shells at high angles, generally forty-five degrees, for reaching objects by their vertical fire. They are used in the navy only under exceptional circumstances.

228. Construction.—They are constructed stronger than guns, on account of the high elevation at which they are fired; and shorter, because the difficulty of loading would be increased by their length. In the new patterns, the axis of the trunnions passes through the centre of gravity, if the piece and the bore is unchambered.

The only mortar used in the naval service, is the thirteen inch of 17,000 lbs., made of cast-iron. (Fig. 25.)

229. Howitzers.—Properly, howitzers are a description of shell-guns; shorter, lighter, and more cylindrical in shape than

a gun of the same calibre, and having a chamber for the reception of the powder. They are employed to fire large projectiles at low angles, with comparatively small charges of powder.

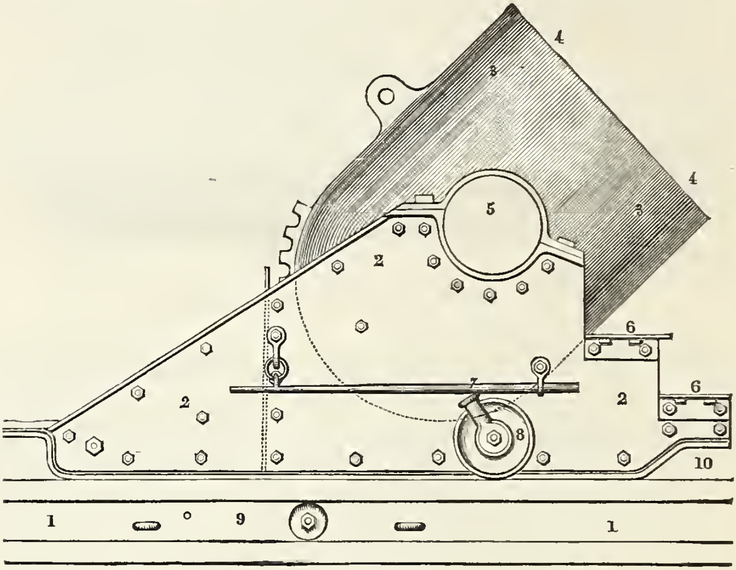


FIG. 25.

230. NAVAL HOWITZERS are bronze shell-guns, adapted to field and boat service. They are made of bronze on account of their comparative lightness for the same strength, and from their being less liable to burst than iron guns of the same calibre.

231. THE BOAT HOWITZERS are both smooth-bore and rifle.

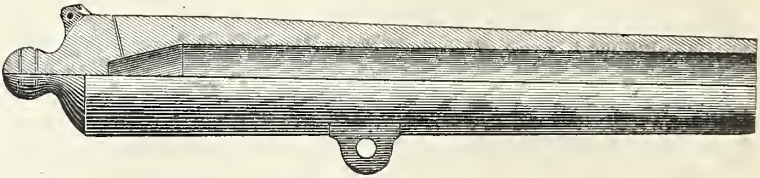


FIG. 26.—Light Twelve-Pounder Boat Howitzer.

They are alike in the principle of construction and general appearance, and differ only in weight and dimensions.

Around the charge the metal is distributed in form of a cylinder (Fig. 26), extending sufficiently in front of the seat of the projectile; thence to the muzzle it is continued as a truncated cone.

The breech is a portion of a sphere. The bore is terminated by a conical chamber (Fig. 18), and the piece is mounted on its carriage by a loop.

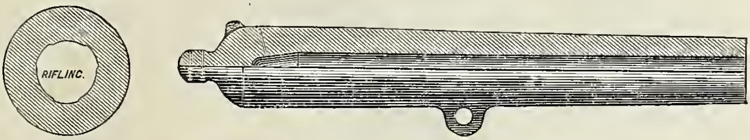


FIG. 27.—Rifled Twelve-Pounder Bronze Howitzer.

232. PERCUSSION-LOCKS FOR NAVAL ORDNANCE.—The ham-

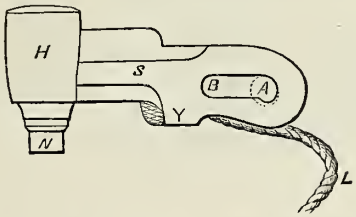


FIG. 28.—H. The head of the hammer. } Made of strong gun metal.
S. The shank. }
N. An iron nipple with a case-hardened face screwed into the head.
A. The hole for the axial bolt of the hammer.
A B. The extension of the hole, termed a slot, in the direction of the head H; its length is such as to admit of the hammer's receding one inch, which takes it entirely clear of the vent-blast.
L. A laniard entering beneath the rear end of the shank, which is rounded for that purpose, then through a perforated stud (Y) on the under-side of the shank.

mer has its revolution about the axial bolt traversing the hole A, and the force is applied by the laniard passing about the rounded rear end of the shank. When the hammer is thrown back, the laniard being steadily and quickly drawn, compels the hammer to turn on its bolt until down on the vent. Now, if there were no other perforation for the bolt than that at A, the hammer could not escape from the gas issuing out of the vent, and must be thrown off by it. But when the hammer is down, if the force of the laniard be continued, the effort is to withdraw directly from the vent, and the slot or extension of A permits this to be done until the end of the slot at B is arrested by the axial bolt. The receding motion thus obtained

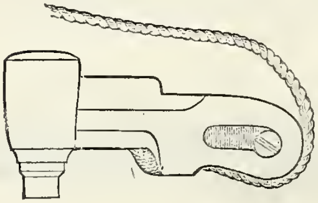


Fig. 29.

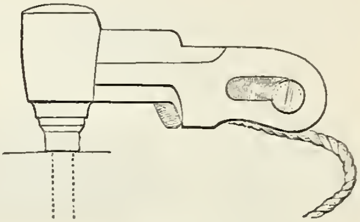


Fig. 30.

has the extent of one inch, which is sufficient to take the hammer-head clear of the blast of the vent.

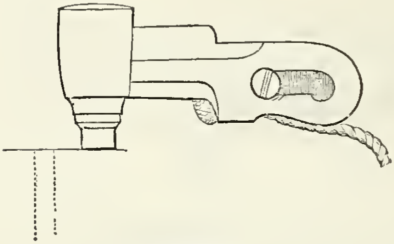


Fig. 31.

A lock-mass is cast with the gun near the vent (Fig. 22). It is slit so as to form studs, between which the hammer is secured and has its movement.

On boat-howitzers the lock has no slot, and does not recede from the vent. The vent-blast is avoided by having a perforation in the head of the hammer; which allows for its escape without throwing back the lock.

233. THE GATLING-GUN—(Fig. 32)—is a machine-gun consisting of a set of ten barrels, A, in combination with a grooved cartridge carrier, M, and a lock-cylinder, O and O′ (Fig. 36). The whole being rigidly secured to a centre-shaft, N. The grooves in the carrier, the holes in the lock-cylinder, and the barrels, all correspond in number. Each barrel is provided with a lock, F (Fig. 37), which works in a chamber formed in the lock-cylinder; O and O′, in a line with the axis of the barrels. The lock-cylinder is surrounded by an outer casing, H, connected to the framing, B, which is carried along on each side of the barrels and across the front of the gun; the rear end of each side frame forming a support for the breech-casing, H. In the breech-casing is a verticle trans-

verse partition, D (Fig. 39), into which the main central shaft, N, which carries the lock-cylinder, O, carrier M, and barrels, A, is journalled. At its front end the main shaft is also journalled into the cross-piece of the frame, B.

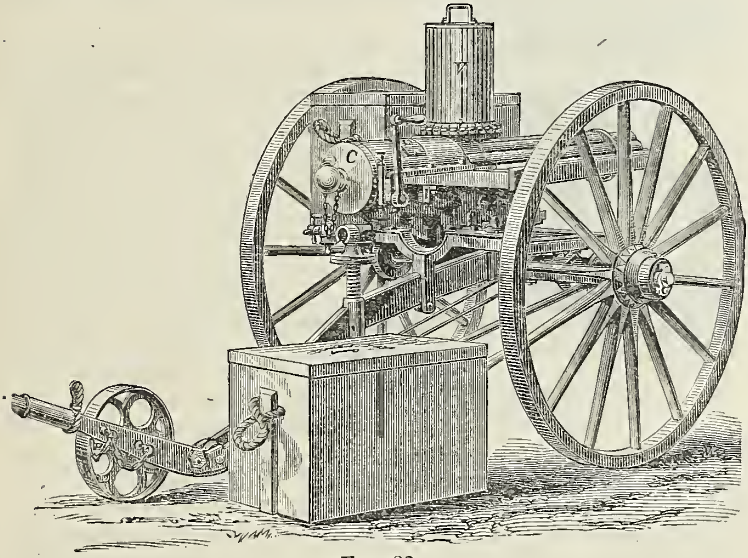


Fig. 32.

234. On the rear end of the main shaft is fixed the revolving gear (Fig. 39), which is worked by a crank, G, on the right side of the breech-casing, H. The rear of the chamber in which the gear is placed is closed by a cascabel plate, C (Fig. 37), having an opening through which the lock may be entered

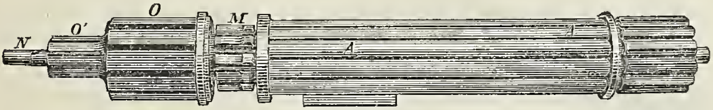


Fig. 33.

and withdrawn when necessary. This opening is closed by a plug of special construction, E, attached to the cascabel plate by a chain.

In front of the breach-casing and hinged to the frame, B, is a curved plate, I (Fig. 34), called the *hopper*, through which the cartridges are fed to the gun.

The gun is mounted on a swivel block, L (Fig. 32), on which are formed seats to receive the trunnions of the gun; this block is secured to the carriage by a centre-pin, which allows it to turn and bring the gun to bear upon any object within the arc of twelve degrees, the trunnions permitting vertical motion of the muzzle of the gun.

235. THE HOPPER (Fig. 34) is a brass curved plate, I, hinged to the frame-work of the gun on the right side and encasing the chambers of the barrels. It is provided with an aperture, K, through which the cartridges descend to their places in the grooves of the carrier or chambers of the barrels; whereupon they are instantly taken possession of by the locks, forced into the barrels, and fired. A short distance in front of the cartridge aperture, is an upright pin I′, in which the *feed drum*, V (Fig. 42), rests and revolves. The upper side of the hopper is flat and circular.

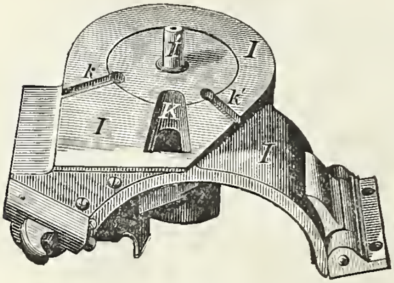


FIG. 34.

236. THE APERTURE, K (Fig. 42), for the cartridges, is nearly of the form of a cartridge and tapered downward. Its sides serve to guide the cartridges into the carrier singly, so that they can be removed one by one. The front end of the aperture is projected downward nearly into the carrier next the barrels, and thus serves to cut off the entrance to that particular barrel which is in front of it, while in this position; and prevents the cartridge which lies upon the one already in the groove from sliding forward and prematurely entering the opposite barrel.

237. THE CARRIER, M (Fig. 35), is a metal cylinder, attached to, and revolving with, the main shaft; its forward edge being sufficiently near the rear end of the barrels to insure the cartridges entering without jamming (Fig. 42). On its circumference are as many grooves as there are barrels, in which the cartridges rest and are pushed forward into the barrels by the locks; thus the grooves of the carrier act as chambers for the barrels (Fig. 33).

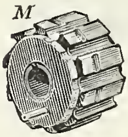


FIG. 35.

238. THE LOCK-CYLINDER, O and O′ (Fig. 36), is a metal piece, consisting of two cylinders of different diameters, O, and O′. On the circumference of the smaller and parallel with the

axis of the barrels, are as many slots as there are locks, and in these slots, the lug on the underside of the lock-case, P (Fig. 37), travels. In the larger cylinder, and in line with the axis of the barrels, are the same number of holes, in which the locks move forward and back. A slot or opening is made between the holes and the circumference of the cylinder, forming a guide for the lug, *x*, on the firing-pin, Z (Fig. 37), of the lock.

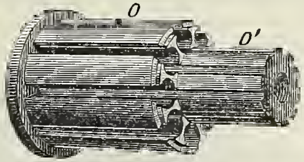


FIG. 36.

239. THE LOCKS consist of hollow steel cylindrical cases of different diameters, F (Fig. 37); the larger cylinder, or rear part of the lock-case being open at the top for a portion of its length. In this portion is placed the firing-pin and spring, Z, the former, which is reduced in diameter at its forward end to about one-eighth of an inch, passes through the smaller portion of the lock-case, W, and projects very slightly beyond it. The spring, Z, is confined between the end of the slot and a lug, *x*, formed at the forward end of the larger part of the firing-pin. This lug is designed to take against the cocking-plate in the breach-casing and gradually press the spring and firing-pin backward, until the proper moment, when it is released and the firing-pin is thrown violently forward, exploding the cartridge.

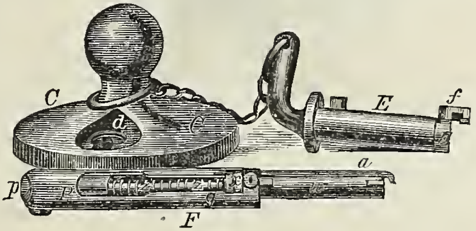


FIG 37.

Attached to the lock-case, on the under side, are two lugs, P, intended to travel in the slot on the circumference of the smaller portion of the lock-cylinder O′ (Fig. 36). At the rear upper side of the case is a lug, *p*, which taking against the cam surface, R, in the breach-casing, (Fig. 38), communicates a forward and backward motion to the lock.

On the upper left-hand side of the lock-case (Fig. 37), is fixed a piece of steel, *a*, about four inches long, called the *Extractor*, having its forward edge rounded on the upper side and a shoulder on the latter, strikes a cam just at the edge of the barrel, drops over the rim of the cartridge, and when the lock moves back, brings the cartridge-shell with it and drops it on the ground beneath the gun.

240. The Breech-casing, H (Fig. 38 and Fig. 39), is a hollow cylinder extending from the front end of the lock-cylinder to the rear portion of the frame, B. Flanges, *h h*, on its sides rest on and are screwed to the frame (Fig. 32); near the rear end is a partition called the *diaphragm-plate*, D (Fig. 39), which divides the cylinder into two parts and separates the lock-cylinder and worm gear, which is placed in the rear portion of the casing. A cascabel plate, C (Fig. 37), screws to the rear end of the casing and serves to encase and protect the worm or revolving-gear. In the forward division of the casing are placed the cams, R (Fig. 38), for forcing forward and drawing back the locks. In the upper left-hand side of the diaphragm-plates is an aperture, *d* (Fig. 39), through which the lock passes when entered or withdrawn; a brass tube, *e*, screwed to the aperture, serving as a guide to the lock and breach-plug. At the proper distance from the front end of the casing, and on the right side, is placed a cocking-plate, which will be explained under the head of cocking apparatus.

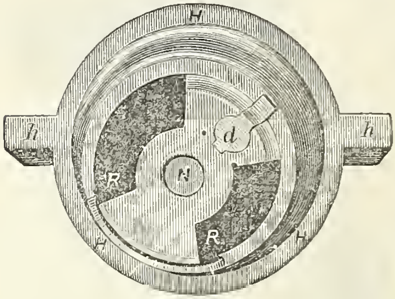


Fig. 38.

241. The Revolving or Worm-gear (Fig.39).—To the rear end of the main staff passing through the diaphragm-plate, D, is fixed a worm-wheel, W, worked by a shaft, S, extending across the rear portion of the casing. On this shaft is a worm, *s*, which works in the worm-wheel, W. A crank, G, at the right end of the transverse shaft conveys motion by means of the worm to the worm-wheel, and thus the lock-cylinder, carrier, and barrels are revolved.

242. Traversing-gear.—To the opposite side of the transverse shaft on which the crank, G (Fig. 39), is fitted, is keyed a sleeve, *t*, having cut on its exterior a right and left-hand screw, on which works the tapered end of a forked piece, T. This is dropped into a socket, in the outer end of a brass casting, U, against which the upper end of the elevating-screw presses at U′. The fork, T, passes through the upper socket, then through a brass ring fitted with a clamp, T′, and finally through the lower socket of the casting, by which means the fork is permitted to turn as it passes along the cross-cut thread, *t*, in either direction. Fig. 40 represents the

fork detached and enlarged, and also in its proper position on the sleeve.

On the outer end of the sleeve is keyed a ring, t', capable of adjustment at every half turn of the cross-cut-thread. This is effected by a pin on the ring, and corresponding holes midway between the intersection of the threads of the screws, thus regulating the range of motion of the breach of the gun. This ring serves to close one end and thus make the screw endless, and also to turn the fork into the return groove, the inner end of the sleeve being arranged so as to accomplish the same object.

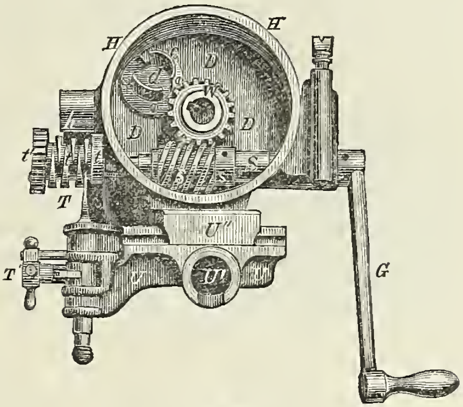


FIG. 39.

As the firing-crank, G, is turned, the bands, carrier, lock-cylinder and right and left-hand screw are revolved. The latter, working on the fork, T, gives the piece a continuous lateral traverse which may be enlarged or contracted as desired, by means of the ring, t'; thus spreading the fire over a wide range, or contracting it.

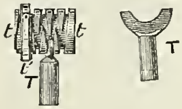


FIG. 40.

Elevating or depressing the gun does not interfere with the lateral traverse, as the elevating screw presses against the bottom of the casting to which the fork is attached, and thus both run up or down alike.

243. THE ELEVATING-GEAR (Fig. 32) consists of a screw whose lower part rests upon the trail of the gun, and whose upper part ends in a ball, working in a socket, U' (Fig. 39), on the under side of the brass-casting, U. On the upper surface of the casting is a rib which works in a corresponding slot, in a square brass plate, U'', screwed to the under side of the breech-casing. By referring to Fig. 39, the arrangement of the elevating and revolving gear will be readily understood.

244. THE MOVEMENT OF THE LOCKS is accomplished by means of two spiral cams, R (Fig. 38), placed in the breech-casing and

a slot in the casing itself, along the edge of the cams. As the crank, G (Fig. 39), is turned, the rear lug, *p* (Fig. 37), on the lock-case travels in the slot along the spiral cam, forcing the lock forward on the lock-cylinder and carrier. The front end taking against the cartridge in the carrier, pushes it into the barrel. At the moment that the cartridge has fully entered the barrel the lug, *x* (Fig. 37), in the firing-pin takes against the cocking-plate and forces back the spring, *z*. When the lug, *x*, on the pin passes the highest point of the cocking-plate, the pin flying forward explodes the cartridge. The rear lug, *p*, having then reached the highest point of the spiral-cam, R, moves straight forward a short distance and then enters the slot of the other cam and is drawn back to its original position. The same occurs as each lock arrives at the cam and slot.

245. Removing the Locks.—The locks are removed and inserted through an aperture, *d*, cut in the cascabel and diaphragm plates (Figs. 37 and 39). Both these apertures are closed by a brass breech-plug, E (Fig. 37), which is inserted from the rear through the cascabel-plate, C. This plug carries at its front end a sleeve, E′, which has a projecting cone, *f*, on the under side of which is cut a slot. When the plug is in position in the gun, this slot forms a continuation of a groove cut in the rear chamber, and in which a lug formed on the rear end of each lock revolves. When the lock is brought into line with the plug, by means of the outside handle, G, which is indicated by an arrow on the hopper, I, and a line on the rear brass barrel-plate, the lug, *p*, on the lock engages in the slot on the arm of the plug, and on the latter being withdrawn, the lock follows. The sleeve, E′, is connected to the body of the plug by a pin formed with the plug, and around which it is just free to revolve without being a close fit. To withdraw the plug, it is first partially rotated so as to bring the lug by which it is locked opposite the aperture, the sleeve still retaining its hold on the lock to be extracted, and being retained against it by a spiral spring, which is interposed between the plug and the sleeve. The lock and sleeve are guided into the aperture in the diaphragm-plate by a tube, *e*, having a slot in its upper side, through which the sleeve, E′, of the plug passes, carrying the lock with it.

246. Cocking the Locks is accomplished by means of an inclined spiral cocking-plate, projecting on the inner side of the breech-casing, so that when the lock is moved forward, a lug, *x*, formed on the firing-pin, is arrested by it, the spring of the lock is gradually contracted, and the firing-pin drawn back into the lock-case. When the lug, *x*, passes the end of the stationary

cocking-plate, it is suddenly released, relieving the spring, *z*, which forces the pin violently forward and explodes the cartridge. As the cocking-plate is stationary and the lugs, *x*, revolve with the locks, the cocking-plate acts upon the firing-pins, in the several locks successively, causing the discharge of each barrel, as its lock-lug passes the plate.

247. THE FEED-DRUM V (Fig. 41), consists of a metal framing of cylindrical shape, having any convenient number of divisions or slots (usually sixteen) around its circumference, radiating from the centre. Each division, V′, contains twenty-five cartridges, placed one above the other in a horizontal position, V″ (Fig. 42). A hole in the centre of the drum fits over a pin, I′, on the hopper, I. The cartridges are fed to the carrier, M, below, and thence to the barrels, A. The cartridges pass to the hopper through an aperture at the bottom of each division of the drum. On the bottom face of the drum and to the left of the hopper is a projecting rib, *k*″, which fits into the slot, *k*′, on the hopper-plate to steady the drum when firing. On its lower periphery the drum has a series of thumb-lugs, *m* (Fig. 41), by which it is revolved. A small brass weight in each division is caused to bear upon and slide down a groove provided for it, so that it follows the cartridges as they descend, and prevents their becoming choked in the divisions. In firing the gun the man at the drum brings one of the thumb-lugs, *m*, coincident

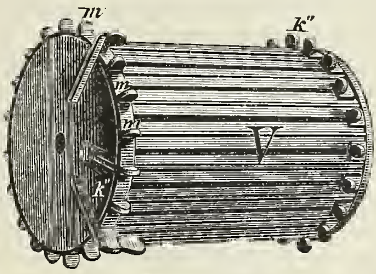


FIG. 41.

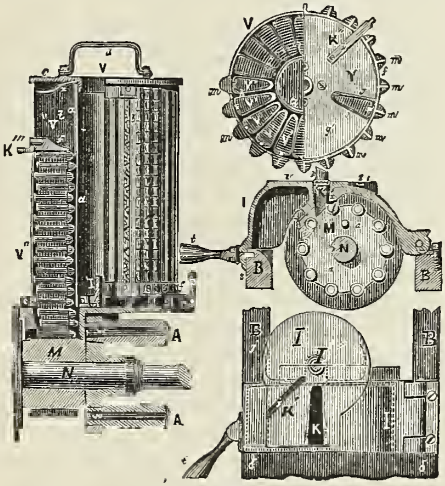


FIG. 42.

with the rib on the hopper-plate, the one at the crank revolves the barrels and carrier, and the cartridges drop into the hopper from one division until it becomes empty. The operator then reverses the drum one-sixteenth part of its circumference, bringing the next lug over the rib, and at the same time the next division of cartridges over the hopper; the feed thus continues until the whole number of divisions are emptied, when a full drum replaces the empty one, and the firing continues. A locking arrangement is provided for retaining the drum in position when not in use.

248. To Fill the Feed-drum.—Invert and unlock it, turn the bottom-plate, Y (Fig. 42), until the hole in the plate comes directly over a division of the drum, then raise the brass weight and fill in the cartridges regularly, letting the weight descend slowly until the division is full. Proceed in like manner with the remaining divisions; then lock the plate and place the drum upright.

249. The Working of the Gun.—One man places the feed-drum filled with cartridges on the hopper-plate, with the two apertures coinciding; another, at the firing-crank, revolves it, which, by means of the worm-gear, revolves the main shaft, carrying with it the lock-cylinder, carrier, barrels, and locks. As the carrier revolves the cartridges in the drum drop one by one into the grooves of the carrier. Instantly the lock, by its impingement on the spiral cam in the breech-casing, moves forward, pushing the cartridge into the barrel, and when the lug on the firing-pin passes the highest point of the cocking-plate the charge is fired. As soon as this occurs, the lock is drawn back by the spiral cam in the breech-casing, bringing with it the shell of the cartridge, after it has been fired, which is dropped upon the ground beneath.

250. Thus, when the gun is revolved, the locks in rapid succession move forward to load and fire, and returning extract the cartridge-shells. The whole operation of loading, closing the breech, discharging, and expelling the empty cases is thus conducted while the barrels are kept in continuous revolving movement. In operating the gun, firing in succession, there is no accumulation of recoil, and therefore no resighting, or relaying the gun, necessary between each discharge. When once sighted its carriage does not move, except at the will of the operator. The gun can be moved laterally while firing is going on so as to sweep the sector of a circle of 12°, or more, without moving the trail or changing the wheels of the carriage.

251. Its locks are made interchangeable, strong, and durable; but should they get out of order, they can be replaced by new

ones in a very few moments. The lock mechanism is the only portion liable to derangement, the other parts being protected, or of sufficient strength to withstand all usage incident to the service.

252. The feed-drums are not absolutely necessary, except at close-quarters, and are likely to cause a wasteful expenditure of ammunition; the drums being liable at any time to become deranged and work badly.

The crew should therefore be exercised at feeding the gun by hand, in which case, all that is necessary is for one man, when the hopper is turned back, to lay the cartridges, one at a time, into the grooves of the carrier. The revolving of the crank loads and fires the gun.

253. When rapid fire is continued, the piece becomes heated, and the barrels are liable to bind and prevent the free working of the gun; recourse is then had to the adjustment-nuts in the front of the barrels. These must be eased up sufficiently to enable the barrels to revolve freely, care being taken that the crank is fastened to prevent the possibility of the piece being fired while the adjustment is being made.

254. In firing, the crank must be turned steadily, in a uniform manner, and not too rapidly; otherwise the cartridges will jam in the carrier, and thus effectually stop the fire until they can be removed.

The cartridge used is the same as that of the Navy Rifle, .5 in., and the arm is effective to the same distance—about 1,200 yards.

255. In exercising on board ship the locks should be removed to avoid unnecessary snapping of the spring, and the cartridges can then be run through the hopper at will, familiarizing the men with the use of the arm without wasting ammunition.

256. It is believed that the "Gatling" cannot be substituted for the "Howitzer" in boats, therefore no boat-carriage is provided, the instability of the boat causing the continuous fire (the great feature of the gun) to be extremely scattering, while the shrapnel or canister from its Howitzer is delivered only where the gun points.

In smooth water it may be used as a boat-gun by removing the wheels, resting the axles on the gunwale, with the trail of the carriage under the forward thwart.

257. Preservation.—The Gatling Gun, although an intricate piece of mechanism to put into the hands of seamen, is not liable to get out of order in use, or have its parts deranged, unless tinkered with by the quarter-gunner. It is not injured by being wet in handling, or liable to be clogged with sand or mud, provided it is cleaned and dried before the next firing.

258. The gun should never be taken apart unless absolutely necessary, and then, if possible, by a competent mechanic, under the supervision of an officer. It should be kept free from rust, dust, and moisture, and oiled frequently, using fine sperm-oil.

When it is possible, before firing, the barrels and carrier should be wiped and cleaned; in doing this the crank should be reversed to avoid unnecessary snapping.

259. Directions for taking the Gun apart.

1*st.* Take out the locks. To do this, turn the breech-plug so that the marks upon it and the cascabel-plates correspond; then turn the crank until one of the marks on the rear brass barrel-plate is brought in line with the arrow on the hopper, and then pull out the plug, which will bring out a lock. Re-insert the plug, and repeat the operation, until all the locks are removed.

2*d.* Take off the cascabel-plate, which is screwed to the breech-casing.

3*d.* Remove the crank-axle; first taking off the traversing-screw and worm, which are fastened to the shaft by a screw and a taper-pin through it; then remove the worm gear.

4*th.* Take out the screws that fasten the casing to the frame.

5*th.* Raise the barrels a very little by means of the *assembling-rest;* then remove the breech-casing.

260. Directions for putting the Gun together.

1*st.* Put the axis in its place through the plates which hold the barrels, and then put to their places the carrier-block, lock-cylinder, and large rear-nut. The last should be screwed up tight, and have the taper-pin put through the nut and shaft.

2*d.* Place the gun within the frame, and let the front end of the axis rest in the hole designated for it, in the front of the frame; then adjust the assembling-rest, and, in this position, the breech-casing can be shoved over the lock-cylinder to its proper place; then screw the casing to the frame.

3*d.* Put on the worm-gear, replace the crank-axle, etc., and then put on the cascabel-plate. Revolve the crank to the right or left until one of the marks on the barrel-plate is brought in line with the arrow on the hopper, and then insert a lock, which is shoved to its place by the plug. Remove the plug, and repeat the operation until all the locks are in their places.

261. THE ARMAMENT OF SHIPS OF WAR.*—The main points to be considered in determining the armaments of ships are:

* Extracts from a paper on "*The Armament of our Ships of War,*" by Captain W. N. Jeffers, U. S. N., in "The Record of the United States Naval Institute," Vol. I., 1874.

First. The proportion of the aggregate weight of the guns to the tonnage.

Second. To dispose of this weight in such a manner as shall develop the greatest power of which it is susceptible.

Third. The relation of the battery to the speed of the vessel.

262. I. The relations of weight of battery to tonnage of ship depends upon the aggregate assigned to ordnance by the constructor in distributing his weights; and the weight of battery which experience shows can be safely and conveniently carried, is from one-third greater to double that allowed on the given displacement.

263. II. Having a ship of a certain tonnage, draft of water, and speed, with so many tons of displacement assigned to ordnance; the question is, how to dispose of that weight to the best advantage, distributing it with a due regard to the necessary power and range of the guns.

264. In every case our practice is, to assign the smallest number of the heaviest guns to form the weight; preferring pivot-guns to those in broadside when the deck arrangements will permit, because the former are always more under command than the latter; and it is thoroughly established that a small number of large pieces will inflict injuries beyond the power of a large number of small ones. The smallest number and heaviest pieces which can be conveniently handled will then form the armament.

265. One of the first elements to be considered is the ability to handle the projectile in the confined quarters of a ship subject to violent motions of rolling and pitching. Only one man can conveniently handle the projectile of a broadside gun, and but two that of a pivot; and experiment proves that the nine-inch and eleven-inch are the largest shells which can be so handled with ease.

266. No effort should be spared to use the heaviest calibre which can be conveniently carried, and any obstacles that are removable ought to be made to give way without scruple. The celerity of fire will not be materially affected, and the superior calibre always possesses superior range, accuracy, and power.

267. III. It is absolutely necessary that a ship of war should exercise a full power of offence and defence, within the circle of which she is the centre: next to this, and to this only, in importance is her ability to transfer this power to another point.

268. In order that a ship may exercise her full measure of offence, speed has become an indispensable attribute. Without

it her powers are altogether incomplete; and experience appe to have determined that it is judicious to sacrifice a large portion of the armament in order to procure great speed at any cost.

269. When a vessel of war encounters a superior force, speed should be able to make her safe, but the necessary diminution of offensive power should not be so great as to disable a first-class steamer from watching any vessel of her own class, of inferior speed, but provided with a proper armament.

270. Our vessels of war should have equal speed with those of other nations, for it is only by this equality that they can select and retain the distances preferred. If, however, our ship is inferior in speed, then the choice of distance is with the enemy, who is supposed to prefer close quarters; but if our ship is properly armed he can only reach this position after passing through the deliberate fire of powerful guns.

271. Kind of Gun.—The armament of our ships of war consists mainly of smooth-bore guns. These cannot compete with rifle-guns, except at short ranges, their efficiency depending on high velocities, which the resistance of the air greatly diminishes; besides, spherical projectiles are deficient in weight, and their form is not favorable for penetration.

272. With wooden ships, the mere lodgment of a shell, in the side, before its explosion, is sufficient to inflict serious injury; but against armored ships complete perforation is essential. Since the general introduction of armored vessels, the conditions of warfare have been altered, and the subject of penetration has become of paramount importance. This necessitates the introduction of rifle-cannon as the entire armament of our ships.

273. The principal advantage of rifle-cannon consists in their greater penetration, due to the concentration of effect on a smaller and better form of surface; next, in greater explosive contents for the same weight; then range, and lastly, accuracy.

274. It is comparatively easy to obtain accuracy to such an extent as is sufficient for the purposes of naval warfare. Under the ordinary circumstances of a naval action, the probability of striking an enemy's ship is dependent far more on an accurate knowledge of the distance, on the steadiness of the ship carrying the gun, and the skill of the man who fires it, than on the qualities of the gun itself.

275. Great extent of range is one of the especial merits claimed for rifled ordnance. But the instances in which a great range would be valuable in naval war are of such rare and exceptional occurrence, that it is not an important requirement in a good naval gun.

*Section II.—Theory of Gun Construction.**

276. THE KINDS OF STRAIN UPON A GUN.—There are:

1*st.* A *tangential strain*, tending to split the gun open longitudinally, and similar in its action to the force which bursts the hoops of a barrel.

2*d.* A *longitudinal strain*, tending to pull the gun apart in the direction of its length. This tendency is a maximum at the bottom of the bore, and diminishes to zero at the muzzle.

3*d.* A *strain of compression*, exerted from the axis outward, tending to crush the truncated wedges of which a unit of length of the gun may be supposed to consist, and to diminish the thickness of the metal to which it is applied.

4*th.* A *transverse strain*, tending to break transversely the staves of which the gun may be supposed to consist, and similar in its action to the force which breaks the staves of a barrel.

277. TANGENTIAL STRAIN.—Barlow shows that the strain, produced on any cylinder by the action of a central force, diminishes as the square of the distance from the centre increases.

The demonstration of this law is based upon the hypothesis that the area of the cross section of the cylinder to which the force is applied remains the same before and during the application of the central force.

Assuming this to be true, call A the area of the cross section of the gun.

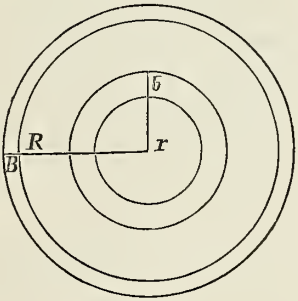


FIG. 43.

In Fig. 43, let

r = the radius of the bore,
R = the radius of the exterior,
b = the increase of the internal radius,
B = the increase of the exterior radius.

Evidently,

$$\pi R^2 - \pi r^2 = \pi(R^2 - r^2) = A. \qquad (1)$$

or

$$R^2 - r^2 = \frac{A}{\pi}. \qquad (2)$$

* Compiled by Lieutenant-Commander C. F. Goodrich, United States Navy.

Differentiating eq. (2), bearing in mind that A and π are constants, gives

$$2RdR - 2rdr = 0 \quad \text{.................(3)}$$

Hence $$RdR = rdr \quad \text{.......................(4)}$$

Multiplying and dividing the first member of eq. (4) by R, and the second member by r, and substituting for dR and dr their values B and b, gives

$$R^2\frac{B}{R} = r^2\frac{b}{r} \quad \text{.......................(5)}$$

whence the proportion

$$\frac{b}{r} : \frac{B}{R} = R^2 : r^2 \quad \text{...................(a)}$$

278. But the strain produced on any two pieces of the same material will be proportional to the increase in length divided by the original length of each respectively—the absolute strain, for a given increase of length, depending upon the coefficient of elasticity of the material strained. Hence, if $\frac{B}{R}$ be the strain on the exterior, then $\frac{b}{r}$ is that on the interior. It will therefore be seen from the proportion (a) that the strain diminishes as the square of the distance from the centre increases.

279. *To find the whole resistance of the gun-cylinder to the tangential strain.*

Let Fig. 44 represent a section of a homogeneous gun-cylinder.

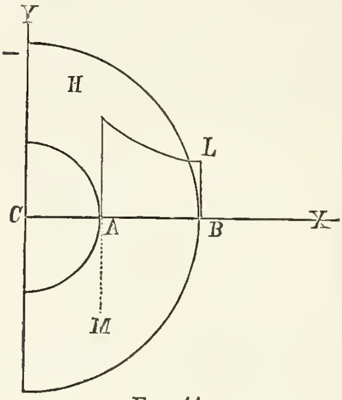


FIG. 44.

Take C, the centre of the bore, as the origin, and two lines at right angles to each other as the co-ordinate axes. Denote CA, the radius of the bore, by r, and CB, the external radius, by R.

We may represent the degree of *expansion* of the metal at any point in the line AB, caused by an explosion at C, by an ordinate, erected at the given point proportional in length to the number of pounds' *strain* at that point, as AH; similarly we may represent a *compression* by a negative ordinate, as AM.

280. Erecting ordinates in this manner at every point in the

line AB, and drawing a line through their extremities, we have the curve HL.

From Barlow's Law we have for the equation to this curve

$$y = \frac{c}{x^2} \dots\dots\dots\dots\dots\dots\dots\dots (6)$$

where c is a constant depending upon the force exerted.

To obtain the form of this curve when the expansion is at its limit, *i.e.*, when the tenacity of the metal is just sufficient to overcome the strain at A, we have for the co-ordinates of the point H, $x = r$, $y = S$, where S denotes the maximum strain in pounds. Substituting these values of x and y in eq. (6), we find

$$S = \frac{c}{r^2} \qquad \therefore c = Sr^2,$$

and the equation to the curve is therefore

$$y = \frac{Sr^2}{x^2} \dots\dots\dots\dots\dots\dots\dots\dots (b)$$

281. Taking $S = 30{,}000$ pounds, $r' = 3$ inches, we find

for $x = 3$ in.,	$y = 30{,}000$.
$x = 4$ in.,	$y = 16{,}875$.
$x = 5$ in.,	$y = 10{,}800$.
$x = 6$ in.,	$y = 7{,}500$.
$x = 7$ in.,	$y = 5{,}510$.

Thus the resistance offered by each part of the cylinder diminishes very rapidly as the distance from the axis increases.

282. As the ordinate at each point of the line AB measures the resistance of the gun at that point, the sum of all the ordinates, or the *area* of the curve AHLB, represents the entire tenacity of the gun-cylinder.

To find this area we have

$$A = \int y dx \dots\dots\dots\dots\dots\dots\dots\dots (7)$$

Substituting the value of y from eq. (b),

$$A = Sr^2 \int \frac{dx}{x^2} \dots\dots\dots\dots\dots\dots\dots\dots (8)$$

Integrating between the limits R and r,

$$A = Sr^2 \int_r^R \frac{dx}{x^2} = Sr^2 \left[-\frac{1}{x} \right]_r^R = Sr^2 \left[\frac{1}{r} - \frac{1}{R} \right],$$

or

$$A = Sr \frac{R - r}{R} \dots\dots\dots\dots\dots\dots\dots\dots (c)$$

283. Taking the same numerical values of S and r as before, giving different values of $R - r$ (the thickness of the wall of the gun),

$$\begin{aligned} R - r &= 1 \text{ inch}, & A &= 22{,}500 \text{ lbs.} \\ R - r &= 2 \text{ inches}, & A &= 36{,}000 \text{ lbs.} \\ R - r &= 3 \text{ inches}, & A &= 45{,}000 \text{ lbs.} \\ R - r &= 4 \text{ inches}, & A &= 51{,}429 \text{ lbs.} \\ R - r &= 5 \text{ inches}, & A &= 56{,}250 \text{ lbs.} \\ R - r &= 6 \text{ inches}, & A &= 60{,}000 \text{ lbs.} \end{aligned}$$

If we integrate between $\propto$ and r, or, what is the same thing, make the wall of the gun infinitely thick,

$$A = Sr \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (9)$$

284. Now it may be shown that the whole force developed by an explosion, to burst a gun tangentially, is pr, where p is the pressure of the gas per square inch, and r the radius of the bore. But we see from eq. (9) that the greatest possible resistance of the cylinder is Sr; therefore when an explosion takes place, and p is greater than S, the cylinder must give way. That is, "*No thickness of metal, however great, in a homogeneously constructed gun-cylinder, can withstand an expanding force greater than the absolute tenacity of a bar of the same metal.*"

285. *To find the whole force exerted by an explosion in a cylinder to rend it longitudinally.*

Let Fig. 45 represent a section of a cylinder, and let it be required to find the force exerted by an expanding gas to rend the cylinder along the line AB. Let OA $= r$, the interior radius of the cylinder, and p denote the force the gas exerts upon a unit of surface. At any point, as P, the gas acts in the line OP, and the force may be resolved into the components Py and Px, respectively perpendicular and parallel to the line AB. The sum of all the forces acting perpendicularly to AB is the force required.

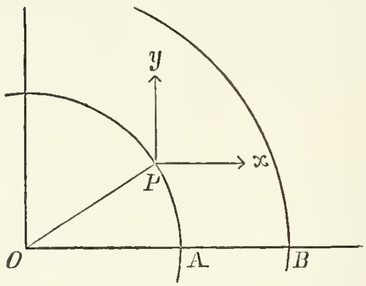


Fig. 45.

Let θ = the angle POA, then P$y = p \sin \theta$.

The element of surface is $rd\theta$.

The required force $F = \int pr \sin \theta d\theta = pr \int \sin \theta d\theta \ldots (10)$

Taking the integral between $\frac{\pi}{2}$ and o,

$$F = pr \ldots\ldots\ldots\ldots\ldots\ldots (d)$$

At the limit of endurance the rupturing effort will be equal to the whole resistance offered.

$$pr = Sr\,\frac{R - r}{R} \ldots\ldots\ldots\ldots\ldots\ldots (11)$$

or

$$p = S\,\frac{R - r}{R} \ldots\ldots\ldots\ldots\ldots\ldots (e)$$

Should p become greater than $S\,\frac{R - r}{R}$, the gun will burst.

As a particular case, let the wall of the gun be one calibre in thickness, *i.e.*, $R = 3r$, then

$$p = \tfrac{2}{3}\,S \ldots\ldots\ldots\ldots\ldots\ldots (f)$$

Rupture will hence ensue in this gun when the pressure per square inch exceeds two-thirds of the tensile strength per square inch of the metal of which it is constructed.

286. Longitudinal Strain.—The tendency of this strain is to blow the breech off.

Expressions for the rupturing effort of this strain, and the resistance of the gun to it, can be readily found based upon the assumption, in itself highly probable, that the law of diminution of strain from the interior outward will be the same for any central section of the sphere of which the breech may be supposed to consist as for any cross section of the gun.

287. *To find the longitudinal rupturing effort.*—If p be the pressure per square inch at the bottom of the bore, the whole rupturing effort in the direction of the axis of the gun will be p multiplied by the number of square inches in the area of the bore, or

$$E = \pi r^2 p \ldots\ldots\ldots\ldots\ldots\ldots (g)$$

288. *To find the resistance of the gun to the longitudinal rupturing effort.*—This will evidently be the sum of the resistances to longitudinal separation of the rings of metal composing the cross section of the gun, at the juncture of the breech and cylinder.

Let r be the radius of the bore.

R be the radius of the exterior of the gun.

S be the tensile strength of the metal per square inch.

Let x be the radius of any ring.
dx be its breadth.

We have already seen that the resistance to an internal explosive force at any point of the wall of the gun is $S\frac{r^2}{x^2}$. Hence, that of a ring whose radius is x, and breadth dx, will be $S\frac{r^2}{x^2} \times 2\pi x dx$, or $2\pi r^2 S\frac{dx}{x}$. The whole resistance of the wall of the gun will be found by integrating this expression between the limits R and r:

$$\int_r^R 2\pi r^2 S\frac{dx}{x} = 2\pi r^2 S\Big[Nap.\ Log.\ R - Nap.\ Log.\ r\Big] \ldots (12)$$

$$= 2\pi r^2 S\ Nap.\ Log.\ \frac{R}{r} \ldots\ldots\ldots\ldots\ldots (h)$$

At the limit of endurance the whole resistance will be equal to the whole rupturing effort, or

$$\pi r^2 p = 2\pi r^2 S\ Nap.\ Log.\ \frac{R}{r} \ldots\ldots\ldots\ldots (13)$$

hence,

$$p = 2S\ Nap.\ Log.\ \frac{R}{r} \ldots\ldots\ldots\ldots\ldots\ldots (i)$$

289. As a special case, assume, as before, that the wall of the gun is a calibre in thickness, or $R = 3r$. Expression (i) now becomes

$$p = 2S\ Nap.\ Log.\ 3 = 2S \times 1.0986 \ldots\ldots\ldots (14)$$

or, in round numbers, $p = 2S \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (j)$

Comparing this with eq. (f), we see that this gun would be three times as strong longitudinally as tangentially—if the bursting-effort were resisted by its tangential strength alone.

The tangential and longitudinal strains are in directions at right angles to each other, and hence, probably, neither affects the ability of the metal to resist the other—while the compressibility of the metal tends to diminish its capacity to resist either.

290. Crushing-force.—This force diminishes from the bore outward, while the area of resistance increases.

The effect of this upon a compressible truncated wedge would be to change its form from that of Fig. 46 to that of Fig. 47. And the appearance of a cross section of the gun after rupture would be that of Fig. 48. If the metal were incompressible, the appearance of a cross section of the gun after rupture would be that of Fig. 49, and no enlargement of the bore would result from the *crushing* of the metal; and any enlargement caused by the action of a central force would be accompanied by an equal enlargement of the exterior diameter of the gun; and hence the strain upon the metal at the inner and outer surface of the gun would be inversely as the radii of those surfaces instead of inversely as their squares (as in the case of compressible metal).

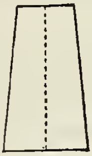


Fig. 46.

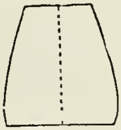


Fig. 47.

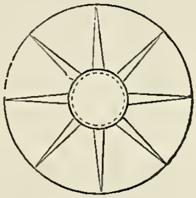


Fig. 48.

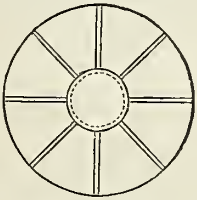


Fig. 49.

291. *To find an expression for the effect of a crushing-force.*

Let p = the pressure per square inch of gas on the surface of the bore,

c = the compression per inch in length, due to p, of a prism one square inch in area of cross section,

r = the radius of the bore of the gun,

x = the radius of one of the thin cylinders which compose the gun.

The elementary compression of any prism taken in the metal of the gun will be $du = cdx$. If the pressure were uniform (or c constant) throughout the length of this prism, the integral of this expression, or cx, would give the entire compression or increase in the radius of the bore. But, in a gun, the pressure per square inch against the interior of each consecutive, elementary cylinder of which we may suppose it to consist, will vary according to some law which must first be determined.

Suppose a thin, hollow cylinder, and

let a = the tangential resistance per unit of length of one side of this cylinder,

r' = its interior radius,

p' = the pressure per square inch against its interior surface which would just produce rupture.

Formula (d), already obtained for the bursting-effort of a central force, gives

$$p'r' = a, \qquad \text{or } p' = \frac{a}{r'} \ldots\ldots\ldots\ldots\ldots (15)$$

Or, the pressure per square inch against the interior of a hollow cylinder necessary to develop a constant amount of tangential resistance in its sides, varies inversely as its interior radius.

It has been shown that, at the limit of endurance,

$$p = S\frac{R - r}{R}.$$

The tangential resistance developed in that cylinder of the gun whose *interior* radius is x will be equal to the total tangential resistance of the wall of the gun *less* that developed in the cylinder whose *exterior* radius is x, or by eq. (c),

$$Sr\left[\frac{R-r}{R} - \frac{x-r}{x}\right].$$

Hence the pressure per square inch against the interior surface of the elementary cylinder, whose interior radius is x, will be

$$Sr\left[\frac{R-r}{R}\cdot\frac{1}{x} - \frac{x-r}{x^2}\right].$$

292. Supposing the compression per inch in length of the same metal to be directly proportional to the pressure per square inch, we shall have

$$p : c = Sr\left[\frac{R-r}{R}\cdot\frac{1}{x} - \frac{x-r}{x^2}\right] : c',$$

where c' is the compression per inch of length due to the force p acting at the distance x from the origin. Solving the proportion with reference to c',

$$c' = \frac{Scr}{p}\left[\frac{R-r}{R}\cdot\frac{1}{x} - \frac{x-r}{x^2}\right] \ldots\ldots\ldots\ldots (16)$$

The expression for the elementary compression now becomes $du = c'dx$. Substituting the value of c' from eq. (16),

$$du = \frac{Scr}{p}\left[\frac{R-r}{R}\cdot\frac{1}{x} - \frac{x-r}{x^2}\right]dx \ldots\ldots\ldots (17)$$

Integrating between the limits R and r,

$$u = \frac{Scr}{p}\left[\frac{r}{R}\,Nap.\,Log.\,\frac{r}{R} + \frac{R-r}{R}\right] \ldots\ldots\ldots (k)$$

As before, in a special case, assume the gun to be one calibre in thickness, or $R = 3r$,

$$u = \frac{Scr}{p}\,[\tfrac{1}{3}\,Nap.\,Log.\,\tfrac{1}{3} + \tfrac{2}{3}] \ldots\ldots\ldots (18)$$

$$= \frac{Scr}{p}\,[\tfrac{2}{3} - \tfrac{1}{3}\,Nap.\,Log.\,3] \ldots\ldots\ldots (19)$$

But the Naperian logarithm of 3 is 1.0986. Assuming this as 1,

$$u = \frac{S}{p}\cdot\frac{cr}{3} \ldots\ldots\ldots\ldots\ldots (l)$$

293. Now supposing $p = S$, or that the pressure per square inch on the bore of the gun is equal to the tensile strength of the metal, we have $u = \frac{cr}{3}$, or, the increase in radius of the bore, due to the compression of the metal, in a gun, one calibre in thickness is equal to one-third of the total compression which a prism, whose height equals the radius of the bore would undergo under a pressure per square inch equal to that against the bore of the gun.

294. Now if we suppose a given pressure to be exerted upon the surface of the bore of a gun, while its exterior diameter is prevented from undergoing any increment, the total enlargment of the bore and the consequent extension of the metal will be wholly due to compression, and all the effects of compression will be produced as if the exterior of the gun were unconstrained.

295. If we now suppose the exterior restraint removed, the interior and exterior diameters would undergo precisely equal increments. Or the gun would expand in the same manner as one of which the metal is incompressible, the metal having already undergone all the compression which this pressure could produce, and the extension of the metal at the two surfaces of the gun, which would take place after the removal of the exterior restraint, would therefore be inversely as their radii.

296. It has just been shown that in a gun one calibre thick the *total* enlargement of the bore due to compression is $\frac{2}{3}rc$; the total extension of the surface of the bore due to this enlarge-

ment is $2\pi r\frac{c}{3}$, and the extension per inch of the same surface is

$$\frac{2\pi r\frac{c}{3}}{2\pi r}=\frac{c}{3}.$$

If a be the total extension per inch of which the metal is susceptible, then $a-\frac{c}{3}$ will be the extension per inch which the surface of the bore underwent after the removal of the exterior restraint, and the extension per inch of the exterior surface is

$$\frac{a-\frac{c}{3}}{3}=\frac{3a-c}{9}$$

297. To exemplify: a cylinder was taken the total extension per inch of which was .00303, the compression per inch .00441, one-third of which is .00147; and .00303 — .00147 =.00156, one-third of which is .00052, the extension per inch of the exterior of a gun one calibre thick, made of this metal, at the moment of interior rupture.

But the strain necessary to produce an extension of .00054 was found to be 11,000 pounds; hence the exterior of the gun would be under a strain of between 10,000 and 11,000 pounds per square inch at the moment of interior rupture; while, if the metal were perfectly incompressible, it would, at the same moment, be under a strain of 18,000 pounds.

298. The expression $\frac{rc}{3}$ was derived from the hypothesis that the compression per inch of cast-iron is directly proportional to the pressure. Experiment shows the compression of this metal to increase in a higher ratio, so that the effects of compressibility will be even greater than those just determined.

299. This example suffices to establish the importance attaching to the property of compressibility in gun metal, its action being to prevent the full development of both the transverse and the tangential resistances, and to that degree it is believed (in guns of large calibre, and consequently of great pressure of gas) as to cause internal longitudinal rupture before the transverse resistance is fully developed, even for the shortest practicable length of surface pressed.

300. Transverse Strain.—In estimating the resistance which a gun can offer to a tendency to transverse rupture, it will

be more simple to regard it as composed of staves, firmly secured at their ends, the rear ends being supposed to be secured to a central cylinder; and, in this case, it will be only necessary to consider a single stave, as all others of equal width and length would be subjected to similar and equal strain.

301. Let us, therefore, consider the action upon a single stave, whose breadth is one inch. If the gun be one calibre in thickness, the exterior breadth will be three inches.

We shall be something below the actual resistance which the stave can offer, if we consider it as of rectangular section of two inches in breadth: this is apparent from inspection of Fig. 50.

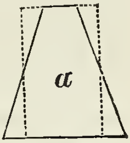


Fig. 50.

Let the stave a be acted upon by the pressure of gas along its inner surface, and suppose the pressure to be applied between the points b and b'. Now this stave is secured at both ends, and the rupturing-force equally distributed along its length between the points of support. It suffers a tendency to

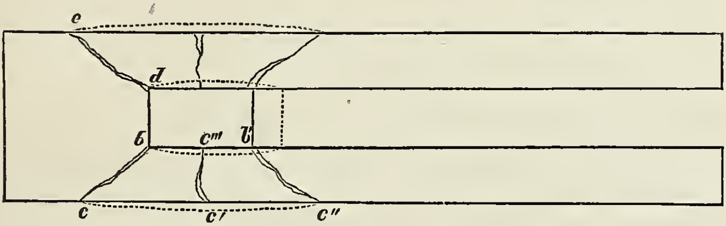


Fig. 51.

rupture at three points, as shown in Fig. 51 by the lines bc, c‴ c′, b′ c″.

302. The formula for the resistance which a bar thus strained can offer is

$$w = \frac{12S'bd^2}{l},$$

in which w is the breaking-weight distributed equally along the bar, b the breadth of the bar, d its depth, l its length, and S' the weight required to break a bar of the same material one inch square, firmly secured at one end, when applied at one inch from the point of support.

If p be the pressure of gas per square inch, the whole pressure on the stave be $p\ l$, and the *tendency to rupture* (i. e., the ratio of the bursting-effort to the resistance) will be represented by

$$\frac{\frac{pl}{12\,S'bd^2}}{l} = \frac{pl^2}{12S'bd^2}$$

It thus appears that the tendency to transverse rupture increases as the square of the length of the bore under pressure, and that the resistance offered to this kind of strain increases as the square of the thickness of metal.

303. The resistance offered by the transverse strength of the staves acts in concert with the tangential resistance, and when the length of the bore under pressure is such that the increase of its diameter due to the bending of the staves *plus* that due to the compression of the metal at the moment of rupture, shall be equal to that which it would attain at the same moment from the action of the tangential strain alone, then will the resistance to rupture be equal to the sum of the transverse and tangential resistances.

304. This can only occur for one particular length of surface pressed; and, for any greater length, the staves would require to be bent out beyond the breaking diameter for the tangential resistance before reaching their breaking transverse strain; and the transverse resistance would only be equal to the pressure necessary to bend the staves out to the position of tangential rupture, *minus* the compression of the metal. Thus the tangential resistance would be overcome and the gun split longitudinally before the transverse resistance would be brought fully into action

305. The effect of the crushing force on compressible metal is to prevent the development of the transverse resistance in the same manner as it did that of the tangential resistance: to diminish the amount of aid which the transverse resistance can bring to the tangential for any greater length of bore.

306. When the length of surface pressed becomes less than that which develops the joint action of both resistances, the diameter due to transverse rupture will be less than that due to tangential rupture, and transverse rupture would first ensue; or, what is more probable, in guns of any considerable thickness of metal, rupture will occur by splitting through the breech, or by forcing the rear ends of the staves outward, causing rupture along the lines bc and de (Fig. 51).

307. Recurring to the expression for the tendency to transverse rupture,

$$\frac{p\,l^2}{12\,S'\,bd^2},$$

and supposing the transverse strength of iron to be one-fourth the tensile or $S' = \frac{1}{4}S$, and substituting for S' this value, we have

$$\frac{p\,l^2}{3\,S\,b\,d^2}.$$

Then supposing $b = 2$ in., $d = 10$ in., $l = 20$ in., we have the tendency to transverse rupture $= \frac{2\,p}{3\,S}$; or the transverse strength alone, supposing the tensile strength to be 30,000 lbs. per square inch, would resist a pressure of 45,000 lbs. per square inch for two calibres in length of a 10-inch gun, if it could be brought fully into action. This, for reasons already given, cannot, however, be done; but the transverse is doubtless a powerful auxiliary to the tangential resistance for short lengths of bore and where the pressure is greatest.

308. THE TENDENCIES TO RUPTURE IN GUNS OF ONE CALIBRE IN THICKNESS, each considered as independent of all others, will be as follows, viz.:—

Tangential.............. $\frac{3\,p}{2\,S}$,

or rupture will ensue when $3\,p > 2\,S$.

Longitudinal............ $\frac{p}{2\,S}$,

or rupture will ensue when $p > 2\,S$.

Transverse.............. $\frac{2\,p}{3\,S}$,

or rupture will ensue when $2\,p > 3\,S$.

309. TOTAL BURSTING TENDENCY.—As already indicated, the *bursting tendency* is the ratio of the bursting effort to the total resistance which the gun can offer.

The bursting effort against one side of the gun is, from what has already been shown, eq. (d), the product of the pressure per square inch multiplied by the radius of the bore and the length of the bore to which pressure is applied.

Let R be the exterior radius of the gun.

r " radius of the bore.

L " length of the bore to which pressure is applied.

l " length of the surface pressed which fully develops both transverse and tangential resistance.

p " pressure per square inch.

Let S be the tensile strength of the metal.

Then $p\ r\ L$ is the bursting effort.

The whole tangential resistance will be equal to that for an element of the gun cylinder one unit in length multiplied by the length of surface pressed, or, from eq. (c).

$$L S r \quad \frac{R-r}{R}.$$

The formula for the transverse resistance of a bar of rectangular cross section is (Art. 302)

$$w = \frac{12\ S' b d^2}{l}.$$

310. By mechanics it is known that the resistances which bars of the same material can offer when the strain is equally distributed along their lengths, and the bars *bent to their breaking deflection*, are to each other directly as the fourth powers of their length. But in the case of the staves forming a gun cylinder, except for short distances, tangential will ensue before transverse rupture. In order to determine, therefore, the transverse resistance, calling x the transverse resistance due to that length, the following proportion may be instituted:

$$\frac{12\ S' b d^2}{L} : x = L^4 : l^4$$

whence

$$x = \frac{12\ S'\ b d^2\ l^4}{L^5} \quad \ldots\ldots\ldots\ldots\ldots\ldots (20)$$

S' may be taken as one-fourth of the tensile strength, or $\frac{S}{4}$; b is the mean breadth of the stave, or $\frac{R+r}{2\ r}$, when the inner breadth is one unit; d is the thickness of the stave, or $R-r$.

Substituting these values, the whole transverse resistance of a bar thus strained whose length is L, is

$$\frac{3\ S\ (R+r)\ (R-r)^2\ l^4}{2r\ L^5}.$$

The total bursting tendency is, hence,

$$C = \frac{p\ r\ L}{L S r \quad \frac{R-r}{R} + \frac{3\ S(R+r)\ (R-r)^2\ l^4}{2\ r\ L^5}}.$$

$$= \frac{2\ p\ r^2\ R\ L}{2\ L S r^2\ (R-r) + 3\ S R\ (R+r)\ (R-r)^2 \frac{l^4}{L^5}}.$$

$$= \frac{2 p r^2 R L}{S(R-r)\left[2 r^2 L + 3 R (R+r)(R-r)\frac{l'^4}{L^5}\right]} \quad \text{..(m)}$$

311. Determination of the Exterior Model of Guns.—In order that the gun may be equally strong throughout, the bursting tendency must be the same at all points of the bore; or, in other words, for all values of L, C, in the foregoing paragraph, must be constant. Equation (m) then becomes that of a portion of the curve of intersection of one side of the gun by a plane containing the axis of the bore.

In this formula, p will obviously be a function of L; and if we suppose the maximum pressure to be exerted upon a length l, of the bore, and the pressure from the forward extremity of l' to the muzzle to be inversely as the volume occupied by the gas (and hence, in this case, as the length of the bore thus occupied), then the pressure at any distance L from the bottom of the bore should be expressed by

$$\frac{p' l'}{L}$$

(p' being the maximum pressure), and the foregoing formula would become

$$C = 2\frac{p' r^2 l'}{S} \cdot \frac{R}{(R-r)\left[2 r^2 L + 3 R (R+r)(R-r)\frac{l'^4}{L^5}\right]} \quad \text{..(n)}$$

Now since $2\frac{p', r^2 l'}{S}$ is constant, the other factor is constant also, so that this last expression need alone be regarded in determining the relative values of R corresponding to the assumed values of L.

312. From the great excess of the transverse over the tangential resistance for the smaller values of L, and from the rapid diminution of the transverse resistance as L increases, the value of this expression, with a constant value of R, will first increase to a maximum and then decrease as L increases.

In order, therefore, to determine the proper exterior model of a gun, we first decide upon the volume of the charge; and, from the quality of the powder, and the form and weight of the projectile, determine the length of the bore subjected to maximum pressure and the value of this pressure.

313. We then establish the relation betwen l' and L, or the law of variation of pressure, and then assume l equal to or a little less than two calibres, since experiment has shown the

transverse resistance to be fully developed for about that length of surface pressed.

Then take R equal to or a little less than the greatest exterior radius of the gun and determine the value of L that renders

$$\frac{R}{(R-r)\left[2r^2L+3R(R+r)(R-r)\frac{l^4}{L^5}\right]} \cdots\cdots (o)$$

a maximum. Then if R have been assumed equal to the greatest exterior radius, the gun will be cylindrical from this point back to the curve of the breech; and the curve of that portion forward of this point will be determined by assuming values for L and determining for R such corresponding values as will cause expression (o) to remain constant and equal to its maximum.

314. Illustration.—On account of the influence of compression in preventing the development of the full strength of

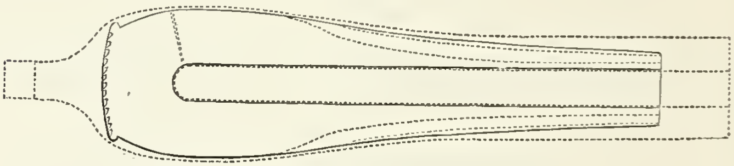


Fig. 52.

the material, only one-third of the theoretical transverse resistance was used in computing the exterior radii of the fifteen-inch gun, and the pressure was assumed to vary not as L but as $\sqrt{L}$. The formula used was

$$C = \frac{2pr^2\sqrt{l}}{S} \times \frac{R\sqrt{L}}{(R-r)\left[2r^2L+R(R+r)(R-r)\frac{l^4}{L^5}\right]} \quad (p)$$

The value of R used in determining the value of L which rendered the bursting tendency a maximum was 22.5 inches.

The *outer* and *extreme inner* dotted lines in Fig. 52 give the exterior form and proportions and the diameter of the bore of the gun as cast. The *inner* curved dotted lines give the form and proportions of a gun of the same bore and maximum exterior diameter computed on the hypothesis that the pressure of the gas is inversely as the space behind the projectile (or p varies inversely as L). The middle dotted lines give the form and proportions of a gun of the same diameter of bore and maximum exterior diameter on the hypothesis that the pressure is inversely as the square root of the space behind the projectile, (or p varies inversely as $\sqrt{L}$). The *full* lines show the form and proportions of this gun as finished.

315. It will be observed that this gun is heavier in the chase than the hypothesis would make it. This was done purposely, for the reason that it was intended to use charges of such character as would produce a more uniform pressure in the chase of a gun, for a given maximum pressure, than is obtained by the use of ordinary powder.

316. It should be here remarked that even for guns in which a quick powder is to be used, the lines due to the law that the pressure is inversely as L should not be strictly adhered to, in that part where the most rapid diminution of exterior diameter occurs; for the reason that, in so doing, the front ends of the staves for those lengths of bore subjected to the greatest pressure would be deprived of their proper support and the transverse resistance would be greatly diminished just where it is most needed, and where its value is greatest in a properly modelled gun.

The beginning of the taper should be, therefore, say half a calibre farther forward and the taper less rapid than the loss of pressure in this part of the gun would make it.

317. Experiment has not yet satisfactorily established the law of variation in pressure due to the ordinary cannon powder. But it is thought that no powder is fit for use in guns of large calibre that will not so far approximate to uniformity of pressure as to conform to the law that the pressure is inversely as $\sqrt{L}$.

318. PREPONDERANCE.—DEFINITIONS.—The *moment* of a solid with reference to a plane is equal to the product of the weight of the solid multiplied by the perpendicular distance of its centre of gravity from the plane.

If moments tending to produce rotation *with* the hands of a watch are considered *positive*, evidently those tending to produce rotation *against* the hands of a watch are *negative*.

The preponderance of a gun is the moment of the weight of the gun about the axis of the trunnions divided by the distance between the axis of the trunnions and the centre of the elevating-screw-hole. It is the pressure in pounds on the screw when the gun is level.

319. TO DETERMINE THE PREPONDERANCE.—It is thus seen that the weight of the gun and its moment about the axis of the trunnions must be determined.

As the measurements in guns are made from the base-ring, it will be convenient to take its plane for the plane of reference. Having obtained the moment of the weight of the gun with reference to this plane, to deduce that about the axis of the trunnions involves but a simple transformation.

The gun being assumed homogeneous, the weights of its parts are proportional to their volumes. The latter can therefore be used in the calculation, and only changed into weights at the last step.

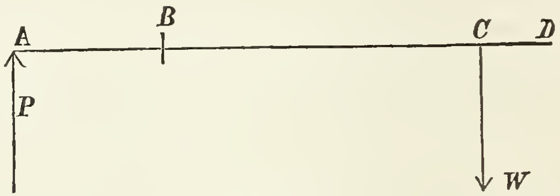


FIG. 53.

In the accompanying figure (No. 53), let A, B, C, and D be the positions of the elevating-screw-hole, the plane of the base-ring, the centre of gravity of the gun, and the axis of the trunnions respectively; P, the preponderance acting at the elevating-screw-hole, and W, the weight of the gun acting at the centre of gravity.

By the principle of the lever, the moments of these forces must be equal; or

$$P \times AD = W \times CD$$

Letting $AB = b$, $BD = a$, and $BC = \bar{x}$

$$P \times (a + b) = W \times (a - \bar{x}),$$

$$\therefore P = \frac{Wa - W\bar{x}.}{a + b,}$$

Since $W = Vd$; by substitution,

$$P = \frac{Va - V\bar{x}}{a + b} d, \dots\dots\dots\dots\dots (a)$$

Where V is the volume of the gun in cubic inches.

$V\bar{x}$, the moment of the volume of the gun with reference to the plane of the base-ring.

a, the distance of the axis of the trunnions from the plane of the base-ring.

b, the distance of the centre of the elevating-screw-hole from the plane of the base-ring.

d, the weight of a cubic inch of the gun-metal.

320. The volume of the gun is obviously the sum of the volumes of the parts of the gun, regarded as solid, diminished by the sum of the volumes of all its cavities.

From Mechanics, it is known that the moment of a solid with reference to a plane is equal to the algebraical sum of the moments of its parts with reference to the same plane.

In applying this principle to the case of preponderance, the following summary may be taken as a guide; subject, of course, to such modification as the form of the particular gun considered necessitates.

The portion of the gun forward of the base-ring is divided into parts whose volumes and moments can be computed, the gun being considered solid. Generally speaking, the gun may be divided into a cylinder, a solid of revolution having an *odd* number of *equidistant* sections, and therefore coming under "Simpson's Rule," and one or more frustums of a cone.

These moments and those of the trunnion and rim-bases are expressed and marked *positive.*

The moments of the bore and chamber are expressed and marked *negative.*

In rear of the base-ring are the breech and cascabel, whose moments are expressed and marked *negative.*

Should there be any cavities here whose moments need be considered, these are expressed and marked *positive.*

This distinction of signs flows from the definition of positive and negative moments.

$$\text{Since } V\bar{x} = \text{sum of the moments,}$$

$$\bar{x} = \frac{\text{sum of the moments}}{\text{sum of the volumes}} \dots\dots\dots\dots\dots (\text{b})$$

321. The formula is written in this manner merely to save space. The division indicated in the second member is not performed, as the *terms* of the fraction, and not its *value*, are sought.

The moments are collected and placed in the numerator with their appropriate signs; the denominator being similarly made up of the volumes.

Factors common to the two terms are then taken out, and written before the algebraical sum of the resulting quotients—and, in turn, such of these quotients as contain common factors are combined into one. By thoroughly carrying out the principle of factoring and combination, much time and labor may be saved in computing.

The indicated additions in the numerator and denominator are performed, and the results used in the expression for the preponderance.

It must be borne in mind that we have assumed the metal to be homogeneous, though in practice, the breech is more dense than the chase, owing to the mode of casting; hence, the preponderance, as calculated, is always somewhat less than in reality.

This excess of weight, in rear of the trunnions, is reduced to a minimum to allow the breech to be easily elevated or depressed. It is practically impossible to place the trunnions so that there shall be no preponderance; nor has it been deemed advisable to dispense with it entirely in Navy guns, as the weight of the projectile in loading would depress the muzzle, and even when home, the breech would not readily follow down the screw for elevation.

Example.

322. The form and dimensions of a XV-inch gun being given in the accompanying diagram (Fig. 54) and table, to compute its preponderance.

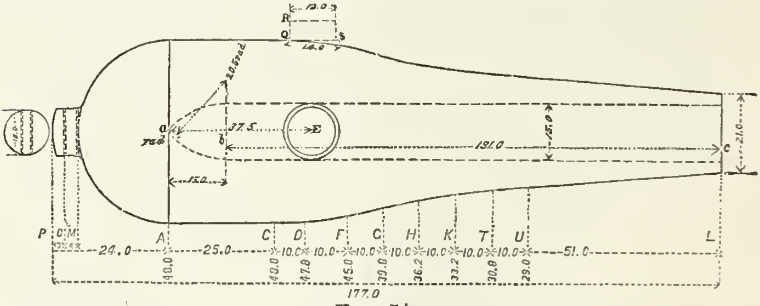


Fig. 54.

Dimensions.

Weight in Pounds.	Length in inches of												
	AC	AD	AE	AF	AG	AH	AK	AT	AU	AL	AM	AO	AP
42,000	25	35	37.5	45	55	65	75	85	95	146	24	28	31

Diameter, in inches, at

A	C	D	F	G	H	K	T	U	L	O	P
48	48	47.8	45	39.8	36.2	33.2	30.8	29.0	21.0	12.0	12.0

Trunnions. *Bore and Chamber.*

Length.	Span of Rim-bases.	Diameter at		Length of		Diameter at	
QR	QS	Q	R	ac	ab	b	c
5.5	48	12	12	146	15	15	15

Taking the moments of the parts of the gun with reference to the plane of the base-ring, due regard being had to the signs, gives equation (1) [from formula (b)].

323. *a.* *Volume* of cylinder $= \pi r^2 h = \pi \times 24^2 \times 35$.

Its centre of gravity is distant $\frac{h}{2}$, or 17.5 from its base. Its *moment*, therefore, is $\pi \times 24^2 \times 17.5 \times 35$.

324. *b.* By Simpson's Rule, the *moment* of the solid DV with reference to the plane of its first section is equal to

$$\frac{d}{3}(h_1x_1 + 4h_2x_2 + 2h_3x_3 + 4h_4x_4 + 2h_5x_5 + 4h_6x_6 + h_7x_7),$$

and its *volume* is equal to

$$\frac{d}{3}(h_1 + 4h_2 + 2h_3 + 4h_4 + 2h_5 + 4h_6 + h_7),$$

the h's being the areas of the sections, the x's their distances respectively from the first section, and d the common interval. Substituting the numerical values of these quantities, the expression for the *moment* becomes

$$\tfrac{10}{3}\pi(23.9^2 \times o + 4 \times 22.5^2 \times 10 + 2 \times 19.9^2 \times 20 + 4 \times 18.1^2 \times 30 + 2 \times 16.6^2 \times 40 + 4 \times 15.4^2 \times 50 + 14.5^2 \times 60),$$

and that for the *volume*

$\frac{10}{3}\pi(23.9^2 + 4 \times 22.5^2 + 2 \times 19.9^2 + 4 \times 18.1^2 + 2 \times 16.6^2 + 4 \times 15.4^2 + 14.5^2)$,

which reduce to $\frac{10}{3}\pi \times 157{,}495.4$ and $\frac{10}{3}\pi \times 6{,}408.7$.

Dividing the moment by the volume gives the distance of the centre of gravity of the solid from the first section, equal to 24.58. Hence the *moment* of the solid with reference to the plane of the base-ring is

$$\tfrac{10}{3}\pi \times 6{,}408.7(35 + 24.58) = \tfrac{10}{3}\pi \times 6{,}408.7 \times 59.58.$$

325. *c. Volume* of a frustrum $= \frac{\pi}{3}h(R^2 + Rr + r^2)$,

and its centre of gravity is distant from its larger base

$$\frac{h}{4}\,\frac{R^2 + 2Rr + 3r^2}{R^2 + Rr + r^2},$$

where h is the altitude of the frustrum, R and r the radii of the larger and smaller bases respectively; hence the *moment* of the frustrum with reference to the base-ring is equal to

$$\frac{\pi}{3} \times 51(14.5^2 + 14.5 \times 10.5 + 10.5^2) \times \left(95 + \tfrac{51}{4} \times \frac{14.5^2 + 2 \times 14.5 \times 10.5 + 3 \times 10.5^2}{14.5^2 + 14.5 \times 10.5 + 10.5^2}\right) = 17\pi \times 55{,}691.3,$$

and its *volume* $17\pi \times 472.7$.

326. *d.* The trunnions are cylinders whose *volumes* are $\pi \times r^2 \times h = \pi \times 6^2 \times 5.5$, and their centres of gravity are distant from the base-ring 37.5. Their *moment* is $2\pi \times 6^2 \times 5.5 \times 37.5$.

327. *e.* The rim-bases are sections of cylinders by cones. The expressions for their volumes and the positions of their centres of gravity are integrals of such complicated forms, that, in practice, the rim-bases are taken as cylinders; on account of their small volume and their proximity to the centre of gravity of the gun, the error introduced through this assumption is so small as to be inappreciable.

Volume of each rim-base $= \frac{1}{2}\pi \times 7.5^2 \times .75$.

Moment of both rim-bases $= \pi \times 7.5^2 \times .75 \times 37.5$.

328. *f.* The breech is a hemisphere whose *volume* is $\frac{2}{3}\pi r^3$, and *moment* with reference to the plane of the base is $\frac{2}{3}\pi \times r^3 \times \frac{3}{8}r$, or $\frac{2}{3}\pi \times 24^3 = 2\pi \times 24^2 \times 8$, and $\frac{2}{3}\pi \times 24^3 \times \frac{3}{8} \times 24 = 2\pi \times 24^2 \times 8 \times 9$, respectively.

329. *g.* The cascabel is taken as a cylinder whose height is

7, and its radius 5. Its *volume*, therefore, is $\pi \times 5^2 \times 7$, and its *moment* $\pi \times 5^2 \times 7(24 + 3.5) = \pi \times 5^2 \times 7 \times 27.5$.

330. *h*. The metal of the juncture of the cascabel with the breech may be assumed, in practice, to compensate that taken from the screw-hole ; both are neglected.

331. *i*. The bore is a cylinder whose height is 131, its radius 7.5. Its *volume*, therefore, is $\pi \times 7.5^2 \times 131$, and its *moment* $\pi \times 7.5^2 \times 131(15 + 65.5) = \pi \times 7.5^2 \times 80.5 \times 131$.

332. *j*. The chamber is taken as a paraboloid of revolution whose height is 15, and radius 7.5. Its *volume*, being half that of the circumscribing cylinder, is $\pi 7.5^2 \times 7.5$. Its centre of gravity is distant $\frac{2}{3}$ its height from the vertex. Its *moment*, therefore, is $\pi \times 7.5^2 \times 7.5 \times 10$.

333. Substituting these numerical expressions in equation (1) gives equation (2).

(See page 110 for equations.)

334. To Determine the Position of the Trunnions.—In designing a gun, the preponderance is decided upon beforehand, thus giving rise to the inverse problem, " For a desired preponderance, where should the trunnions be placed ? "

The weights and moments of the trunnions and rim-bases are neglected, as being at the axis about which the gun rotates, these cannot perceptibly affect the result. The remaining volumes and moments are obtained as before.

Referring to equation (a) (Art. 319), P is now known, and $BD = a$ becomes the unknown quantity to be determined. Solving this equation with reference to a gives equation (c).

$$a = \frac{Pb + V\bar{x}d}{Vd - P} \quad \text{(c)}$$

For convenience P may be assumed equal to Qd. With this substitution and the cancelling of d in numerator and denominator

$$a = \frac{Qb + V\bar{x}}{V - Q} \quad \text{(d)}$$

Example.

335. In the XV-inch gun already computed, where should the trunnions be placed that the gun may have a preponderance of 1,784 lbs. ?

Here $Q = \frac{1784}{0.26} = 6,861.54$, $b = 28$, $V\bar{x} = 5,980,271.2$, and $V = 162,087.7$.

$$\bar{x} = \frac{\pi \times 24^2 \times 17.5 \times 35 + \frac{1.0}{3}\pi \times 381830.3 + 17\pi \times 55691.3 + 2\pi \times 6^2 \times 5.5 \times 37.5 + \pi \times 7.5^2 \times .75 \times 37.5 - 2\pi \times 24^2 \times 8 \times 9 - \pi \times 5^2 \times 7 \times 27.5 - \pi \times 7.5^2 \times 131 \times 80.5 - \pi \times 7.5^2 \times 7.5 \times 10}{\pi \times 24^2 \times 35 + \frac{1.0}{3}\pi \times 6408.7 + 17\pi \times 472.7 + 2\pi \times 6^2 \times 5.5 + \pi \times 7.5^2 \times .75 + 2\pi \times 24^2 \times 8 + \pi \times 5^2 \times 7 - \pi \times 7.5^2 \times 131 - \pi \times 7.5^2 \times 7.5} \quad \ldots\ldots (2)$$

Taking out the common factor 5π in numerator and denominator, without cancelling, and collecting terms having common factors remaining, give equation (3),

$$\bar{x} = \frac{5\pi}{5\pi} \times \frac{24^2(17.5 \times 7 - \frac{2}{5} \times 8 \times 9) + \frac{2}{3} \times 381830.3 + \frac{1.7}{5} \times 55691.3 + 7.5^2(7.5 \times .75 - 131 \times 16.1 - 7.5 \times 2) + 5.5(2 \times 6^2 \times 7.5 - 5^2 \times 7)}{24^2(7 + \frac{2}{5} \times 8) + \frac{2}{3} \times 6408.7 + \frac{1.7}{5} \times 472.7 + 7.5(.75 \times 1.5 - 1.5 \times 131 - 7.5 \times 1.5) + 35 + 6^2 \times 2.2} \quad \ldots\ldots (3)$$

Reducing, gives equation (4),

$$\bar{x} = \frac{5\pi}{5\pi} \times \frac{24^2 \times 93.7 + \frac{2}{3} \times 381830.3 + \frac{1.7}{5} \times 55691.3 - 7.5^2 \times 2118.5 + 5.5 \times 365}{24^2 \times 10.2 + \frac{2}{3} \times 6408.7 + \frac{1.7}{5} \times 472.7 - 7.5 \times 206.7 + 35 + 6^2 \times 2.2} \quad \ldots\ldots (4)$$

MOMENTS.

$24^2 \times 93.7$	=	52971.2
$\frac{2}{3} \times 381830.3$	=	254553.5
$\frac{1.7}{5} \times 55691.3$	=	189350.4
5.5×365	=	2007.5
		499882.6
$7.5^2 \times 2118.5$	=	119165.6
Algebraic sum		380717.0

VOLUMES.

$24^2 \times 10.2$	=	5875.2
$\frac{2}{3} \times 6408.7$	=	4272.5
$\frac{1.7}{5} \times 472.7$	=	1607.2
35	=	35.0
$6^2 \times 2.2$	=	79.2
		11869.1
7.5×206.7	=	1552.5
Algebraic sum		10316.6

$\bar{x} = \frac{5\pi}{5\pi} \cdot \frac{380717}{10316.6}$; $\quad \therefore V\bar{x} = 5\pi \times 380717$ by (b),

and $V = 5\pi \times 10316.6$.

Using (a), where $a = 37.5$, $b = 28$, and $d = 0.26$,

$$P = \frac{Va - V\bar{x}}{a + b} d = \frac{5\pi \times 10316.6 \times 37.5 - 5\pi \times 380717}{37.5 + 28} \times 0.26,$$

$$= \frac{5\pi}{65.5} \times 0.26(386862.5 - 380717) = \frac{\pi \times 0.26}{13.1} \times 6155.5,$$

$P = 384$.

Substituting these numerical values in equation (d), and solving,

$$a = \frac{6861.54 \times 28 + 5980271.2}{162087.7 - 6861.54} = \frac{6172394.3}{155226.2} = 39.76.$$

Hence the axis of the trunnions must be placed at the distance of 39.76 inches from the base-ring in order that the gun may bear the desired preponderance.

336. To Determine the Effect on the Preponderance of a Change in the Position of the Trunnions.

Different values of P are taken, and the corresponding values of a computed. P and a are assumed to vary proportionally, and the variation in pounds of P for a change of a tenth of an inch of a thus obtained.

This assumption is not absolutely true, but nearly enough so for all practical purposes.

Example.—Had we taken 780 lbs. for the desired preponderance of the XV-*inch* gun, a would have been found equal to 38.12.

Hence changing the position of the axis of the trunnions by 1.64 inches, has caused the preponderance to vary by 1004 lbs. —or 61.2 lbs. for each tenth of an inch.

CHAPTER III.

CAST GUNS.

Section I.—Standard of Iron.

337. Smelting of Iron for Cannon.*—It is in the smelting furnace that the character of the iron is fixed. Iron of good character and high susceptibility may be spoiled by its treatment at the foundry; but this, with ordinary experience and intelligence, ought rarely to occur.

It is impracticable, with our present knowledge, to make good and reliable guns from iron that leaves the smelting-furnace with bad qualities.

338. The smelting of iron is a purely chemical process, and should be conducted with the same regularity and precision as any other important chemical process. There are so many disturbing causes tending to affect its character and qualities, that, after every precaution shall have been taken to remove them, perfect uniformity in the quality of the iron produced from day to day cannot be effected, yet a near approximation to uniformity is practicable.

339. All the stock for a "blast" of gun-iron should be carefully prepared and housed before beginning to "blow." The ore should all be roasted and well mixed so as to be as nearly uniform, as to size of lumps and all other qualities, as possible.

The charcoal should all be made as nearly as possible from the same kind of wood, of the same uniformity as to quality, and well mixed together after charring. All the stock should be carefully weighed and supplied to the furnace at regular intervals of time.

340. The pressure, temperature, and hygrometrical condition of the "blast," should be kept as nearly constant as possible. The temperature of the blast may be kept very nearly constant without using what is termed a "hot-blast," by warming it just enough to bring it above the highest summer temperature.

* Rodman.

341. The quantity of moisture may, it is believed, be kept nearly constant by passing the blast some distance over water heated to the proper temperature. And this may be readily done by passing the blast through a long horizontal tube, like a cylindrical steam-boiler, partly filled with water, and kept at a constant temperature by the waste heat from the furnace.

The temperature of the water should be such as to saturate the blast with moisture, and thus render it hygrometrically independent of atmospheric changes.

342. Piling the Pigs.—Supposing a standard of quality to have been determined (Art. 374), with the stock all prepared for a given number of guns, and having determined by comparison with the *standard* the quality of iron required, a further approximation to identity in quality of the metal in the guns may be made by casting each run of metal from the smelting-furnace into a number of pigs of equal size, something greater than the number of the guns to be made, and piling them in separate piles—each run of metal furnishing one pig to each pile.

343. Each pile should contain metal enough for one gun and one test-cylinder; and be kept separate and distinct from all others in transportation, and be repiled in the foundry-yard in the same order as at the smelting-furnace: one gun being made from each pile, after the treatment which the iron should receive at the foundry shall have been determined by experiments made on the iron in the surplus piles. The pigs should be cast in molds as prepared from a pattern, so as to be smooth and free from adhering sand as possible.

344. Difference in Quality.—The difference between iron as it exists when presented for use in "pigs" and when in the body of the finished gun is very great, sometimes amounting to a difference in density of more than 20 pounds per cubic foot, and in tenacity more than as 1 to 2.

This serves to show how unreliable the tests of the first fusion pig-iron are, as means for determining the quality of iron and its suitableness for making cannon.

345. The quality of cannon may be improved by endeavoring to ascertain the different qualities of the metal used in making them, and the best methods of treating it in the processes of melting, casting, and cooling.

346. It is found that some kinds of iron are susceptible of very great improvement, by different methods of treatment at the foundries; while other kinds are at their maximum strength in the crude pigs. The cause of this difference in the susceptibility for change and improvement will doubtless be found in

the qualities of ores used, and in the processes of smelting them.

347. The following table enables us to compare the various qualities of cast-iron and bronze, and see the variations which occur in each.

VARIOUS QUALITIES OF CANNON METALS.*

Metals.		Density.	Tenacity.	Transverse Strength.	Compressive Strength.	Hardness.
Cast-iron..	Least...	6,900	9.000	5,000	84,529	4 57
	Greatest	7,400	45,970	11,500	174,120	33.51
Wrought-iron.....	Least...	7,704	38,027	6,500	40,000	10.45
	Greatest	7,858	74,592	....	127,720	12.14
Bronze....	Least...	7,978	17,698	....	......	4.57
	Greatest	8,953	56,786	....	.....	5.94
Cast-steel .	Least...	7,729	....	....	198,944	....
	Greatest	7,862	128,000	23,000	391,985	....

A prominent feature of this table is that which shows the great difference between the lower and higher grades of the same metal. In cast-iron the density differs as 6.9 to 7.4. a difference equal to 31 pounds per cubic foot; in tenacity it differs as 45,970 to 9,000 pounds per square inch, or as 5 to 1, and in hardness as 7 to 1. The bronze varies in tenacity from 56,786 to 17,698, more than 3 to 1, and in density it is as 8.953 to 7.978, equal to 61 pounds in the cubic foot.

348. Effects of different Treatment.—Usually the quality of iron is greatly modified and improved by remelting and long continuance in fusion. But all kinds of iron are not affected in like manner by these processes.

In examining the effects of the different treatment of iron at the foundry, such samples should be chosen as will best exhibit the following particulars and characteristics, viz.:

1st. The properties which distinguish the different grades of iron made from the same ores at the same furnace.

2d. The changes in the mechanical properties of iron produced by repeated meltings of one of these grades, separately, showing the changes effected at each melting.

3d. The changes produced by repeated meltings of the different grades of iron and of different fusions mixed.

* Reports of Experiments on Metals for Cannon.—U. S. Ordnance Dept.

4th. The changes produced in iron of the same melting and quality, by casting it into masses of different bulk, and by different methods of cooling.

349. The softest kinds of iron will endure a greater number of meltings with advantage than the higher grades. It appears from Major Wade's experiments with Greenwood iron that when it is in its best condition for casting into proof-bars of small bulk, it is then in a state which requires an additional fusion to bring it up to its best condition for casting into the massive bulk of cannon.*

In selecting and preparing iron for cannon, we may proceed by repeated fusion, or by varying the proportions of the different grades and different fusions, until the maximum tenacity is attained.

350. Variation of Density and Tenacity.—An increase of density is a consequence which invariably follows the rapid cooling of cast-iron, and as a general rule, the tenacity is increased by the same means. The density and tenacity usually vary in the same order. It appears that the tenacity generally increases quite uniformly with the density, until the latter ascends to some given point; after which an increased density is accompanied by a diminished tenacity.

The turning-point of density at which the best qualities of gun-iron attain their maximum tenacity appears to be about 7.30. At this point of density, or near it, whether in proof-bars or in gun-heads, the tenacity is greatest.

As the density of iron is increased its liquidity when melted is diminished. This causes it to congeal quickly, and to form cavities in the interior of the casting.

351. If in preparing iron for guns it is carried *too high*, either by long continuance in fusion or by using a large portion of a hard grade of iron, the casting will be lost.

High Iron.—The condition of the iron at casting is said to be *too high*, when the process of decarbonization has been carried too far; and the result will be a very hard iron.

352. Practical Treatment in Fusion.—In the practical treatment of iron in fusion while preparing it for casting into cannon, it may be safely continued in fusion, with increasing improvement of its quality, so long as sufficient liquidity is retained to insure an exemption from cavities in the interior of the casting.

The point at which such cavities of a fatal character will form, will be reached before arriving at the point of density for maximum tenacity.

* Reports of Experiments on Metals for Cannon: 1856.

353. Tests while in Fusion.—A convenient method for determining the condition of the iron while in fusion, and whether it has arrived at the proper condition for casting, or should be longer continued in fusion, is found, in dipping from the melted pool of iron and casting into small bars about 10 inches long and from 1 to 2 inches square at one end, and tapering to a point at the other end. The first one is taken from the furnace and cast soon after the iron is all melted, and others are cast at such intervals afterwards as may be judged proper. They are cast vertically, point downwards, in sand-molds, and cooled rapidly.

354. Great care must be taken in the preparation of the molds for these samples, as upon sample-bars so small, even a little, more or less moisture of the sand of the molds will make a difference as to the rate of progress towards white iron.

355. As samples cannot be obtained from the heads of large guns (Art. 367) until several days after they are cast, separate proof-bars are made and tested, to aid in directing the progress of the work. This enables the founder to determine the relative quality of the iron soon after it is cast, and in the intervals between each successive daily casting.

356. The proof-bars are broken in different places, and the condition of the iron is judged by the appearance of the several fractures.

These fractures will exhibit various aspects, from white at the small end to dark gray at the large end; and the bars at the latter periods of the fusion will exhibit the white at a greater distance from the small end, and the mottle, bright, and lighter shades will be found advancing towards the large end. This method, although much less reliable than that of an actual measure of density and strength, is convenient, because of its ready application at short intervals, while the iron is in fusion; and a practical eye will soon be able to mark the progress of the changing quality of the iron, and to determine the proper time for casting the gun.

357. CRYSTALLIZATION.—Of the various circumstances which affect the strength of cannon-metal, the most important appear to be those which connect themselves with crystallization.

General Law.—It is a law of the molecular aggregation of crystalline solids, that when their particles consolidate under the influence of heat in motion, their crystals arrange and group themselves with their principal axis in lines perpendicular to the cooling or heating surfaces of the solid; that is, in the lines of direction of the heat-wave in motion, which is the direction of least pressure within the mass; and this is true, whether in the case of heat passing from a previously fused solid in the act of cooling and crystallizing on consolidation, or of a solid not having a crystalline structure, but capable of assuming one upon its temperature being sufficiently raised, by heat applied to its external surfaces, and so passing into it.*

358. Molecular Constitution of Cannon Metals.—The metals used in gun construction are crystallizing bodies, which in consolidating obey more or less perfectly, according to their conditions, this law; so that in castings of these metals, the planes of crystallization group themselves perpendicularly to the surfaces of external contour; that is, in the directions in which the heat of the fluid metal has passed outwards from the body in cooling and solidifying. Because the crystals of these metals are always small and are never very well pronounced, these directions are seldom very apparent to the eye, but they are not the less real.

359. Development of Crystals.—Their development depends upon:

First. The character of the metal itself; all irons that present a coarse, large-grained, dark, or spangled fracture, contain a large proportion of uncombined carbon or graphite, and form in castings of equal size the largest crystals.

Second. The size or mass of the castings—the largest castings presenting for any given variety of metal the largest and coarsest aggregation of crystals; but by no means the most regular arrangement of them, which depends chiefly upon—

Third. The rate at which the mass of the casting has cooled, and the regularity with which heat has been carried off by conduction from its surfaces to that of the mold adjacent to them.

360. Chilled Castings.—Those castings in which the fluid iron is poured into a nearly cold and very thick mold of cast-iron, whose high conducting power rapidly carries off the heat, present the most complete and perfect development of the crystalline structure perpendicular to the chilled surfaces of the casting. In such, crystals are often found penetrating more than an inch into the substance of the metal, clear and well-defined.

361. Illustrations.—These prevailing directions of crystalline arrangement may be made more clear to the eye by the accompanying Figure 55, which shows sections of a round and a square bar of cast-iron where the crystallization is well devel-

* Mallet.

oped. In the round bar the crystals all radiate from the centre; in the square bar they are arranged perpendicularly to the four sides, and hence have four lines in the diagonals of the

FIG. 55.

square—in which the terminal planes of the crystals abut or interlock, and about which the crystallization is always confused and irregular.

The result of this arrangement is to create *planes of weakness* where the different systems of crystals intersect.

362. EFFECT OF CRYSTALLIZATION ON STRENGTH.—The size and arrangement of the crystals of a metal have an important influence on its strength. This arises from the fact that the adhesion of the crystals by the contact of their faces is less than the cohesion of the particles of the crystals themselves, and that consequently rupture takes place along the larger or principal crystalline faces.

A metal will therefore be strongest where its crystals are small.

363. SIZE OF CRYSTALS.—The size of the crystals of a particular metal depends on the rate of cooling of the heated mass; the most rapid cooling giving the smallest crystals. The size of the crystals or coarseness of grain in castings of iron depends, for any given *make* of iron and given mass of castings, upon—

First. The high temperature of the fluid iron above that just necessary to its fusion, which influences—

Second. The time that the molten mass takes to cool down and assume again the solid state.

The lower the temperature at which the fluid iron is poured into the mold, and the more rapidly the mass can be cooled down to solidification, the closer will be the grain of the metal, the smaller its crystals, the fewer and least injurious the planes of weakness, and the greater the specific gravity of the castings.

Slow cooling develops a coarse, uneven grain, with large but thoroughly irregular and confused crystallization; cast-iron with such a grain is never strong or cohesive, though soft and extensible.

364. The more rapidly a casting once consolidated can be cooled, without introducing injurious effects, the finer, closer, and more even will be its grain on fracture, and with any given metal the greater will be its strength. The rate of cooling cannot be accelerated beyond a moderate limit. If this limit be exceeded, as by casting in a cold, thick, highly conducting metallic mold, the iron is "chilled," its constitution changed, and the carbon, not having time to crystallize out, remains combined or diffused through the mass.

It cannot be so fast as to endanger unequal contraction, nor must it be so fast in large castings, such as guns requiring to be "fed," from a *feeding* or *sinking-head*, with fresh portions of hot fluid metal during consolidation to fill up the internal cavities or porosity due to contraction and crystallization, that this feeding cannot be accomplished.

The larger the mass of the casting, with any given quality of iron, generally the coarser is the grain; that is, the larger are the crystals that develop themselves in the mass.

The same metal that shall produce a fracture bright gray, mottled, and without a crystal visible, in a small bar, will in a large casting produce a dark, confusedly crystalline surface of fracture as coarse as granite rock.

365. Contraction of Castings.—A certain amount of contraction, on becoming solid from the liquid state, occurs in all castings. For iron this is variable, and depends upon the mass of the castings; being greatest for small and least for large castings, of the same make of iron, and poured at the same temperature.

There are two conditions that principally affect the degree of contraction, namely, the extent to which the fluid metal as entering the mold has been expanded by elevation of temperature, and the state of final aggregation of the particles, depending upon the size of the mass.

366. Effect of Sudden Change of Form in Castings.—Sudden changes of form or of dimensions in the parts of cast-guns, besides the injury they do to the crystalline structure of the mass, introduce violent strains, due to the unequal contraction of the adjoining parts, whose final contraction has been different.

For this reason, in the method of casting heavy guns as adopted in Sweden, it is considered necessary to form the exterior of the casting as a perfect cylinder.

367. Time Required for Cooling Castings.—The enormous

time required by a large casting for cooling is not generally known. A solid casting sufficiently large for a XV-inch gun weighs about 35 tons; it is red-hot three days after having been cast, and only becomes cold enough to handle after a fortnight. The cooling of a casting must be uniform, so far as uniformity is possible. This is impossible strictly in any casting; the approach to it is most difficult in heavy solid castings, and hence the great advantage of the practice of hollow casting upon a suitably made core, admitting of internal cooling by artificial means.

368. Effects of Irregular Cooling of Castings.—The contraction of cast-iron in becoming solid introduces strains into the mass by consolidation of one portion of the casting before another. When a large gun is cast solid and the metal cools in the ordinary way, the external portions solidify long before the interior has ceased to be liquid, and the process of solidification is propagated as it were, in parallel layers from the outside to the centre of the mass. When the first layer or thickness of solid crust has formed in the exterior, it forms a complete arch all round, so that the contraction between fluidity and solidification of each subsequent layer is accommodated by portions of matter withdrawn radially from the interior towards the still cooling exterior; that is to say, from a smaller towards a larger circumference.

369. The final effect of this, propagated to the centre of the mass, is two-fold.

First. To produce a violent state of internal tension in the particles of the metal in radial lines from the axis of the gun inward as a cylinder, tending to tear away the external portions of the mass from the internal nucleus.

Second. To produce about the centre or along the axis a line of weakness, and one in which the texture of the metal is soft, porous, and of extremely low specific gravity.

370. The effect of this unequal contraction may be so great as to crack the interior metal of cast-iron cannon, even before it has been subjected to the force of gunpowder, and large masses of iron which have been cooled very rapidly by casting them in iron molds, have been known to split open longitudinally, from no other cause than the enormous strains to which they are thus subjected.

371. Sinking-head.—Guns have long been cast in a vertical position and with a certain amount of head of metal above the topmost part of the gun itself. From this head the casting is fed with fresh portions of fluid metal during consolidation; it also affords a gathering-place for all scoria or other foreign

matter. But the great value of increased head of metal is in adding to the density of castings, and so also to their strength. Fineness of grain, smallness of crystal, density, increased cohesion and elasticity, are all induced by casting under largely increased statical heads of fluid metal. By apparatus not difficult to contrive, atmospheric pressure or that of condensed air might easily be brought to aid that of the head of metal, with economy in reducing the labor and cost of the mass of metal to be melted, and with the advantage of enabling the pressure on the solidifying mass to be varied.

372. Effect of Age on Endurance.—The length of time that a piece has been cast influences its endurance. A gradual adjustment takes places of the internal strains produced in cooling, and like many other substances iron possesses the property of accommodating itself to an unnatural position, and finally of adopting this as its natural one.

373. Improvement in Castings.—The principal improvement in the fabrication of cast-iron guns, is Captain Rodman's process of cooling them as far as possible from the interior, and for this purpose casting them hollow.

The design is to remedy the various defects of the old process; principally to obviate the tendency of solid castings to burst by their own initial strains, by reversing the process of cooling and shrinking described above. Since there would then be no force opposed to the contraction of the inner layers of metal, except the trifling cohesion of the liquid or pasty mass that they shrink away from, they would not be left in tension, and therefore they could not exert any power to pull the exterior layers into compression.

The method employed is, to carry off the internal heat by passing a stream of water through a hollow core, inserted in the centre of the mold-cavity before casting, and to surround the flask with a mass of burning coals to prevent too rapid radiation from the exterior. (Art. 445.)

Extensive trials have been made to test the merits of this plan, and the results show that cast-iron cannon made by it are not only stronger but are less liable to enlargement of the bore from continual firing, the surface of the bore being the hardest and densest part of the casting, and best calculated to resist pressure and abrasion.

374. STANDARD OF QUALITY.—Before proceeding to execute a contract for cannon, a *trial-gun* should be made and exposed to extreme proof with service charges. After undergoing this proof in a satisfactory manner, the trial-gun should serve as a standard, and the proportions of the several kinds of metal

used, and the methods employed in its manufacture should be followed in all respects in the fabrication of other guns. With the trial-gun should be cast a *sample-gun* or a cylinder of equal diameter, and at least half the length of the gun, from which test specimens should be cut and tested.

375. The sample-gun or cylinder should be of the same diameter as the guns to be made, and should be made under the same circumstances which are to attend the preparation of the iron for, and the casting and cooling of, the guns themselves.

The object of the sample is to obtain specimens which have not been subjected to previous strain and vibration, as would be the case if taken from the fragments of the broken trial-gun.

For it is impossible to reason back to what would have been either the capacity for work or the work due to elasticity of an unstrained specimen by knowing to what extent these properties were possessed by that specimen after it had been subjected to both strains and vibrations of unknown intensity and number.

And although it is interesting to know to what extent these properties are possessed by the fragments of a worn-out gun, yet it would be of far greater practical utility and importance to know the value of these properties in the new untried guns.

Specimens thus obtained would afford reliable results; and in connection with the powder-proof with service-charges of guns, cast at the same heat, these results would become standards with which to compare other lots of iron or other guns, and thus determine beforehand the number of rounds which a gun will stand.

376. Comparison with Standard.—While the cannon are making, the inspecting officer examines and tests the metal before it is used, witnesses its melting and casting, and tests the metal in the first gun made, before the second one is cast. If the first proves unsatisfactory, such changes are made, either in the material or in its treatment, as will tend to produce the desired result.

This practice of ascertaining the quality of the material used, and of the casting made from day to day, as the work proceeds, enables the founder to distinguish the material, to select those of best quality, and to treat them in the best manner.

If these tests are satisfactory, the inspecting officer is assured of the good quality of the guns, before any proof by firing is made. And this supersedes the necessity of using excessive proof-charges in the final proof, which may do serious and even fatal injury to guns, without bursting them or leaving any visible marks of the injury.

377. Means of Comparison.—The *testing-instrument* (Art. 396) furnishes to the founder a convenient and accurate method of comparing the qualities of iron. It therefore enables him to select his materials before casting, with greater certainty and safety. He can also by this means determine the comparative utility of different methods of melting and casting the gun. As the quality of the iron is essentially changed by the different ways of treating it while in the melted state, and by the different means adopted for cooling it after it is cast into the mould, the testing-instrument enables one to ascertain the effect produced by these processes in all their several stages of progress, and to decide upon that which is found most suitable for making the guns of the best quality.

378. Contract with Founder.—The metal of guns made for the naval service is subjected to tests to ascertain its hardness, specific gravity, and tensile strength.

The particular hardness, density, and strength which the metal must possess is specified in the special contracts with the Founder.

Each foundry keeps an accurate record of the character, mixture, and mode of working the metal of each gun, so that its foundry number will at once refer to its class, date, weight, etc.

379. Samples.—The quality of the iron as it exists in the gun is more accurately represented by samples taken from its *sinking-head* than by any which can be obtained from other parts of the casting without injury to the gun. These samples are taken from the lower end of the sinking-head, next to the muzzle of the gun, and are cut out so that their axes will be parallel to the axis of the casting, at a distance from the centre of the head equal to the distance between the axis of the bore and the middle of the metal in the wall of the piece when bored.

When guns burst from extreme proof, samples are taken from different parts to test the strength of the metal. The radial specimens are generally found to be somewhat stronger than the longitudinal from the same cross-section of the gun. (Art. 362.)

380. Marking-samples.—The sinking-head and the gun to which it belongs have the same foundry-number.

The samples have the foundry-numbers and the letter H stamped upon both ends of them.

All samples taken from any gun-casting, whether from the sinking-head, the proof-bars, or other casting, from the same melting, bear the foundry-number of the gun. The letter H, added to the number, denotes that the sample is taken from the head. OH denotes a sample from near the outer or exterior surface. IH an inner sample, and other letters are used denoting the locality from which the specimen has been taken. The letter B on any sample, denotes that it was taken from a proof-bar. The figures which follow the letter indicate the fusion or the number of times the iron has been melted.

381. VALUE OF TESTS.—The samples are tested as soon as practicable. The tests are carefully made and recorded with the other proofs and inspections, and afford the means of comparison between the metal of different guns and of different foundries.

No particular value is attached to these tests as an indication of the absolute endurance of the gun, but only as exhibiting the similarity that the several guns bear to the standard. Experience has shown that a variation of about 2,000 pounds more or less, in the tensile strength, is a sufficient limit to be allowed, and within which to confine the founders; an exact adherence being impossible.

382. STANDARD SPECIMEN.—In order to obtain a suitable sample for determining the density and strength; a cylindrical piece about four inches long and two inches in diameter is taken, and prepared by reducing it to a form that will fit the holders of the testing-machine (Fig. 56), and of such bulk as will be convenient for ascertaining its density. In order to obtain reliable comparative results, it is necessary that the specimens shall all conform to the standard in size and shape.

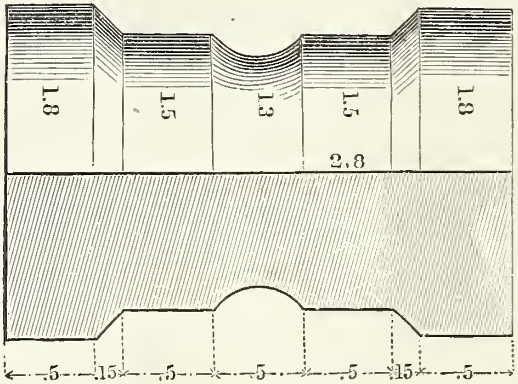


FIG. 56.

383. TO DETERMINE THE DENSITY.—The sample is weighed in air and in pure distilled water; clear rain or river water may be substituted, if its relative density be first accurately determined.

In taking the specific gravity of iron, the operations are unavoidably performed with water at different temperatures, varying with the state of the weather at the time; and as the density of the water varies with its temperature, it is necessary to note the temperature of the water at the time of weighing the sample, and to reduce the ascertained density to what it would have been if the sample had been weighed in water at the temperature of the assumed unit.

A thermometer is suspended in the water, and its temperature is noted at each weighing. The temperature of 60° F. is taken as the standard; and when a sample is weighed in water of any other temperature, the weight of water displaced by it is corrected by the table compiled for that purpose.

The instruments employed for determining the density of specimens are—The *Hydrometer* and the *Densimeter*, or *Balance for specific gravities.*

384. THE HYDROMETER.—Fig. 57 exhibits the form of the instrument. The bulb B is of thin copper about 7 inches diameter at top, and 8 inches high, having a brass handle, H, and a solid stem of brass, S, screwed into the bottom.

FIG. 57.

A vertical index-stem made of steel, I, is inserted in the upper part of the handle. The upper end of this stem receives the weight-pan, W, which is supported in its place by a conical socket on its under side.

The height of the hydrometer, from the bottom of the ball to the weight-pan, is 21 inches. Its general form and the distribution of the metal within it, place the centres of gravity and buoyancy so far apart that it readily takes a vertical position, when immersed, and will deviate very little from it, however irregularly it may be loaded.

Its maximum buoyancy is about 14,000 grains; but this may be reduced when weighing lighter samples, by adding at the bottom one or more adjusting-weights, which may vary it one-half.

The index-stem is of very small diameter, a length of one inch displacing one grain of water.

The zero-mark is in the middle of the length of the stem.

The weights are marked in grains, decimally divided, varying from one-tenth of a grain to 4,000 grains.

The vessel which contains the water is a glass jar about a foot in diameter and two feet in height. It must be placed on a level support, and the height of the water in the jar should be such that when the hydrometer descends to the bottom, the weight-pan shall still be above the surface of the water.

The weight-pan is attached to the index-stem by an open socket, so that it may be removed with its load, and placed on a table, where the weights may be more safely and accurately counted.

385. To Determine the Density of Water.—The hydrometer may be employed to determine the relative density of distilled and any other kind of water. The weight of the hydrometer, added to its balance-weight in distilled water, at the temperature of 60°, gives the weight of a quantity of pure standard water, which is equal in bulk to the immersed part of the instrument. The weight of the hydrometer and its load when immersed in like manner, in other kind of water at the same temperature, gives the weight of an equal bulk of the latter, and this weight divided by the former, gives the multiplier for correcting the density, when ascertained in any other than pure distilled water.

At the foundries generally, river-water is found to be sufficiently pure for use without needing any correction.

386. To Use the Instrument.—First load the pan with grain weights until the instrument rests at its zero, and record the sum of these weights, as the *balance of the hydrometer.* Next, place in the pan the samples together with as many weights as will again bring the instrument to its zero, and record these weights, as the *sample balance in air.* The difference between these balances is equal to the weight of the sample in air. Then place the sample on the bulb of the instrument at P, and immerse both until the hydrometer again rests at zero, and record the weights on the pan, as the *sample balance in water.* The difference between this balance and that in air is equal to the weight of the water displaced by the immersed sample. The temperature of the water at the time

of weighing is noted, and if it is not at 60°, divide the weight displaced by sample, by that number in the table which is opposite the noted temperature, and the quotient will give the corrected displacement for the temperature of 60°. Then, the weight of the sample in air divided by the corrected displacement gives the density of the sample.

387. EXAMPLE.

Sample No. 4, H.	Grains.
Balance of the hydrometer	11485.0
Balance with sample in air	923.0
Difference = weight of sample in air	10562.0

Balance with sample in water	2370.4
Balance with sample in air	923.0
Difference = weight of water displaced	1447.4

Noted temperature, $72\frac{1}{4}°$.
Tabular number, $72\frac{1}{4} = .998912$.

Then, $\frac{1447.4}{.998912} = 1449.0$ corrected displacement,

and $\frac{10562}{1449} = 7.289 =$ density.

Or by Logarithms—

	Logarithms.
Water displaced at $72\frac{1}{4}° = 1447.4$	3.1605886
Tabular number for $72\frac{1}{4}° = .998912$	$\bar{1}.9995274$
Logarithm of corrected displacement	3.1610612

Weight of sample in air = 10562	4.0237461
Corrected displacement	3.1610612
Density = 7.289 =	0.8626849

The determination of densities by the hydrometer requires much practice to arrive at correct results, and is, moreover, very tedious.

The *densimeter*, or *balance*, may therefore be advantageously substituted for it, the results being occasionally checked by the hydrometer.

388. THE DENSIMETER,* or BALANCE FOR SPECIFIC GRAVITIES, is in principle a simple beam scale of accurate workmanship. As made by Wurdemann, it consists of an open beam of German silver, A (Fig. 58), fitted with knife-edge bearings, and mounted

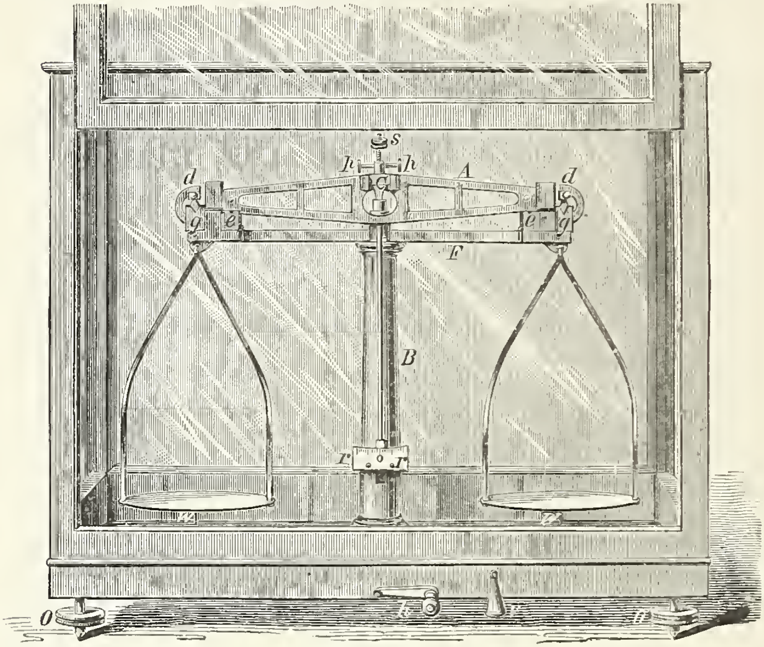


FIG. 58.

in a hollow standard, B. The central knife-edge, *C*, upon which the beam is balanced is 1.4 inch long, and those at extremities, *d*, from which the scale-pans are suspended are 0.9 in. long; all bearing their lengths on steel plates.

When not in use the beam rests on its Y's, *e e*, on a cross-bar, F, at the top of the standard.

This cross-bar also supports the scale-pans on separate rests, *g g*, free from contact with their knife-edges.

Through the standard a rod passes for lifting the beam when in use; it connects with the crank, *h*.

The standard is set on a brass plate furnished with a circular spirit-level and foot-screws, *o o*, for accurately levelling it.

* Inspection and Proof of Cannon—U. S. Navy.

The whole apparatus is enclosed in a glass case to protect it from dust or currents of air; the case is fitted with a sliding front which is counterpoised for convenient manipulation.

389. When not in use the glass case should be kept closed to protect the balance from dust, and a vessel containing crystalized *chloride* of *calcium*, to absorb the moisture of the air, ought to be always placed inside the case.

The best arrangement for this purpose is a glass funnel, containing the chloride set in a beaker-glass. The beaker should always be emptied before the water reaches the end of the funnel-stem.

390. ADJUSTMENTS.—*The beam* is balanced by two adjustments placed above it.

First, by the horizontal screws, *p p*, with milled heads, for the zero of the index below *r*, and, second, by the large nut, *s*, on the perpendicular screw for vertical balance. This last, when once set, it is seldom necessary to touch.

391. *The Arms* are adjusted to equal length. There is to each knife-edge end a steel screw with capstan-head, which when screwed forward will spring out the part upon which the knife-edge rests, and thus lengthen its distance from the centre. Both ends are made thus adjustable, by which means perfect symmetry of the two parts of the beam is obtained and the necessity of screwing back during the adjustment is obviated, since it will merely be necessary to lengthen the arm which proves to be shortest.

To test this the relative place of the scales should be changed after first balancing them exactly, if, after the change either preponderates, it proves that arm to be the longest. One half the difference is to be corrected with weights, and the other half with the adjusting-screws. Great caution must, however, be observed in not screwing up too much at a time.

A correct result in weighing may be obtained without this adjustment being absolutely exact, by first balancing the specimen to be weighed, with any convenient substance, then removing the specimen and substituting in its place known weights until equilibrium with the counterpoise is restored.

392. USE OF THE INSTRUMENT.—By the crank, *h*, placed in front of the case, the centre bearing is gently raised, which, lifting the beam off its Y's, also takes up the scales.

When the beam is completely raised the oscillations of the scales are arrested by touching the spring-lever, V, on the right of the crank, which works the steadying-pins, *w w*, under each pan.

On abandoning the lever the preponderance of the specimen or the weight, will immediately be manifested, and additional weights may be added or removed until they are in equilibrium.

When placing the specimen and estimated counterbalancing weights in the scales, the beam should always be let down on the supports; but small weights may be added or changed whilst simply arresting the scales with the lever.

The door should not be pushed up higher than is just necessary to obtain convenient access, as the balance is very sensitive. Care should be taken not to abrade the pans by carelessly putting in the specimens or rubbing to remove dust.

393. Determination of Specific Gravity.—For the determination of specific gravities a German-silver vessel is used just large enough to conveniently hold the specimen, and open at the top, which is planed off perfectly straight so that a plate-glass provided for the purpose can be slid over it, and will shut air-tight. This vessel is filled with distilled water, carefully removing air-bubbles from inside the vessel, or drops mechanically adhering to the outside.

Weight and temperature are noted, and a table may be computed, so that this element constitutes for the instrument used a constant.

It will be convenient to keep the water in a reservoir of considerable size, to avoid the inconvenience of frequent changes of temperature.

The absolute weight of the specimen having been previously taken and noted, it is then submerged in the vessel, a small pair of tongs being used for the purpose, when it will displace a quantity of water equal to its volume. The vessel is again covered with the plate-glass, using the same precautions as before, and the weight taken.

394. Since specific gravity is represented by the ratio of the absolute weights of the same volume of water, and of the article to be determined, we have to divide the weight of specimen by a quantity obtained, by deducting the weight of the vessel, with specimen inserted, from the sum of weight of vessel filled with water, and of the weight of specimen.

Therefore if —

C = Weight of vessel filled with water (constant),
W = Absolute weight of specimen,
W_1 = Weight of vessel with specimen submerged,
S = Specific gravity.

We have

$$S = \frac{W}{C + W - W_1}.$$

Example.

Grains.		Logarithms.
$C =$	8618.5	
$W =$	9888.0	3.9951085
$C + W =$	18506.5	
$W_1 =$	17137.7	
$C + W - W_1 =$	1368.8	3.1363400
$S =$	7.223	0.8587685

395. Form of Record of Computation.

By Densimeter.

Calibre.	No.	Spec.	Tem.	Weight.	Grains.	Grains.	Tem.	Logarithms.	Sp. Gr.
IX-in.	1910.	H.I.	63°	Tank filled.....	8962.1	....	63°	$\bar{1}$.9999020	
				Spec. in air.....	9845.5	18807.6	....	3.9932378	
				Spec. in water..	......	17465.0	....	3.9931398	
				Water displaced.	......	1342.6	....	3.1279466	
								.8651932	7.332
IX-in.	1910.	H.I.	63°	....	8962.1	....	63°	$\bar{1}$.9999020	
					9787.2	18749.3	....	3.9906585	
						17416.5	....	3.9905605	
				Water displaced.	......	1332.8	....	3.1247650	
								.8657955	7.342

By Hydrometer.

Calibre.	No.	Spec.	Tem.	Weight.	Grains.	Grains.	Tem.	Log.	Sp. Gr.
IX-in.	1910	H.I.	64°	Bal. of hyd.....	12784.2	......	64°	$\bar{1}$.9998660	
				Bal. with Spec. in air.....	2938.5	9845.7	....	3.9932466	
				Spec. in water..	4281.3	......	....	3.9931126	
				Water displaced.	....	1342.8	....	3.1280113	
								.8651013	7.330
IX-in.	1910.	H.2.	64°		12784.2	......	64°	$\bar{1}$.9998660	
					2996.7	9787.5	....	3.9906718	
					4329.6	......	....	3.9905378	
				Water displaced.	....	1332.9	...	3.1247976	
								.8657402	7.341

Section II.—Mechanical Tests.

396. THE TESTING-MACHINE affords the means of ascertaining those properties of metals on which the endurance of guns is believed mainly to depend.

As yet, however, no standard of properties has been determined, nor is it believed to be practicable to fix such standard except by connecting the mechanical tests of a metal with the endurance under the powder-proof of the guns made from it.

397. The Rodman Testing-machine.—This instrument is used to determine the capacity of any metal to resist a *tensile*, *transverse*, *torsional*, or *crushing* force. It is also used to obtain the indenting-force, and an internal force can be applied for bursting hollow cylinders.

398. Power Exerted.—By a combination of levers and cog-wheels the action of the power employed is greatly augmented and transmitted to the specimen under trial.

The machine consists essentially of a system of three levers, AC, A′C′ and A″C″. (Fig. 59.)

The position of the fulcrum in each of these cases is denoted by F, F′ and F″ respectively. The power is applied at P, and the position of the weight is denoted by W. The levers are connected by rigid rods.

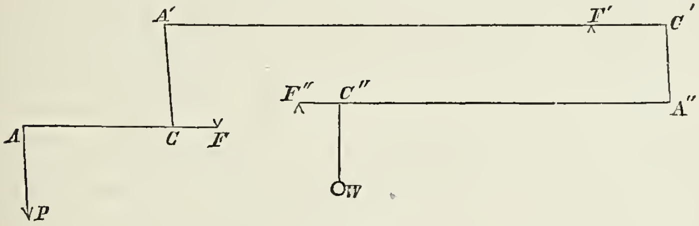


Fig. 59.

The mechanical advantage of the lever AC is 10 to 1; that of A′C′ is 20 to 1, and that of A″C″ is 10 to 1.

We have, therefore, by the formula for compound levers:

$$\frac{W}{P} = \frac{10}{1} + \frac{20}{1} + \frac{10}{1} = 2000.$$

399. EXPLANATION OF THE RODMAN MACHINE.—The Middle Lever, so called because it is intermediate between the other two, is the upper lever, A′F′ (Fig. 60). All its bearing knife-edge pivots are in the same horizontal plane. Its fulcrum, F′, is supported by an interior frame which is attached to the screw, D, above it. The knife-edge A′ connecting by means of a long vertical rod, A′C, with the *small lever*, AF, is ninety-seven inches from the fulcrum, F′, and the knife-edge C′ connecting by means of a strap, A″C′, with the main lever, A″F″, is four inches and eighty-five hundredths from the fulcrum F′, making a proportion between the two arms of the lever as 20 to 1.

400. The Main Lever, A″F″, is the one which acts directly upon the specimen under trial, and is acted upon by the middle lever through a long iron strap, A″C′, which connects them. All its knife-edges are in the same plane.

Its fulcrum, F″, is supported by a pair of heavy iron stanchions, BB, fitted to the bed-piece, EE. The knife-edge A″ which is linked with the middle lever is ninety inches from the fulcrum, F″, and the knife-edge C″, which acts upon the specimen under trial is nine inches from the fulcrum, F″, making the power of this lever as 10 to 1.

401. The Small Lever, AF, is the one to which the weights are attached.

All its bearing knife-edge pivots are in the same plane. Its fulcrum, F, is supported by the lower end of the guide, G.G′, attached to the main lever stanchions. The knife-edge C, connecting with the middle lever, is two and twenty-five hundredths inches from the fulcrum, F, and the knife-edge A, to which the weights are attached, is twenty-two and five-tenths inches from the fulcrum, F, making the power of this lever as 10 to 1.

402. The Combination of Levers.—A combination of the small lever with the middle lever gives a proportion of two hundred to one; and a combination of all three of the levers gives a proportion of two thousand to one. A weight of one pound, therefore, applied to the platforms of the suspending rod, T, on the small lever exerts a force of two hundred pounds on the strap, A″C′, connecting with the main lever, and of two thousand pounds at C″, where the strain acts upon the sample.

403. Capacity of the Machine.—The weights used are of two denominations, viz., half pounds and five pounds, representing respectively one thousand and ten thousand pounds. Smaller increments of strain than one thousand pounds are noted on the small lever, which is provided with a sliding weight and graduated from zero to ten; each number representing an additional hundred pounds.

Of the first denomination, there are ten weights, representing a strain of ten thousand pounds, and of the second, there are nine weights, representing a strain of ninety thousand pounds.

The aggregate strains of all the weights or the capacity of the machine being one hundred thousand pounds.

404. The Cog-wheel Gearing.—The large vertical frame, EH, at one end of the machine (Fig. 60), supports the cog-wheel gearing which is set in motion by a crank.

To the heavy main lever stanchions, BB, a guide, G.G., is attached; through the upper end of which the small end, G′, of the middle lever passes. This guide ascends and descends evenly with the screw, D, and the fulcrum, F′, of the lever, by means of a rack and pinion, L″L″, at each end of the revolving-rod, L. A mortise through the guide receives the lever and allows it a free motion to a limited extent. The lever is thus maintained in a position always nearly horizontal, while it remains free to oscillate on its fulcrum in either direction, as the strain or the weights may preponderate. The supports of the small lever are attached to the guide, G.G′, so that it ascends or descends with the middle lever.

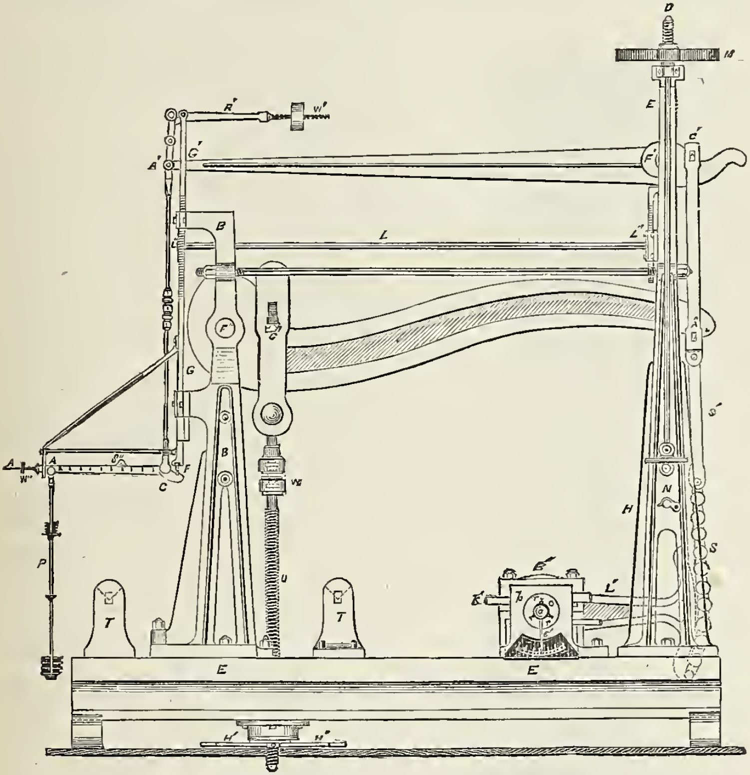


FIG. 60.—Testing-machine. (Side elevation).

405. MULTIPLICATION OF POWER.—Fifty turns of the hand-crank, I, gives one turn to the horizontal wheel, M, at the top of the frame, E.

A screw nut is cut in the axis of this wheel, through which the vertical screw, D, passes. This wheel, when turned, elevates or depresses the screw, and sets in motion all the movable parts of the machine.

Two turns of this horizontal wheel move the vertical screw one inch, and this requires one hundred turns of the hand-crank, and gives one-tenth of an inch of motion to the knife edge of the main lever, where the strain on the samole is exerted.

The crank to which the power is first communicated moves a distance of seventy-two inches at each turn, and seventy-two hundred inches for each tenth of an inch of motion at the straining-point of the machine. Such a great power is needed only when heavy strains are exerted.

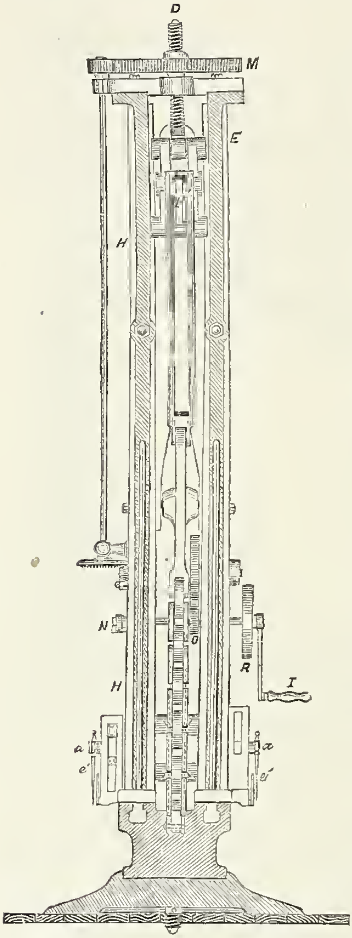


FIG. 61.—Testing-machine. (End Elevation.)

When beginning a strain, or when lowering down the levers, the small pinion, o, on the crank shaft is thrown out of gear, by lifting the latch, N, and shifting the shaft; thus bringing into action the large pinion, R, which change of gearing gives a velocity nine times as great to all the movable parts of the machine, but the force exerted will be only one-ninth as great as before.

406. THE TORSION LEVER, L′, works between two heavy pillow-blocks, B′, fitted on the bed-frame, E, and within these pillow-blocks the journals of the torsion-lever revolve. Its axle has a cylindrical aperture concentric with its axis. This lever is set in motion by a chain, S, which connects directly with the middle lever through the strap, S.

407. PEDESTALS FOR TRANSVERSE STRAINS.—Two hollow movable pedestals, TT, are attached to the bed-frame, E, fitted with steel knife-edges, which serve as points of support for the test-bars.

Horizontal braces secure the stability of the frame-work of the machine.

408. WORKING THE MACHINE.—ADJUSTMENTS.—All the working knife-edges, and the seats on which they bear, are made of hardened cast-steel; the other principal parts of cast-iron.

Before beginning a test, it is necessary to see that all the knife-edges are properly adjusted, and that the vertical screw through the horizontal wheel on the top of the machine is run down its full length, to obtain all its scope.

To adjust the equilibrium, there is a small horizontal rod, R′, with a weight working upon it, which is attached to the upper end of the slide, G.G′, supporting the small lever.

Before the specimen is secured in its place, the machine must be accurately balanced by moving the weight, W′, of the adjusting-rod either in or out, as it may require. The final and accurate adjustment is made with the small brass weight, W″, attached to the end of the small lever.

409. The Sample Holders in all forms of strain, excepting that of torsion, are attached at one end to a stirrup, C″, on the main lever, and at the other to the bed-frame. *To apply the strain* to the specimen, the hand-crank, I, is turned with regularity in the direction which raises the screw, and sets in motion all the movable parts of the instrument.

The slide on the small lever, S″, is moved gradually, just keeping its equipoise; as the strain is increased, weights are supplied at P, in such manner as will keep the lever evenly balanced, so that the force applied at the instant of breaking may be accurately determined by counting the weights then on the platforms.

410. Tensile Strain.—After the density of a specimen has been ascertained, and before it is inserted in the holders, its smallest diameter is accurately measured and recorded. This is done by sliding-calipers, an instrument provided with a Venier, which measures hundredths of an inch, and thousandths of an inch may be readily determined by a practiced eye.

The specimen is now fitted between the holders used for the purpose; one of which is attached to the shackle hung on the stirrup of the main lever; the screw, U, connecting with the bed-frame, is then run up by the handles, H′, underneath, until the specimen can be caught between the holders that fit on its upper end.

After the sample is secured between the holders, the screw is run down until a sufficient strain is obtained, to keep them in place. Then proceed with the test.

The breaking-weight is divided by the area of the smallest diameter of the specimen, and the quotient gives the tenacity, or the strength per square-inch.

That is, let a represent the breaking weight, b the area, and x the tenacity per square-inch.

$$b : 1 \text{ sq. in.} = a : x.$$

Examples.

Sample No. 4. H. Logs.
Breaking-weight, 50500.................4.7032914
Diameter, 1.25 in.; area (πr^2), 1.22719 in..0.0889099

Tenacity per sq. in., 41151 lbs.............4.6143815

411. The following table contains the area and the logarithms for all the variations of diameter likely to occur in tensile samples:

Diam.	Area.	Logs.	Diam.	Area.	Logs.	Diam.	Area.	Logs.
1.190	1.11220	.0461839	1.204	1.13853	.0563429	1.297	1.32120	.1209698
1.191	1.11407	.0469135	1.205	1.14042	.0570639	1.298	1.32324	.1216393
1.192	1.11594	.0476425	1.206	1.14231	.0577845	1.299	1.32528	.1223083
1.193	1.11782	.0483707	1.207	1.14421	.0585045	1.300	1.32732	.1229767
1.194	1 11969	.0490985	1.208	1.14610	.0592237	1.301	1.32937	.1236446
1.195	1.12157	.0498257	1.209	1.14800	.0599425	1.302	1.33141	.1243120
1.196	1.12345	.0505523	1.210	1.14990	.0606607	1 303	1.33346	.1249788
1.197	1.12533	.0512783	1.290	1.30398	.1162693	1.304	1.33550	.1256451
1.198	1.12721	.0520035	1.291	1.30901	.1169423	1.305	1.33755	.1263109
1.199	1.12909	.0527283	1.292	1.31104	.1176148	1.306	1.33960	.1269763
1.200	1.13097	.0534523	1.293	1.31307	.1182868	1.307	1.34165	.1276411
1.201	1.13286	.0541759	1.294	1.31510	.1189583	1.308	1.34370	.1283033
1.202	1.13475	.0548989	1.295	1.31713	.1196293	1.309	1.34576	.1289691
1.203	1.13664	.0556211	1·296	1.31617	.1202998	1.310	1.34782	.1296325

412. Transverse Strain.—For determining the transverse strength of metals, a specimen-bar is taken two or three feet long, and about two inches square. It is prepared for the test with a slight dressing with the file or grind-stone, on one of its faces near each end, in order that the bar may bear more evenly against the supports when under the strain. The middle of the bar—the part where the fracture occurs—is dressed in like manner on each of its four faces, in order that its breadth and depth in this part may be accurately measured.

413. To Place the Bar.—Run the screw, U, down nearly level with the bed-frame, out of the way; slide the pedestals to the proper distance on either side, to accommodate the length of the specimen. Suspend the long link, S (Fig. 62), from the same shackle used in the tensile-strain, and pass the bar through the pedestals and the long link, so that it rests in the middle of its length on the knife-edge in the bottom of the link. The latter is then drawn upward until the ends of the bar bear

firmly against the knife-edge supports in the pedestals, which must be at equal distances from the link.

414. THE DEFLECTION.—The breaking-force is applied on the under side of the bar, in the middle, and forces it upwards against the supports at the ends.

The deflection is measured by inserting a graduated, tapered metallic scale between the upper surface of the bed-frame and the under side of the bar-holder, directly beneath the forcing-line of the latter, against the centre of the bar. The space enlarges as the bar bends, and the graduated wedge measures minutely the deflection of the bar at any stage of its progress.

A record is kept of the "*deflection*" and "*set,*" which shows the quantity of deflection and permanent set under a given pressure, which is designed to be near to, but somewhat less than, the minimum breaking-weight. Also of the "last deflection," which gives the amount of deflection under the pressure of the breaking-weight.

415. *The Unit of Strength* represents the weight in pounds required to break a bar one inch square, rigidly supported at one end; the weight being applied at a distance of one inch from the point of support. For square bars it is determined by the formula—

$\frac{l\,W}{4b\,d^2} = S$, the unit of strength.

l = the length between the supports.
W = the breaking-weight.
b = the breadth of the bar.
d = the depth of the bar.

The breadth and depth are accurately measured near the fracture; and, as the dimensions are irregular, it is proper to measure in three places for each; one measure to be taken in the middle of the bar, and the other two near the corners. The mean of the three measures to be taken as the true dimension. If the bar is defective, the results cannot, of course, be relied on.

EXAMPLE.

Proof Bar No. 484.	Logs.
$b = 1.969$ (mean of three measurements).........	0.2942457
$d = 1.9683$ (mean of 3) log. $0.2940913 \times 2 = d^2$...	0.5881826
	-0.8824283
$\frac{1}{4} l \times W = \frac{20}{4} \times 13900 = 69500$	4.8419848
Transverse strength = S = 9111 lbs...............	3.9595565

416. TORSIONAL STRAIN.—For determining the torsional strain, or the weight required to break by twisting, a specimen-bar is used, which is long enough to project beyond the journals of the torsion-lever, and receive the indices, *e′*, which are attached to its ends, *a*. The parts against which the holding-keys, k′, are pressed are made square. All the other parts are round.

The part between the keys is dressed to a true cylinder, the length of which should not be less than three diameters.

This length is necessary to allow a full development of the fracture to occur within the dressed part of the specimen. The distance between the keys is nineteen inches.

417. *To Place the Specimen.*—The bar passes through the axle of the torsion-lever.

One end is held firmly to the pillow-block of the bed-frame, and the other to the journal of the torsion-lever, L′, by means of keys, K′. The axis of the bar is made to coincide with the axis of the torsion-lever, by passing its ends through concentric rings, *r*, inserted in recesses provided for the purpose, before the keys are fixed in their places. Indices, *e′*, are attached to the projecting ends of the bar and adjusted to the zero of the arc beneath, before the strain is commenced.

The diameter of the specimen is carefully measured before it is secured in the journal. Bring the keys up on the bottom, until the bar rests firmly upon them, then key up from the top to keep it firmly in its place. Connect the chain on the torsion-lever to the strap communicating with the middle lever, and proceed with the test.

When a bar is in the machine for torsion, the lever, L′, is placed at its lowest point, but sometimes the screw, D, ascends to its highest limit before the bar breaks. When this happens the lever is propped up, the chain is detached and shortened by removing its upper link; then, on its being again attached, the work is resumed and the strain extended until the bar breaks.

418. *Recording the Strain.*—In torsional strains the main lever of the testing-machine is inoperative. The recorded breaking-weight then is only two hundred times greater than the actual weights on the platforms, which is equal to one-tenth of the usual reading in other tests. But as the torsion-lever is thirty inches long from its axis to the point where the centre of the chain acts upon it, the weight as above ascertained is multiplied by thirty, and the product represents the strain exerted at a point one inch from the axis of the strained bar. In practice it is found more convenient to read off the weights

for torsion in the same manner as in other tests, and to multiply that reading by three.

419. *The Deflection.*—Although one end of the bar is firmly fixed, it will yield a little by its compression on the keys, and

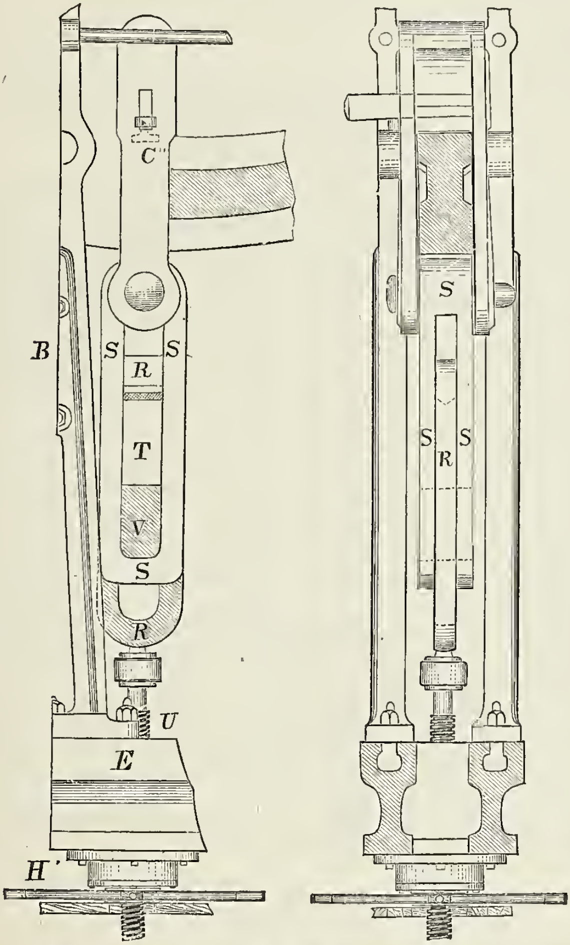


FIG. 62.—Stirrup for Holding Indenting Apparatus.

therefore its angular deflection is determined by the difference between the reading on the arcs.

The deflection of the bar is noted at each addition of a certain number of pounds of pressure; and at each addition of, say, five hundred or a thousand pounds, the bar is released from strain and the permanent set ascertained. The greatest angle of deflection and the breaking-weight are also recorded.

The torsional strength is

$$S = \frac{wr}{d^3},$$

in which

w = breaking-weight,
r = radius of torsion-lever,
d = diameter of specimens.

420. Crushing-force.—The samples submitted to the test of compression are small cylinders, the lengths of which are generally two and a half times their diameters. Bars of greater length than these diameters are liable to bend under the pressure before the fracture occurs; and if the length be less than two diameters, the fracture in its regular form may not be fully developed, and a portion of the sample may be pulverized or reduced to small grains. The ends of each sample are made perfectly parallel and perpendicular to the axis, so that all parts of the sample will be equally pressed.

421. *Placing the Specimen.*—Fig. 62 shows the form of the stirrup used in holding the instruments for *crushing*, *bursting*, and *indenting* samples when the straining force is applied. *S* is a stirrup attached at its upper end to the straining-stirrup, *C''*, on the main lever; and *R* is attached to the bed-frame by means of the screw *U*.

V is a block of iron upon which the sample may rest.

The samples or the instruments for holding them are inserted in the space, T.

422. *Recording the Compression.*—The dimensions of the sample are carefully measured before placing it. The depression or permanent set at every five thousand pounds, for instance, are then carefully noted. The breaking-weight is recorded as well as the angle of fracture of the specimen.

The strength per square inch will be

$$S = \frac{\text{weight}}{\text{area}}.$$

423. Indenting-force.—The comparative softness or hardness of metals is determined by the bulk of the cavities or indentations made by equal pressure; the softness being as the bulk directly, and the hardness as the bulk inversely.

424. *Indenting-tool.*—Of the different forms of cavity

made by indenting-tools, that of the pyramid is preferred, because of its simplicity and the ease with which its volume may be computed.

The instrument used for making indentations is represented by Fig. 63.

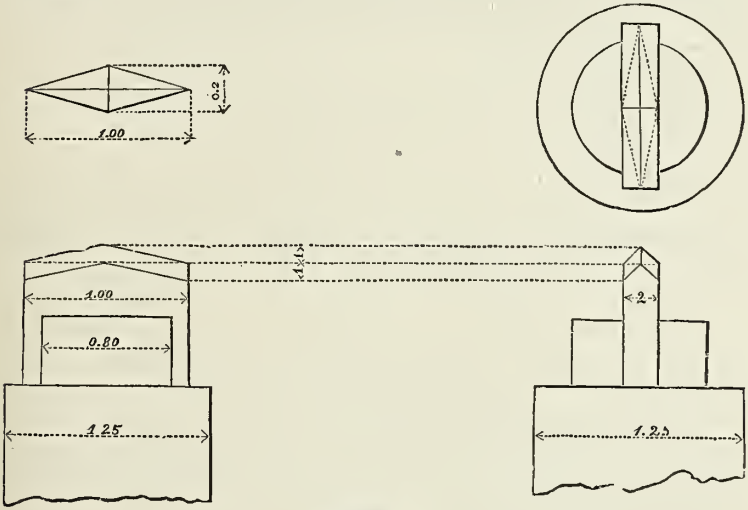


Fig. 63.

The indenting part of the tool is in the form of a pyramid, having a rhombus for its base, the diagonals of which are respectively one inch and two-tenths of an inch; the height of the pyramid one-tenth of an inch.

In late experiments the form of the pyramid has been changed and improved somewhat, by causing it to make a longer line, and mark minute differences more accurately.

425. *Standard of Comparison.*—The volume of an indentation made with this tool is taken as the measure of the work required to produce it, and is inversely proportional to the hardness of the specimen, that is (denoting by H the hardness of any specimen).

$$H = \frac{k}{v}, \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1.)$$

k denoting any convenient constant, and v the volume of the indentation corresponding to H.

It has been found by experiment that a pressure of 10,000 pounds on the base of the pyramid, makes an indentation, in the softest metals used in guns, about nine-tenths of an inch long.

The maximum indentation, one inch in length, of the instrument is therefore assumed as the unit of hardness; therefore, denoting by V the volume corresponding to an indentation one inch in length, we obtain from equation (1),

$$1 = \frac{K}{V} \text{ or } K = V;$$

and in general,

$$H = \frac{V}{v};$$

or, putting $l =$ the number of tenths of an inch in the length of any given indentation,

$$H = \frac{V}{v} = \frac{1000}{l^3};$$

since pyramids are to each other as the cubes of any similar dimensions.

A pressure of less than 10,000 will probably be found better suited to the purpose, with the improved tools. A better standard of comparison may be found in some metal of uniform density and hardness, easily obtainable in all places.

The silver coin of the country best fulfils these conditions. The volume of the cavity made in this, by the adopted unit of pressure, may be assumed as the unit of hardness; and this divided by the volume of the cavity in any sample tested, will denote the hardness of that sample as compared with that of silver coin.*

426. Errors of the Rodman Machine.—The errors incidental to the use of this machine are due to three causes:

1st. Weight of its different movable parts.

2d. Motion of the centres of gravity of the levers towards or from their fulcrums.

3d. Friction.

The First cause of error is avoided in practice by means of the adjusting-weights, already described.

The system is brought into perfect equilibrium, so that any increase of W will be balanced by a proportionate increase of P.

The Second cause of error is comparatively unimportant,

* Rodman.

because the levers AC and A′C′, are so adjusted as never to make a large angle with a horizontal line passing through the fulcrum, and in the case of the lever A″C″, which makes a larger angle, the shape is such as to bring the centre of gravity very near the centre of motion.

Let D denote the distance through which the centre of gravity moves.

a denote the distance of the centre of gravity from the centre of motion.

L denote the angle described by the lever during the breaking of a specimen.

In general the levers are so adjusted that the line connecting the centres of gravity and of motion is horizontal when the movement of the lever is half completed.

$$\therefore D = a \text{ versine } \tfrac{1}{2} L.$$

It is evident that one or both of these factors is very small in each case.

The Third cause of error is made as small as possible by the use of knife-edges and steel plates, and is practically inconsiderable.

The determination of the absolute breaking and other strains involve the elimination of errors due to friction, etc., but for obtaining the comparative strength of specimens, the machine is all that can be desired.

427. Modifications of the Machine.—This machine is arranged for short tensile specimens only, and as the power is at present applied, admits of only a very slight stretch, which is unsuited to the breaking of specimens giving elongations of several inches.

A change has therefore been tried in the lower fastening of the specimen, by which the power was applied at that point, through a screw and cogwheels, and this arrangement was found to answer the purpose in the most satisfactory manner.*

Another change was made in order to get a continuous increase in the weight upon the scale-beam, instead of adding one weight at a time as is generally done. This was accomplished by using a chain for a weight, which, being wound upon a reel, was readily reeled into the scale as fast as required to balance the strain upon the specimen. The principal advantage of this method is in working the *indicator*.

428. The Indicator.—In connection with the testing-machine it has been found desirable to have an instrument which would give a continuous curve representing the elonga-

* King.

tions and corresponding tensile-strains for specimens of various kinds, in order to arrive at the exact dynamical value of the metal.

429. An instrument has been devised for this purpose (Fig. 64). It consists of a brass frame, AB, supporting a vertical cylinder, C, revolved by the endless screw, S. This screw being turned by the tape, T, which draws around the pulley, P, as the weight, W, is wound along the scale-beam. When the chain was used as a weight, the cylinder revolved as the chain was paid into the scale.

INDICATOR
(for tensile strains and elongation.)

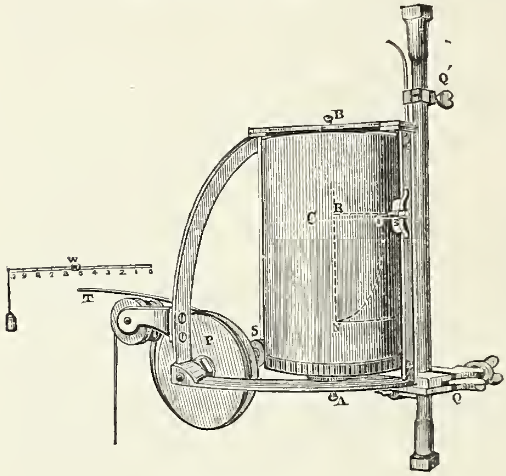


Fig. 64.

This arrangement causes the cylinder to revolve as the weight or strain upon the specimen increases or diminishes, and if the marker, M, remains stationary, it will describe a horizontal circle upon the paper with which the cylinder is covered. Starting from the zero-point of the scale, the length of any arc of the circle will represent the strain upon the specimen at the instant the marker has arrived at the end of the arc.

430. If now the elongation of a given portion of the specimen carries the marker in a direction parallel to the axis of the cylinder, it is clear that the curve, NO, described upon the paper, will accurately and continuously represent the relation between the elongation of the specimen and the corresponding strain upon it. In order to move the marker in this manner, it is connected with one end of the specimen by the clamp, Q′, which fits into a centre-punch-mark on the specimen, while the frame and cylinder are attached to the other end, Q, of the specimen in a similar manner.

431. The portion of the specimen between the two centre-

punch-marks is evidently the only portion whose elongation will move the marker along the paper, and the space passed over by the marker divided by the original length of this portion, will give the elongation per unit of length of the specimen, or the per cent. of elongation; and the area bounded by the curve, NO, and the co-ordinates, NR and RO, measures the *work* of breaking the specimen.

432. Fig. 65 shows examples of the record made by the *Indicator*. It will be seen that in the specimens indicated, the

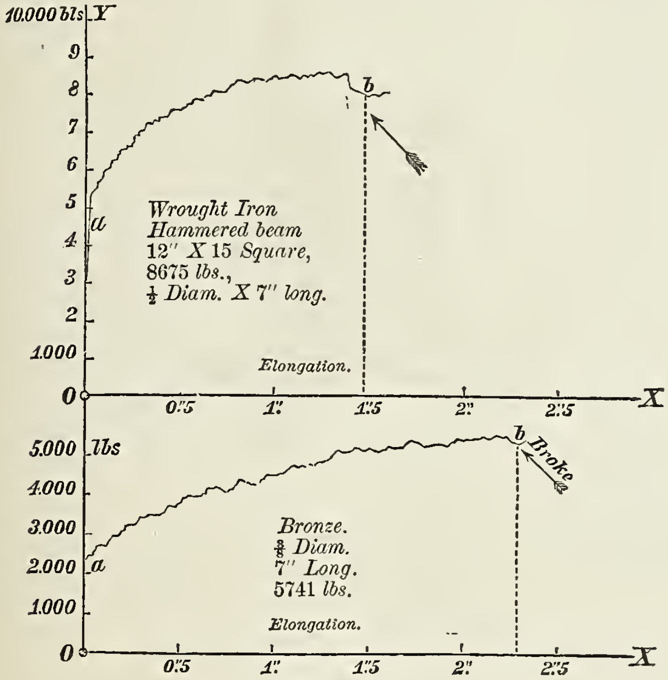


Fig. 65.

first part of the elongation gives a very slight curve, which shows that the elongation increases rather more rapidly than the strain upon the specimen.

This part of the curve extends from the origin to the point *a*. When the specimen begins to elongate freely, and there is a well-defined change in the rate of increase, the point *a* probably coincides with the elastic limit.

The strain increases as the elongation continues almost up to the breaking-point, *b*. This shows that the tenacity of metal, which has been stretched beyond the elastic limit, is not entirely destroyed, as is commonly believed, but the work of the rupture has but just commenced.

433. Just before rupture takes place, in case of good wrought-iron, the specimen is observed to suddenly contract at some point, sometimes at two, and very rarely at a greater number; strain slightly diminishing at the instant, and the specimen breaks generally with a sudden snap, though very soft iron sometimes breaks so quietly as not to be heard at all.

434. The effect of the elongation of specimens in this manner is to change the smooth surface of the specimen to a rough and scaly appearance, and in case of bronze the specimen becomes so irregular as to resemble a roll of putty flattened in various directions between the fingers. The elongation of steel develops innumerable fine cracks nearly perpendicular to the surface.

435. In breaking a specimen a second or third time, it would seem that the metal must get weaker, especially since the sudden breaking produces a violent shock; but on the contrary, the specimen evidently breaks at the weakest point, and the shock and previous stretching have not been sufficient to reduce the strength of the next weakest part of the specimen below that of the first one. It is sometimes found that even the third breaking requires a greater strain than the second.

436. Much labor in turning out specimens may be saved by the use of sockets with conical wedges (Fig. 66), which have been devised for the purpose of taking hold of the middle portion of broken specimens, and breaking them a second time. It will be seen that by cutting out the specimen barely large enough to turn up to the required diameter, a great saving may be effected over the usual method which requires the ends of the specimen to be quite large, while the middle portion, for nearly the whole length, has to be turned down to a much smaller diameter.

Quite a number of specimen of each kind should, if possible, be tested under as nearly identical circumstances as practicable, in order to get reliable mean results.

437. The usual form of specimens for tensile strain is such, that unless the weakest point happens to occur at the smallest section of the specimen, the fractured area will be larger than the measured section. By using longer cylindical specimens this source of error will be avoided, in all but exceptional cases, arising from flaws or other defects. Besides, the usual or standard form of specimen admits of transverse strains due to

the unequal bearing of the ends in the sockets of the testing-machine. This defect is greatly improved by using longer specimens.

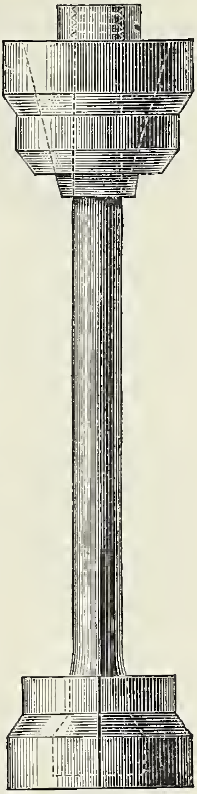


Fig. 66.

438. The simple measure of the strain required to break a piece of metal, without regard to the elongation produced before rupture takes place, is not a measure of what occurs in practice; for when a bar of iron is broken, a certain space is passed over by the breaking-force in separating the fibres, and as this space bears no analogy whatever to the tensile strength of the metal, it must come in as an independent factor. For example, the metal of cannon is stretched at every discharge; and whenever metal is subject to a variable strain, there must be a corresponding change of length. These elongations may be very small in amount; so small, in fact, as to be inappreciable in ordinary measurements, but it is no less certain that they exist.

439. RIEHLE'S TESTING-MACHINE.—This is a good example of a horizontal testing-machine adapted to testing rope, chain, wire, bar or plate iron, etc. The iron frame, CC (Fig. 67), and the timbers which support the iron guides, SS, are all firmly secured to a solid foundation of masonry.

440. The Levers.—Enclosed in the frame, CC, is a heavy intermediate lever, A, one fulcrum of which bears against a smooth steel surface composing a part of the frame. The lower fulcrum, D, presses against the clevis, E, which connects directly with the clamps holding one end of the test specimen. This lever is suspended at the larger end by clevises, F, swinging from the iron frame, C, and at the smaller end by a link or rod connecting with the *differential lever*, or scale-beam, G.

441. Recording the Strain.—On this beam is an ordinary weight-dish, H, upon which standard weights are placed for recording the strain to which the specimen is being subjected. A weight of one pound on the weight-dish indicates a strain of one thousand pounds on the specimen under trial.

442. Application of Power.—At the other end of this

machine is placed a hydraulic pump and jack, I; the cross-head, L, carrying the clamps for one end of the specimen, being attached to this by the bolts MM. The whole arrangement

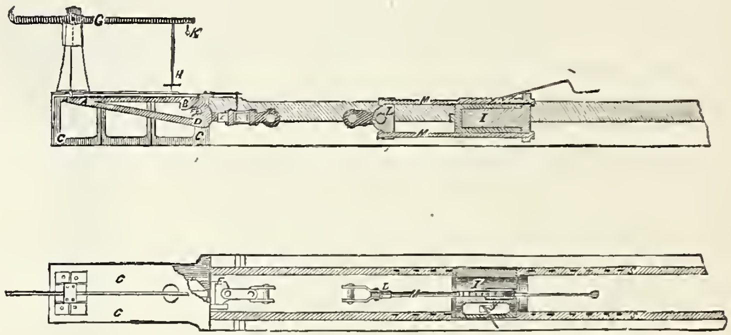


FIG 67.—Riehlé Testing-machine.

travels along a railway, SS, on low, strong wheels, and may be secured in any position, to accommodate the length of the specimen, by keys dropping into slots on the railway. The power is applied to the jack, I, by the pump, J, while the scale-beam is kept horizontal by the use of the weights; its equipoise being indicated by a pointer attached to the centre fulcrum of the beam.

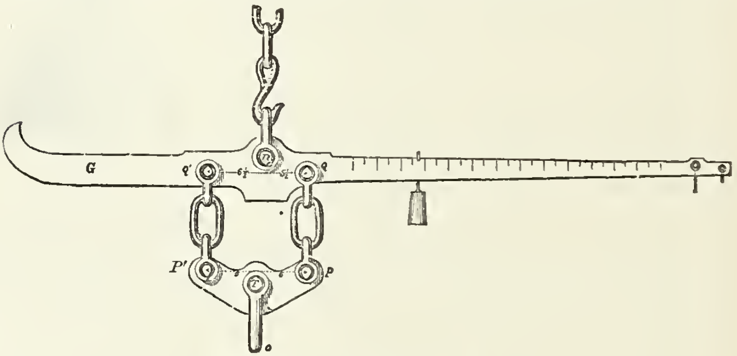


FIG. 68.—Differential Lever.

443. ADJUSTMENT.—When the specimen is in position, the lever and beam must be balanced by means of the balance-cup, K, hanging from the extreme end of the scale-beam. All the knife-edge bearings and fulcrums are made of steel, and are

very strong and true. As each part swings perfectly free, there is comparatively no friction, and the strain on a specimen can be weighed to within a few pounds.

444. THE DIFFERENTIAL LEVER.—Fig. 68 represents the differential lever and scale-beam used in this instrument.

The link O is connected with the intermediate lever, A (Fig. 67). If a weight of one hundred pounds be suspended from the link O, one half, or fifty pounds, will be suspended by the bearing P, and fifty pounds by the bearing P′. These weights being transmitted through links to the bearings Q and Q′, P and P′ are equidistant from the bearing T, while Q and Q′ are at unequal distances from the centre bearing or fulcrum, R. If the distance Q′ R be $6\frac{1}{2}$ inches, and Q R be $5\frac{1}{2}$ inches, and the weight at Q and Q′ 50 pounds, then the moment on the side Q will be $50 \times 5\frac{1}{2} = 275$; and the moment on the side Q′ will be $50 \times 6\frac{1}{2} = 325$. The difference of these moments, or $325 - 275 = 50$, will be the unbalanced moment; and if a weight of 5 pounds be suspended on the scale-beam at a distance of 10 inches from the fulcrum, R, it will counter-balance the extra moment on the side Q′. The vertical planes passing through R and T are one-half inch apart; therefore if a one-hundred-pound weight be suspended at one-half inch from R, acting as a simple lever, it will be under precisely the same conditions as the differential lever with the above dimensions.*

Section III.—Fabrication.

445. FABRICATION OF CAST-IRON GUNS.—The details of the casting of a XV-inch gun, as practiced at the Fort Pitt Foundry, Pittsburgh, Pa., will be taken as an example. †

446. THE FURNACES.—Two reverberatory air furnaces are used for melting the iron of which the gun is made, the draught being produced by high chimneys instead of by a blast. Fig. 69 represents the Fort Pitt Air Furnace, the peculiarity being that, as the iron melts, it runs backwards toward the bridge-wall, C; the crown of the furnace being so constructed as to cause the flame to impinge against the surface of the pool of melted metal, while at its greatest temperature; thus it is melted without coming in direct contact with the carbon, as in the blast-

* See a description of Kirkaldy's machines in the *London Mechanics' Magazine* of the 9th March, 1866.

† Commdr. R. F. Bradford, U. S. Navy.—Navy Ordnance Papers, No. 3.

furnace — where the fuel and fire are mixed together. Bituminous coal is used in these furnaces.

447. In the Fig. 69, A represents the metal-chamber, being

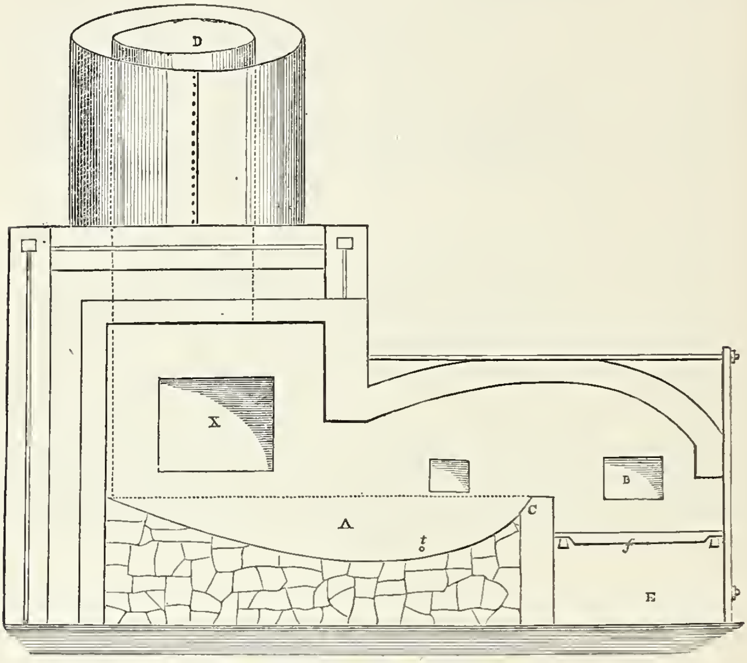


Fig. 69.—Sectional Elevation.

that part of the furnace where the iron, for what is termed a "*heat*," is placed. The bed of this chamber is first prepared by covering it with a layer of sand, which is hardened down, giving it at the same time the desired curve; then boards are laid, upon which the pigs of iron to be melted (or charged) are piled; B represents the fuel chamber, or fireplace, the flame passing over the bridge-wall, C, and through the metal chamber on its way to the chimney, D; *t* is the tap-hole; X, the charging-door, made of fire-brick bound together by iron bands; E is the ash-pit; and *f*, the grate-bars. The dotted line represents the surface of the metal when "*down*," or melted.

448. In the charge used for a XV-inch gun, the greatest depth of metal, when down, is about nine inches, exposing about one hundred square feet of surface to the flame.

It is very necessary, in casting a lot of guns, to have the bed of the furnace prepared, in every instance, the same as with the standard gun, as the treatment of a given charge of iron may be varied by the manner of dressing the bed of the furnace. By exposing the same amount of iron in a broad, shallow pool, it is more effectually brought under the influence of the flame than when collected in a narrow, deep pool.

449. *Charging the Furnaces.*—In charging the furnace for a "*heat*," the different grades of iron which have been decided upon are weighed and piled, in the proper proportions, in the metal-chamber of the furnace, always having the second-fusion iron nearest the fire.

450. FUSIONS.—The iron, as it comes from the smelting-furnace, is termed "*raw pig*," and is a first fusion. The second-fusion iron (as understood by founders) is produced by a combination of raw pig and second-fusion, melted in an ordinary air-furnace, and then run out. These pigs are usually of a different shape than the raw pig, but to prevent confusion, and at the same time to distinguish different second-fusion irons one from another, each should be distinctly marked and piled separately.

451. The object of using a second-fusion iron in a casting is to obtain greater density than can be produced from the raw pig alone; it also increases the tensile strength. (Art. 349.)

452. THE CHARGE.—In casting the XV-inch gun, the furnaces were each charged as follows:

Bloomfield raw pig	21,143	lbs.
Bloomfield second fusion (red-dot)	13,214	"
Bloomfield second fusion (red-cross)	2,643	"
	37,000	"
Total in both furnaces	74,000	"

The second fusion, marked "red-dot," consisted of the following combinations, viz.:

Bloomfield raw pig	50,000	lbs.
Bloomfield second fusion	19,575	"
Run into pigs and marked "red-dot"	69,575	"

The proportions of the other grade, marked "red-cross," are as follows, viz.:

Bloomfield raw pig	29,410	lbs.
Bloomfield second fusion	32,590	"
Run into pigs and marked "red-cross"	62,000	"

The second-fusion iron used in these combinations is produced by melting two parts of raw pig with one of second fusion.

453. MOLDING, in general terms, is the process by which a cavity of the form of the gun is obtained, by embedding a model in sand and then withdrawing it.

454. *Molding-composition.*—The sand most used for this purpose is a kind of loam, which contains a sufficient quantity of clay to render it moderately cohesive when damp. Sand, possessing all the qualities required for molding, is seldom, if ever, found in a state of nature; but when the requisite qualities are known the materials may be selected, and an artificial composition produced without difficulty. The sand should be principally of silex, very refractory, and of the kind commonly called *sharp-sand.* When not sufficiently refractory, the sand is vitrified by the high temperature of the melted metal, and protuberances are found upon the casting which are not easily removed.

455. The method of preparing the molding-composition artificially, varies according to the kind of casting for which it is to be used. In preparing it for cannon, great care is taken to introduce the exact quantity of clay required. When too little is used, the composition is not sufficiently adhesive; when too much is used, the mold is injured by contraction in drying. The sand is first carefully sifted, then properly mixed and moistened with water in which clay has been stirred; the composition is considered sufficiently adhesive when it will retain its form after having been taken in a moist state and squeezed in the hand.

456. The same composition may be repeatedly used for molding, but as the adhesive property of the clay is destroyed by the heat to which it is exposed in casting, more clay must be added every time, in the same manner as when the composition is first formed.

457. MODELS.—The wooden model is technically called the *pattern.*

Models for casting should be made of one or several pieces, according to the form of the mold required. When the form is such that the whole model can be withdrawn from the sand at once, without injuring the mold, a single piece will suffice; but generally the model is composed of several pieces, so fitted that they can be put together in succession as the molding progresses, and finally taken apart and removed by piecemeal when the molding is complete.

458. THE FLASK.—The mold is formed in a case of cast-iron, called a *flask,* consisting of several pieces, each of which has

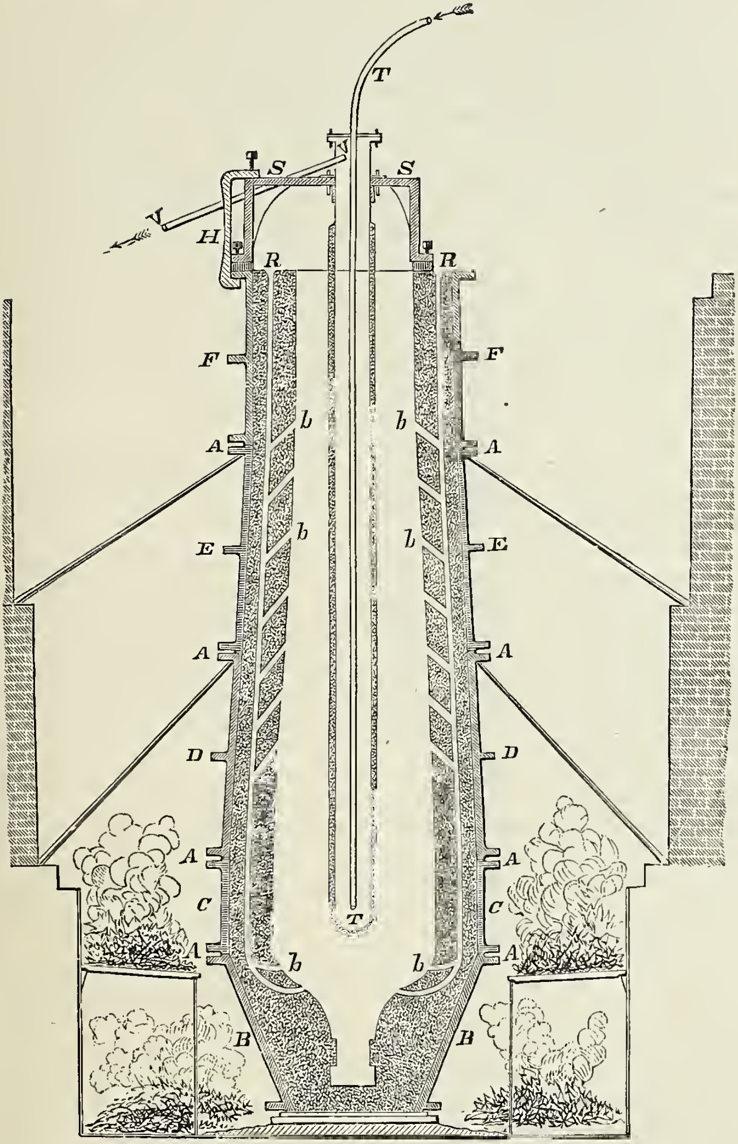


FIG. 70.—Circular Flask in Pit.

flanges perforated with holes for screw-bolts and nuts, to unite the parts firmly.

In casting the XV-inch gun, a circular flask (Fig. 70) is used, consisting of five upright sections, secured together by clamps fitting over flanges, AAA, at either end of the sections; its thickness is one inch, and it is pierced with holes. (Art. 481).

459. Divisions of the Flask.—The breech, or lower section, BB, is made of sufficient length to cast the base of breech, cascabel, and square knob; the next above, CC, is twenty-five inches in length and cylindrical, being the part which embraces the cylinder of the gun; the next is the trunnion-sections, DD, fitted with trunnion-boxes having movable plates on their ends, that the trunnion pattern may be placed and removed after the mold is finished; then there are two sections above this, EE and FF, the upper being about three feet longer than the required length of the gun, to admit of a "*sinking-head*."

The entire length of the flask is twenty feet.

460. Process of Molding.—The pattern is in five sections, each slightly tapered, that the mold might be uninjured in its withdrawal. The average thickness of sand forming the mold is about eight inches.

461. In making the mold, the lower section is placed upon a plate of iron in an upright position; the pattern being introduced and centred, the space between the pattern and the flask is then filled with molding-sand, using thin layers, which are rammed uniformly until the whole of that section is complete. The patterns for the "runners," RR, and their branches, b, b, b, are introduced as the work progresses; the latter, being tapered, are easily removed.

462. After the mold for the breech, or lower section, is finished, the next section of the flask is placed upon it and secured, the pattern for which is introduced, and, being fitted with dowels, held accurately in place. The molding is continued with this section as with the first, and when completed is lifted off, care being taken not to break the mold (the pattern being left in the mold).

463. The third or trunnion section is then placed upon the second, the model being adjusted as with the second, and the molding is continued in this way, until the whole is completed, thus insuring a perfect mold throughout, free from irregularities at the junction of the sections.

464. The patterns are then withdrawn, and the molds finished and smoothed about the lock-lugs, sight-masses, and side-gates, after which it is placed in the drying-oven, the two lower

sections being clamped together, the others singly; and when thoroughly dry, withdrawn.

465. A wash composed of pulverized coke-cinders, molasses, and water is then applied; this dries quickly, and produces a smooth, hard surface, thus preventing the molten metal from entering into the sand of the mold, and it insures a smooth, clean coating.

466. The Core-barrel.—The core-barrel (Fig. 71) consists of a water-tight iron tube, AD, about fifteen feet long, and

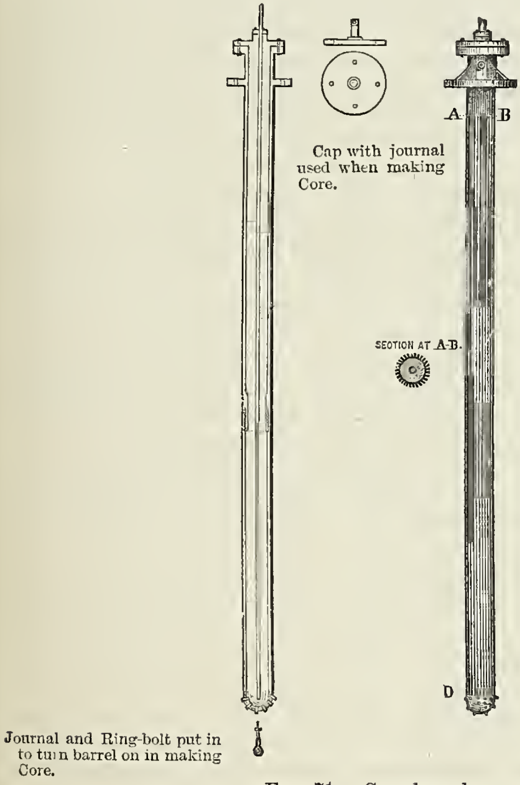


Fig. 71.—Core-barrel.

three-fourths of an inch thick, its exterior diameter at the head being twelve inches, and tapering one-fourth of an inch, at the lower extremity, to facilitate its withdrawal after the cast.

It is rounded at its lower end, D, and fluted throughout the cylindrical part, to allow the escape of gas generated by the burning of the composition with which it is covered.

467. Preparing the Core.—To prepare the core for casting, journals (Fig. 71) are first fitted, at either extremity of the barrel; it is then placed in a horizontal position upon an iron truck, being supported by the journals, which rest in bearings. While so supported it is easily turned by means of a crank attached to one of the journals, and is first wrapped or served with white-hemp stuff (18-thread), covering that portion of the barrel which comes in contact with the molten iron.

468. Over this a coating of molding-composition is applied quite wet, which is wrapped with twine, to insure its adhering. When about half dry, the outer or last layer of composition is applied, which, being made quite sticky, adheres readily. Great care is taken to have the surface of the core perfectly smooth, and the composition of uniform thickness. The diameter of the core-barrel for a XV-inch gun, when complete, is 13.75 inches at the top, and slightly tapered at the bottom.

469. When ready, the truck supporting the core-barrel is rolled into the drying-oven, and when perfectly dry removed; the usual time required being eighteen hours. The composition then receives a coating of coke-wash, when it is again placed in the oven, where it remains until thoroughly dry.

Upon its final removal the journals at either extremity are removed, being replaced by the regular cap on top, and a tight-fitting screw-plug at the bottom, which is covered with molding-composition, and dried by a fire built under it.

470. The Pit.—The pit (Fig. 70) is circular in form, nineteen feet deep, and twelve feet in diameter; the walls are of brick, and the bottom, an iron tank of one-half inch sheet-iron, extending upwards eight feet.

The mouth of the pit is provided with iron covers, made to fit closely to prevent escaping of heat from the fire built around the flask.

471. Placing the Flask.—The mold being thoroughly dry, the two lower sections, clamped together, are lowered and secured in an upright position in the centre of the pit—a layer of sand having been previously placed in the bottom, for the flask to rest upon; the other sections are lowered singly, and secured in their places, the whole being braced from the sides of the pit to retain it in a vertical position.

472. Cranes.—Cranes are employed for moving cannon, molds, and other heavy masses about a foundry. They are fitted with cog-wheel gearing to obtain power at the expense of time, and are often worked by steam. Care must be taken

to give great strength to this machine, and to cause its motion to be easy on its pivot. When properly adjusted a weight may be lifted and transported from one point to another, anywhere within the limits of the circle described by the arm.

473. Adjusting the Core.—The core is then lowered into the mold of the gun. To centre and secure the core-barrel in position it is necessary to have a frame, usually termed a "*spider*," to support and hold rigidly in place the core when properly centred.

The spider, SS (Fig. 70), is of cast-iron, about two and one-half feet high, having three legs, each of which having a projection at the bottom, fitted with an adjustable screw, which rests upon the upper flange of the flask; there is also a funnel or sleeve fitted in the central part of the top, through which the core-barrel passes and fits closely, holding it firmly, so that any movement of the frame will produce a change in the position of the core.

474. *The Gauge*, for centering the core, consists of a long, wooden rod, on the end of which a piece of board is fixed at right-angles, and on this board a light is placed.

The length of this projecting board, previously determined, is the distance the core should be from the mold when in the centre.

Having adjusted the core in the mold, by means of the screws fitted in the legs of the spider, it is secured firmly by clamps, H (Fig. 70), made to fit over the top of the frame and under the flange of the flask.

475. Melting down the Charge.—The mold and core-barrel being in readiness, and the furnaces charged, the fires are started and regulated so that the iron will be "*down*" in both furnaces at about the same time.

Particular attention is paid to the manner of firing, that it be uniform and steady; also that the fires be kept clean to produce not only the best, but uniform, results.

The length of time required to obtain complete fusion of the charge depends in a great measure upon the state of the atmosphere, etc., being from five to eight hours.

476. When nearly "*down*" it is necessary to work or puddle it, that any lumps or balls of unmelted iron may be brought in contact with the flame. This is done by inserting long iron rods or green saplings in the air-holes of the metal-chamber. Saplings are preferred, as the steam generated from the sap in the wood causes the molten iron in the pool to boil, and the more dense iron at the bottom is mixed with that of the surface, while many of the impurities are dispelled at the same time.

477. When the charge is "down" specimens are taken out to ascertain if the iron is in proper condition, or sufficiently "*high*" (Art. 351); that is, sufficiently decarbonized; these specimens are run in dry-sand molds, and are about six inches in length, varying in size from one-quarter of an inch to one inch square. When cold they are broken, and the appearance of the fracture indicates whether the iron is sufficiently "*high*" (Art. 356). The three-quarters of an inch specimen is required to be well mottled.

478. As the density and tensile strength of the iron depends in a great measure upon the "highness" to which it is brought, extreme care is required in this operation. Where the first specimens proved are unsatisfactory, the iron is kept in fusion still longer, during which time it is puddled with green-poles.

479. TAPPING THE FURNACE.—When everything is in readiness the furnaces are tapped, and the molten metal conducted by runners or troughs coated with fire-clay directly to the side-gates of the mold, RR. It flows into these and down to the bottom, entering the mold by branch-gates, b, b, b, at intervals of one foot apart from bottom to muzzle.

The branch-gates are cut so that the metal will enter the mold in a direction toward the axis, upward, care being taken to keep the molten iron after it enters the mold well stirred with long poles to prevent *scoria* from entering the trunnion-holes, and also to assist in mixing the metals from the different furnaces.

480. When the mold is nearly full the tap-holes are stopped, and the surface of the metal in the gun-head covered by a layer of pulverized charcoal, to prevent its chilling. The time of filling the mold is about fourteen minutes.

The surplus iron remaining in the furnaces is run into pigs, but is not used again for gun-metal.

481. HEATING THE PIT.—During the casting, the gas which is generated and passed out through the holes in the flask is ignited by dropping small quantities of molten metal into the pit, and as soon after the "cast" as possible, a fire is built in the pit, about the bottom of the flask—wood and bituminous coal being used in sufficient quantities to burn four or five days; the mouth of the pit being covered, after the mass is thoroughly ignited.

482. COOLING THE CASTING.—The water for cooling is taken from a hydrant, where the supply is constant and uniform, the connections being made by rubber hose. It is conducted to the bottom of the core-barrel by means of a copper tube, one and a half inches in diameter, TT (Fig. 70). This tube passes through

a water-tight joint in the centre of the cap, and extends to within a few inches of the bottom of the barrel; being open at its lower end, the water passes out and ascends through the annular space between the tubes, and is discharged from the core-barrel at a point above the casting, V.

483. The water for cooling the core is started before the furnaces are tapped, and allowed to run through the barrel, and off by the discharge-pipe, V, V, to ascertain if every part is perfectly tight; it continues thus to circulate until the core is removed, at about the rate of forty gallons per minute.

484. *Withdrawing the Core-barrel.*—This is done about eighteen hours after the casting, as soon as the metal becomes sufficiently cool to permit of its removal. The withdrawal causes no delay or trouble, as the rope with which it is wrapped is consumed, and therefore leaves the barrel detached from the composition surrounding it, the latter adhering to the bore of the gun.

485. *Cooling by air.*—After the withdrawal of the core-barrel the cooling is continued by forcing a continuous stream of air into the cavity thus left, by means of a rotary blower, driven by a small steam-engine, the air being conducted from the blower to the gun through an eight-inch sheet-iron pipe, which is introduced into the bore and to within one calibre of the bottom.

486. A record of the rate of cooling is kept by noting at regular intervals of time the temperature of the water or air on entering and leaving the core. When the temperature of the air in the bore is nearly down to that of the outside atmosphere, the blower is stopped, and the pipe removed.

Time of Cooling.—The time of cooling is about eight days.

For XV-inch guns it usually varies from seven to nine days, depending mainly upon the temperature of the air and the speed of the blower.

487. Removing the Casting.—The gun is hoisted from the *pit* ten days from the time of casting. Preparations for removing the flask commence the day before.

Transporting-lugs are cast on the sinking-head, to which slings are attached for hoisting and landing the casting in the foundry, where all irregularities are chipped off, and the surface thoroughly cleaned of sand or foreign substances, and prepared for the lathe.

Weight of rough casting, including sinking-head, etc.	66,000 lbs.
Weight of rough gun	61,000 "
Weight of finished gun	43,000 "

488. Condition of the Casting.—This mode of casting, by

means of side-gates, is resorted to in order to preserve the form of the mold. If the metal was conducted into the upper opening of the mold itself, its fall upon the sides and bottom would injure their forms.

The condition of the casting in reference to smoothness depends in a great measure upon the state of the mold when the metal is run. It should be perfectly dry and hard, otherwise the metal mixes with the sand, and adheres in clumps, producing a rough and irregular casting, the cleaning of which is a difficult and laborious job.

489. HEADING-LATHE.—The casting is next placed in what is called the "*heading-lathe* (Fig. 72), where it is prepared for the *boring-lathe*. The cascabel-bearing, base of breech, and a

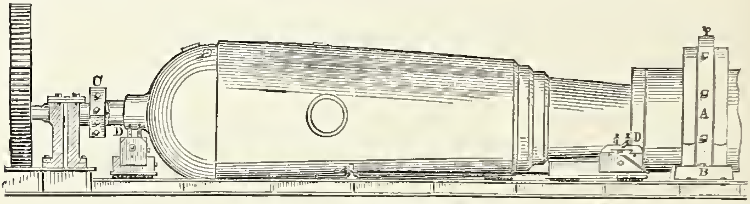


FIG. 72.—Heading-lathe.

section of the chase are all turned down to finished dimensions while in this lathe, as the chase and rounded part of the cascabel-knob form the bearings for the boring-lathe.

The cut at the muzzle, or place where the *sinking-head* is to be broken off, is also made in this lathe.

A (Fig. 72) represents the muzzle-ring with adjustable screws; B, the bearing in which the muzzle-ring revolves; C, the *chuck*, or mortise, into which the square knob of the cascabel is inserted and secured; D, the tools or cutters with rests.

The bearing in which the muzzle-ring revolves is a heavy casting, the bottom of which fits into grooves in the rack, and can be moved to or from the chuck, being adaptable to long or short guns.

490. ADJUSTMENT IN LATHE.—The gun is lowered into place, the square knob in rear of the cascabel fitting into the chuck, while the muzzle is introduced and projects several inches beyond the face of the muzzle-ring, in which position it is approximately centred, and held firmly in place by adjustable screws in the chuck and muzzle-ring.

491. The breech is adjusted by placing a sharp-pointed instrument in the rest, and bringing it in contact with the surface of the casting near the base-line, and while turning the gun—which is done by machinery—the screws in the chuck are moved until coincidence of the line around the gun is obtained.

492. At the muzzle a bar of iron is laid upon blocks, so that it shall be just inside the bore, and nearly in contact with its interior surface. As the gun turns, the distance between this point and the metal of the bore is observed, and equalized approximately, by the screws in the muzzle-ring bearing.

493. A wooden disk turned to fit the bore accurately, bearing a string attached to its centre, is then pushed to the bottom of the bore, and made to assume a position in a plane perpendicular to its axis. The string from the centre of the disk is long enough to reach some distance outside of the muzzle; the outer end being made fast to an upright the same height as the inner end or centre of disk; the string is now hauled perfectly taut, and the gun again turned, a square being placed upon blocks about one foot in front of the muzzle, close to the string; and as the gun revolves, the distance, if any, which the string deviates from the square is observed and corrected by again moving the screws in the muzzle-bearing.

494. When properly centred, the string will remain in the same position in the square and be the same distance from the interior surface of the gun, throughout an entire revolution, showing that the axis of the gun and lathe coincide.

With the hollow cast-gun it is necessary that it should be centred from the bore, as it sometimes happens that its axis does not coincide with the axis of the casting, which is one reason for casting them above the true size, to admit of being finished by the interior, or so that the axis of the cast bore shall coincide with that of the gun when turned.

495. Measuring the Casting.—The casting is next measured, taking diameters at the principal points, length of the casting, sinking-head, diameter and length of trunnions, distance from centre of trunnions to base-line, size of lock and sight-masses; also excess of metal over finished dimensions at points ten inches apart, commencing at forty-five inches ahead of base-line.

Should cavities or defects of any kind be discovered, their depth and full extent will be ascertained and noted, thus preventing useless subsequent labor in case they exceed the limits of toleration.

496. Turning down the Casting.—The gun being centred, the turning commences at the muzzle; this is done by placing a tool in the rest, which is brought in contact with the surface at the desired point, the metal being turned off as the gun revolves. The *rest*, or support which holds the tool, is arranged to move in two directions, one toward the gun, or at right angles to the axis of the lathe, by which means the depth of cut is

regulated, and the other in line parallel with the axis, that is, from muzzle to breech.

497. This last movement is effected by means of a *feed*, the motion being given by a fork attached to one of the trunnions, and at every revolution of the gun the rest is made to advance.

The first cut is usually an inch deep, commencing at the muzzle where the sinking-head is to be cut off and extending thirty inches towards the trunnions.

The second and third cuts are commenced at the same point as the first, and are about one and one-eighth of an inch deep; increasing as the tool advances in the gun, other cuts are made until the metal is reduced to the finishing diameter.

498. Removing the Sinking-head.—The cut at the muzzle, or the place where the "sinking-head" is to be broken off, is next made; its depth is usually about seven inches or to within three or four inches of the cast bore.

The gun is now taken from the lathe, and the "sinking-head" broken or wedged off, at which time the appearance of the metal at the fracture should be examined as to color, form, and size of crystals, texture, and whether sharp to the touch; it is also necessary to ascertain its degree of hardness, and how the metal works under the tools, in the different stages of its fabrication; all of which should be duly noted and form part of the record of the gun.

499. Cutting out Specimens.—Three specimens for density, tensile strength, etc., are taken from the face of the "sinking-head," next the muzzle, at points equally distant from each other around the circle and as near as possible to the outer crust of the casting (about one-fourth of an inch), the axis of the sample being parallel to the axis of the gun. These specimens are of the standard size, and are marked on each end with the letter H, to denote head-specimens; also number of gun from which taken, and the number of specimen. (Art. 380.)

500. Boring-lathe.—This lathe (Fig. 73) consists of the

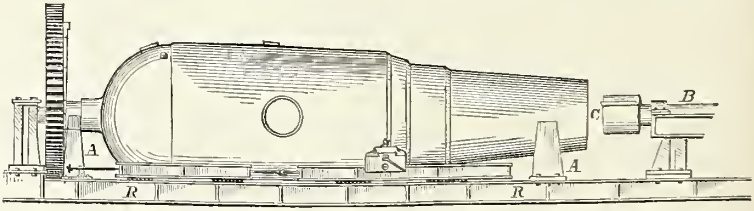


Fig. 73—Boring-lathe.

rack, RR, two journals, AA, and the boring-rod, B, the supports of which rest upon the rack, and are of such a height that the axes of the journals and boring-rod shall be in the same horizontal plane.

501. The gun while in the lathe rests in the journals at the cascabel bearing and chase; the metal at these points having been turned down to the finished size while in the heading-lathe, the square knob or cascabel is secured in the chuck by tightening the screws equally in all directions.

502. ADJUSTMENT IN THE LATHE.—The boring-rod is first introduced a short distance into the bore of the gun, and the space between the exterior surface of the boring-rod, and the exterior surface of the gun at the muzzle, observed. For this purpose a thin wooden gauge is used, pointed at one end and having a notch at the other, which takes the outer surface of the gun at the muzzle, the gauge being laid on the face of the muzzle, and, of course, perpendicular to the axis of the bore. As the gun revolves, the distance above, below, and on either side is observed, thus verifying the perfect concentricity of the axis of the gun at the muzzle.

The adjustment is completed at the breech, by slackening the bolts at the cascabel bearing, leaving it free to move on the rest; and should any lateral motion be perceptible, it is corrected by adjusting the screws in the chuck, after which the concentricity is complete from breech to muzzle.

503. BORING.—In boring, the first tool or cutter used is fourteen inches in diameter, being secured on the end of the boring-rod, or *arbor*, C, which is made to advance by machinery as the gun revolves, until arriving at the bottom of the cylindrical part of the bore. The chamber is next roughed out, and then the "reamer," or finishing-tool (fifteen inch), for the bore is used; and lastly the chamber "reamer."

504. During the process of boring, the turning continues, and the exterior is finished, except between the trunnions and about the lock and sight-masses; the former being planed off by a machine for the purpose, and the latter reduced by chipping and filing. To insure a smooth surface in the bore, all the work on the exterior surface of the gun is suspended while the reamer, or finishing-tool, is being used.

505. The boring being completed, the *cylinder-guage* is inserted before removing the gun from the lathe, to ascertain if it passes freely to the bottom of the bore; the chamber-reamer should also be measured after use in each gun, and, if found correct, the gun is moved from the lathe.

506. TRUNNION-LATHE.—The gun is next placed in the

trunnion-lathe, which consists of the rack, two journals, and the trunnion-head, or shaft.

The gun is placed in the journals, which are of such a height that the axis of the gun, when properly adjusted, shall be level, the gun being supported at the chase and cascabel.

507. *The trunnion-head* consists of a hollow shaft in which the cutters are placed, and is supported upon a rack previously placed at right angles to the axis of the gun, and of such a height that it shall be in the same horizontal plane as the axis of the gun.

508. In turning and finishing the trunnions, the hollow shaft of the trunnion-machine is made to revolve about the trunnion, the gun being stationary; and, as the turning progresses, the shaft moves on its rack towards the gun, its speed being regulated as circumstances require. One trunnion and rim-base being finished, the gun is turned over, bringing the other trunnion in the same position as the first, and is turned in like manner.

509. THE PLANING-MACHINE.—The metal in excess between the trunnions is removed by the planing-machine (Fig. 74),

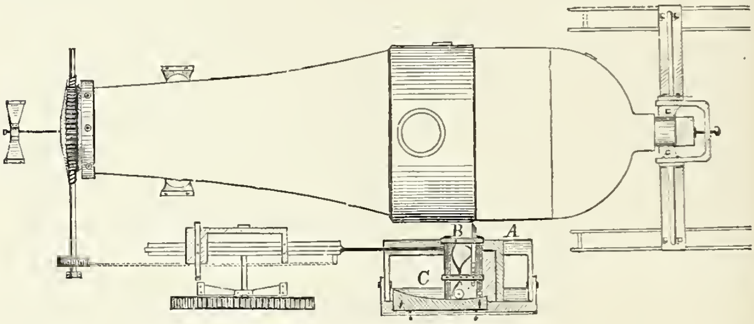


Fig. 74.—Planing-machine.

which is placed on the side opposite the trunnion-machine, and is so arranged that the movable point in which the cutter is secured, A, traverses forward and back in a horizontal plane over that portion of the gun between the trunnions that has not been turned down. The cutter is secured in a spring-set, B, by which means it cuts only while moving forward, the gun being turned the width of the cut after each passage of the planer.

510. The desired curve of metal is obtained by introducing a guide-plate of the proper form, C, in rear of the cutter-rest.

After the planing is finished, the gun is removed from the lathe, and placed upon the skids, where the surplus metal about the rim-bases, lock, and sight-masses is reduced by chipping, and finished by hand.

511. Cutting Hole for Elevating-screw.—The gun being carefully levelled, and the trunnions placed horizontal, the position of the centre of the screw-hole, which in the guns of the Dahlgren pattern is tangent to the radius of the breech, is marked on the neck of the cascabel with a centre-punch.

512. *The Boring and Screw-cutting Machine*, which is a convenient, portable hand-drill press, is then placed on the cascabel, the boring-shaft inserted in the hollow leading-bar, and its movable centre placed in the mark. The instrument is then set vertical, by a spirit-level, on the cogged driving-wheel and the four pairs of set-screws on the clamp-head embracing the cascabel.

513. The centre is then removed, and a drill inserted in the lower extremity of the boring-shaft, which, being held firmly by a shoulder and turned by a four-armed wrench, while pressed up to the metal by slowly turning the cogged driving-wheel, cuts the hole. This is successively enlarged, by two or more counter-bits, to the size of the body of the screw.

The cutter is then inserted in the leading-bar, and the thread cut.

514. Drilling the Vent.—The proper position for the exterior orifice of the vent having been determined and marked upon the base-line, the drill is set at the required angle by the

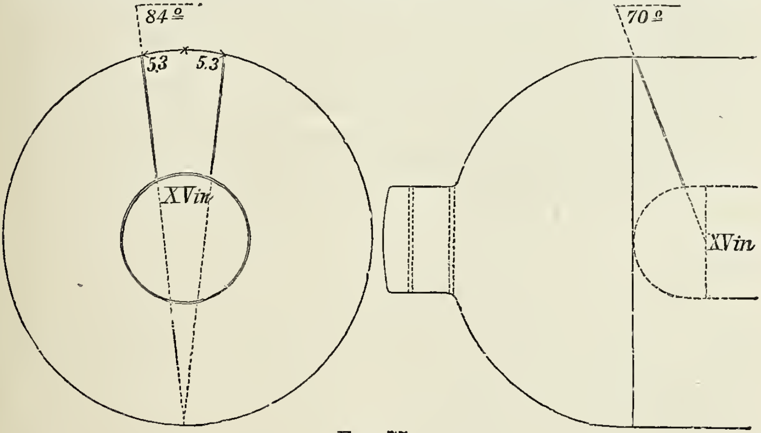


Fig. 75.

vent-guide (Art. 566), and held in position by a frame of cast-iron, which is secured on the gun.

After the vent is fairly started, the gun is turned over, that the cutting may not obstruct the drill. The left vent is simply indicated, being bored two inches.

The square knob of the cascabel is now broken off and the end of the cascabel rounded and finished; also the foundry number is stamped on the right rim-base in one-fourth-inch figures.

515. Marking Guns.—Guns for the Naval service, received by authority of the Bureau of Ordnance, are to be marked in the following manner, viz.:

On the cylinder, in the line of sight near the sight-mass, all accepted guns are to have stamped an anchor two inches long.

On the base ring or line, the initials of the foundry, the register number, and weight of gun in pounds.

On the right trunnion, the calibre and year of fabrication. On the left trunnion, the letter P, and the initials of the Inspecting Officer; all the above in one-inch letters.

On the upper jaw of the cascabel, the preponderance in pounds to be stamped lightly with half-inch figures.

On the end of the upper jaw, the cascabel block, and head of pin, the foundry number in quarter-inch figures.

The foundry number is also to be marked on the right rim-base.

Guns rejected for imperfections of any kind will have the letter C stamped on the anchor, so as to partially obliterate it.

516. FABRICATION OF BRONZE HOWITZERS.—A model or pattern of the gun is first prepared; to do this it is first necessary to lay down on paper an exact drawing of the gun desired; showing, on a convenient scale, its general appearance and the relative proportions of its different parts, both exterior and interior; the full dimensions being put down opposite each part.

517. A drawing of the gun is now made on a smooth board, full size, the dimensions taken from the draught, but laid down by a rule, which is larger than an ordinary one by 0.15 of an inch to the foot, which allows for the shrinkage of the metal in cooling.

518. Two pieces of clear, well-seasoned white pine are selected of such proportions that, when joined, they will form a square piece of timber, considerably larger, and of greater diameter, than the gun itself.

The two corresponding faces being smoothed, so that a perfect junction may be formed, four holes are made in the face of one, while corresponding pins, termed *steadying-pins*, are fitted in the face of the other; this is for the purpose of insuring the exact adjustment of the parts while molding.

The pieces are then joined face to face, the extremities rounded off, and iron bands driven over the ends, for the purpose of uniting them firmly.

Thus fitted, the whole is carefully adjusted in a lathe, so that the axis shall fall directly in the plane dividing the two parts. It is then turned down to the required form.

519. The pattern consists of three parts: the model of the gun itself, the sinking-head, and knob of the cascabel, which is enlarged to form a square projection by which the piece can be held while being turned and bored.

When the pattern is detached from the lathe these parts are separated with a saw. Pieces of wood representing the sight-masses, the lock-lug, and the loop are tacked on in their proper places, and the whole is sand-papered and varnished. The pattern is now complete, and the parts will represent the appearance of two semi-cylindrical bodies exactly similar in size and shape.

520. The Flask is a long, rectangular box, F (Fig. 76), made of iron-plates bolted together, the top and bottom ones, which are movable and called *lids*, being of one-quarter inch wrought-iron and the sides of half-inch cast-iron.

It consists of two equal parts, each of which is large enough to contain half the mold; these parts are each fitted with a flange, extending entirely around the flask, and perforated with holes for screw-bolts and nuts to unite the two parts firmly.

They are also fitted with journals at the ends for convenience in suspending them; and with eye-bolts for the purpose of moving them about, lowering the flask into the pit, etc.

The head of the flask has a large hole and two small ones, in which to pour the metal and to permit the escape of gases. The flask has strengthening pieces at different places, and inside is divided into compartments by iron plates having a score cut in them to receive the pattern. These plates serve to make the mold more compact.

521. Molding.—A smooth, flat board, whose dimensions are a little larger than the flask, is placed on the ground, and the half-model is placed upon it flat side down. The corresponding half-flask with its lid removed is then placed around it and clamped to the board. Molding-composition is introduced in small quantities at a time and rammed compactly around the model. This is continued until the flask is filled; the lid is then bolted on, the flask hoisted, turned over, and again deposited on the ground with the lid down. The board is then unclamped; the face of the mold then brushed off, and

sprinkled with a kind of white sand, called *parting-sand*, to keep the two parts of the mold from sticking together.

The other half-model is then placed in position on top of the first, and the corresponding half-flask with its lid removed secured in place to the under one.

The sand is again introduced and rammed compactly around the upper half-model as before, the steadying-pins holding it firmly in place; when the flask is filled the second lid is bolted on.

The half-flasks are now separated and each is found to contain one-half of the mold with the corresponding parts of the model embedded.

The latter are then carefully withdrawn and all imperfections on the face of the mold are repaired, when it is coated with a composition of brick-dust, pipe-clay, molasses, and water, which gives the interior of the mold a smooth, hard surface.

522. A *runner* is made on one side with a single branch at the bottom for the purpose of introducing the molten metal. This channel is made by embedding a rod in the sand between the two half-flasks in molding the piece. The branch runner enters the mold in an oblique direction.

The entrance of the metal to the mold at its bottom is at an angle which gives a rotary-motion to the liquid, the effect being to produce a depression in the centre and a gravitation to it of all *scoria*.

A narrow channel is cut in the molding-composition somewhat larger than the small hole in the head of the flask, and leading from it to the channel left by the rod. Another narrow channel is cut from the other small hole, intersecting the mold about a foot from the top, by which the height of the metal in the mold can be ascertained during the casting.

523. The drying-oven is a rectangular apartment built of brick, with an arched roof and iron doors, having tracks led into it for the cars upon which the flasks rest. It is heated by an open fireplace which is fed from the outside with coal.

524. *Drying the Mold.*—The half-flasks are securely bolted together, when the whole is placed upon a car and run into the oven or drying-room, where it is allowed to remain three or four days, or until it is perfectly dry. The temperature of the oven ranges from 200° to 250° F.

525. The Pit.—The pit is of a circular form and lined throughout with water-proof cement. It is situated directly in front of the furnace, and is fitted with an adjustable apparatus for receiving the flask, and sustaining it in an upright position.

526. Placing the Flask.—The flask is lowered into the pit,

breech down, until the upper end is about twelve inches below the spout at the mouth of the furnace; it is then secured in this position, and boards are placed over the mouth of the pit for the convenience of the founder.

527. CHARGING THE FURNACE.—A reverberatory furnace is used.

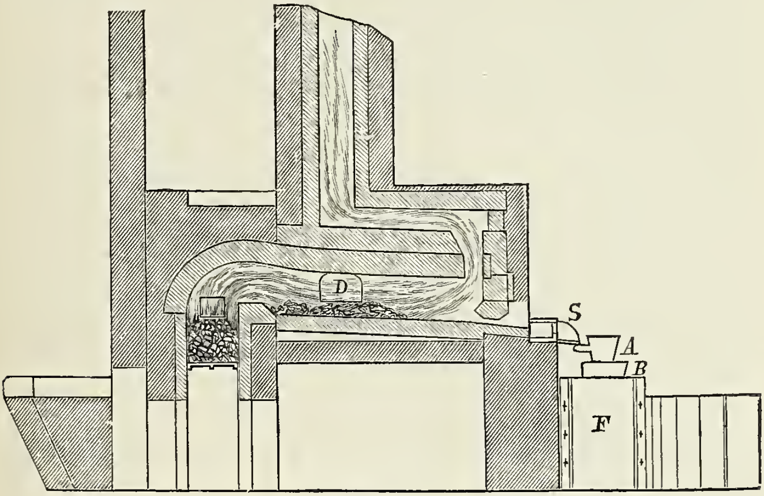


FIG. 76.

The proportions of the metals selected for this species of bronze are such as to produce the toughest and most indestructible alloy. It consists generally of ninety parts of copper and ten of tin. Lake Superior copper is preferred on account of its toughness, and German tin for its purity. The greatest care is necessary to keep the compound free from sulphur, lead, iron, and arsenic, for any of these would lessen the value of the alloy for the required purpose. (Art. 135.)

528. In consequence of the different fusibility of copper and tin, the perfection of the alloy depends much upon the treatment of the melted metal. If the tin be not quickly united with the copper, it will be burned, and converted into scoria; but such are the affinities of the metals, that the loss which might be expected from the burning of the tin is prevented by its being retained by the more stable copper. It is very essential that the metals be thoroughly incorporated, for the tin, being the lighter, would remain on the surface, and there would be no union of the metals whatever.

The copper is first introduced into the furnace through the side-door, D, in the form of ingots of about eighteen pounds weight: two thousand pounds of copper being required in casting the heavy twelve-pounder howitzer of seven hundred and fifty pounds weight.

529. Melting down the Charge.—The fuel used for melting is spruce pine, three-fourths of a cord being required for each ton of copper; wood is used in preference to coal, because the gases evolved are not so injurious to the copper.

The furnace being closed, the fire is started; from three to four hours are required to fuse the copper, depending upon the force and direction of the wind and the state of the atmosphere.

530. At the *moment* at which fusion takes place, the tin, which is prepared in the form of ingots, each weighing about seven pounds, is thrown into the furnace through a door, one at a time; care being taken to submerge the ingot thus introduced in order that it may not spread itself on the surface of the copper and become oxydized; the whole mass being kept in a state of agitation by means of a rabble introduced through the same door.

The molten mass is thus puddled until the metals are thoroughly incorporated, which operation requires about four minutes; the rabble is then withdrawn, the door closed, and the damper raised.

531. The compound is now subjected to an intense heat for about thirty minutes, or until the founder is satisfied that the mass has been reduced to the required state of liquefaction. It is almost impossible to give any rule as to when the metal is ready for running, as those who are experienced in the matter tell by its color and general appearance; which is defined as a *yellow-red color*.

532. When the pure metals are not used, the charge is made up of remnants of other castings and shavings from the lathe, etc., which are re-melted with a sufficient quantity of zinc and tin to preserve the proper proportions. (Art. 138.)

In a light 12-pdr., cast in 1871, the furnace was charged with:

One 24-pdr., Howitzer..................	1,280 lbs.
Lake Copper..........................	75 "
A gun muzzle..........................	100 "
Ingots (Bronze).......................	145 "
Total................	1,600 "

In a light 12-pdr., cast in 1872, the furnace was charged with:

Two Heads	1,420	lbs.
Ingots (Bronze)	205	"
Tin	2	"
Zinc	2	"
Total	1,629	"

In a heavy 12-pdr., cast in 1865, the furnace was charged with:

Lake Copper	800	lbs.
Ingots (Bronze)	1,000	"
One Head	600	"
Total	2,400	"

533. Casting.—In casting it is customary to allow the melted metal to run first through the side-runner until it rises two or three inches above the loop; the stream is then transferred directly through the top of the mold and allowed to run in until the mold is filled. This is done to prevent the upper part of the casting from cooling too rapidly, and thereby causing an unequal distribution of the tin, this metal being found always in the greatest quantities in that part of the casting which retains heat the longest. (Art. 137.) It is considered impossible to render the alloy perfectly homogeneous, because of the difference of fusibility and specific gravity of the constituent metals. (Art. 140.)

534. To transfer the stream of melted metal, a simple device is resorted to. It consists of two *runner-boxes* of cast-iron, A, B (Fig 76). The lower one has a partition dividing it into two chambers, with an orifice in the bottom of each, so fitted that when it is placed on the flask, F, one orifice will lead fair into the runner, and the other directly into the mold.

535. The upper runner-box slides on the upper edge of the lower one, and is furnished with handles to facilitate the operation. Its bottom is pierced with a single orifice to allow the stream of metal to flow successively into the inner and outer chambers of the lower one.

The upper runner-box is also fitted with a *spout*, which, when they are in position, comes directly under the spout, S, at the gate of the furnace; it is long enough to allow for the distance between the first and second positions of the upper runner-box.

536. The spouts and runner-boxes, well lined with clay, being secured in position, and the furnace ready to tap, an orifice is made in its gate and the metal allowed to run in the mold. From the gate it is conducted by the spout into the upper runner-box; flowing from thence through the orifice, it passes into the inner chamber of the lower runner-box, and down through the side-runner and its branch into the bottom of the mold.

537. At the moment the founder, who is looking down into the mold, discovers that the metal has arisen above the loop, he causes the upper runner-box to be shifted, so that the stream is transferred to the outer chamber of the lower runner-box. When the mold is filled the gate is plugged up, the runner-boxes are removed, and the casting allowed to cool. When the casting has become sufficiently solid to be removed, the mold is hoisted out. The remaining metal in the furnace is drawn off in ladles, and cast into rough ingots for future use.

The casting having become sufficiently cool to be handled, the flask is opened, the gun taken out, and with a hammer and chisel the sand and rough projections removed. The gun is then ready for the lathe.

Section IV.—Inspection.

538. Inspection of New Guns.—New guns are to be closely examined and measured inside and out, for defects of metal or manufacture, as soon after being finished as possible, if it has not already been done in the various stages of manufacture.

For this purpose the gun is placed on skids, so that it may be easily moved, and its foundry number is noted so as to identify the piece.

As rust tends to conceal defects, this examination is to take place before exposure to the weather; and previously to the final examination and proof of the guns, they are not to be covered with paint, lacquer, oil, or any material which may conceal defects of metal.

539. If it is ascertained that any attempt has been made to conceal defects, the guns so treated are to be rejected without further examination.

The water-proof, which is of great importance in detecting defects of metal, not otherwise developed, necessarily succeeds immediately the powder-proof, and can only be effectively employed in fine weather, and when the temperature is above the freezing-point; final inspections are to be made at such times only.

540. THE INSPECTING-INSTRUMENTS.—The inspecting-instruments are first carefully verified before any measurements are taken. They may be described and their uses explained as follows:

541. A MIRROR, for reflecting the sun's rays.

Use.—The interior of the bore is to be examined by reflecting the rays of the sun into it from the mirror or mirrors; or, if the sun is obscured, and there can be no delay, by means of a spirit-lamp or of a wax-taper on the end of a rod, taking care not to smoke the surface of the bore.

542. THE SEARCHER consists of a long staff of wood, fitted with a head of six or seven steel points (Fig. 77). The points are arranged at equal intervals around the head, and attached with a tendency to spring out and increase their diameter; this tendency is restrained by a hoop of iron embracing them, and capable of being worked in and out on the the head of a rod extending along the staff.

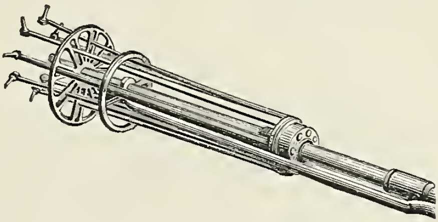


FIG. 77.

543. *Use.*—The searcher is used for detecting the presence of small cracks or flaws. To use the instrument the hoop is pushed out on the head, thus contracting the points; it is then introduced in the gun to the bottom of the bore, and the hoop being pulled back allows the points to spring out and take against the surface of the bore. The searcher is then slowly withdrawn, turning it at the same time; if one of the points catches, its distance from the muzzle is measured on the staff, and its position in the bore noted, and marked on the exterior of the gun. The size and figure of the cavity is then determined by taking an impression of it in wax.

544. THE CYLINDER-GAUGE.—This is a hollow cylinder of iron, turned to the least allowed diameter of the bore, and one calibre in length (Fig. 78). It has a cross-head at each end, one of which has a smooth hole through its axis to fit the staff, and the other is tapped to receive the screw in the end of it.

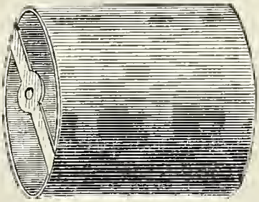


FIG. 78.—Cylinder-gauge.

545. *Use.*—The cylinder-gauge is introduced in the bore of the gun, and must pass freely to the bottom of the bore.

This instrument shows that the bore is not too small.

546. A Measuring-staff.—This is a staff of steel or iron (Fig. 79), in joints of suitable lengths, connected together by screws. Each joint is provided with a light brass disk, DD, the diameter of which is 0.05 inches less than that of the bore.

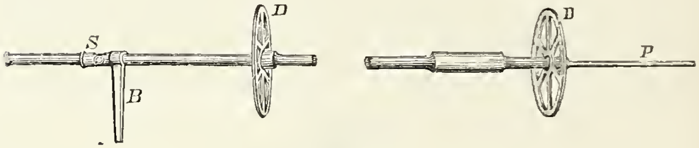


Fig. 79.

Through the centre of the disk there is a hole which fits upon the shoulder at the joint; the whole is so arranged that when the joints are screwed together the disks between them are held firmly in place, while the length of the staff is not affected by them. A steel point, P, is screwed on to the end. When pushed to the bottom of the bore, the staff coincides very nearly with its axis. The outer joint is graduated to inches and tenths.

A slide, S, is made to play upon it with a vernier scale, graduated to hundredths of an inch. On the inner end of the slide, a branch, B, projects at a right angle, sufficiently long to reach across the muzzle-face, and, when in contact with it, to indicate the precise length obtained from that point to the end of the measuring-point on the other end of the staff.

547. *Use.*—The instrument is introduced until the point reaches the bottom of the bore, and the branch placed so that it takes across the muzzle-face, and the reading shows the length of the bore of the gun.

548. Chamber-gauge.—The head should be made of close-grained, well-seasoned wood, and of the exact dimensions of the chamber.

Two planes crossing each other at a right angle, coinciding with the vertical and horizontal central sections, have been found better than a solid block. The edge should be bevelled. A socket in its centre connects it with the measuring-staff.

549. *Use.*—Being pushed to the bottom of the bore, if the length coincides with that obtained by the point, it is obvious that the chamber is large enough, provided the cylindrical part has not been bored too deep, in which case a shoulder would be found at the junction.

The edges of the gauge should be chalked before inserted. When withdrawn, if the chalk-marks are visible all around the chamber, it is evident the chamber is not too large.

An examination of the *chamber-reamer* (Art. 503) will be very satisfactory, and if found correct in size and shape, the impossibility of making the chamber too large will be apparent.

550. Star-gauge.—This instrument is composed of the *staff*, the *head*, and the *handle* (Fig. 80).

Fig. 80.—Star-gauge.

The staff is a brass tube, S, made in three pieces, for convenience of storage, and connected, when required, by screws. It is graduated to inches and quarters, so that the distance of the head from the muzzle of the gun may always be known.

A centre-line, starting from the centre of the upper socket in the head, is marked upon the staff throughout its length.

551. *The Head.*—The inner end of the staff expands into a head, H (Figs. 81 and 82), in which are placed four steel

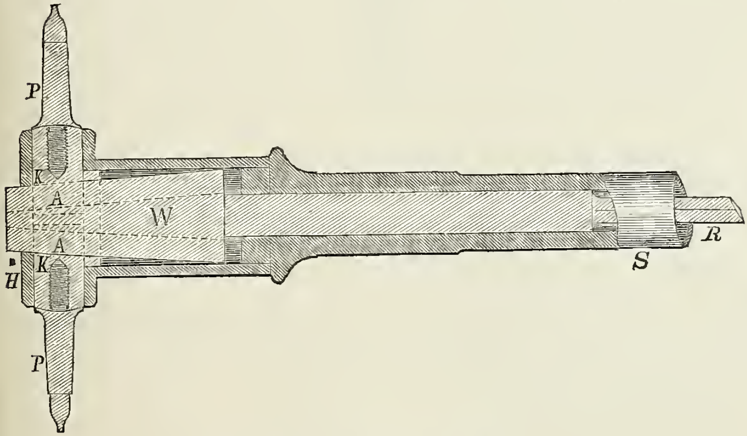


Fig 81.—Head of Star-gauge.

sockets, K, at equal distances from each other; two of the sockets opposite to each other are secured permanently, and the other two are movable.

552. A wedge, or tapering plate, W, the sides of which are cylindrical, runs through a slit in the head (Fig. 82); an aper-

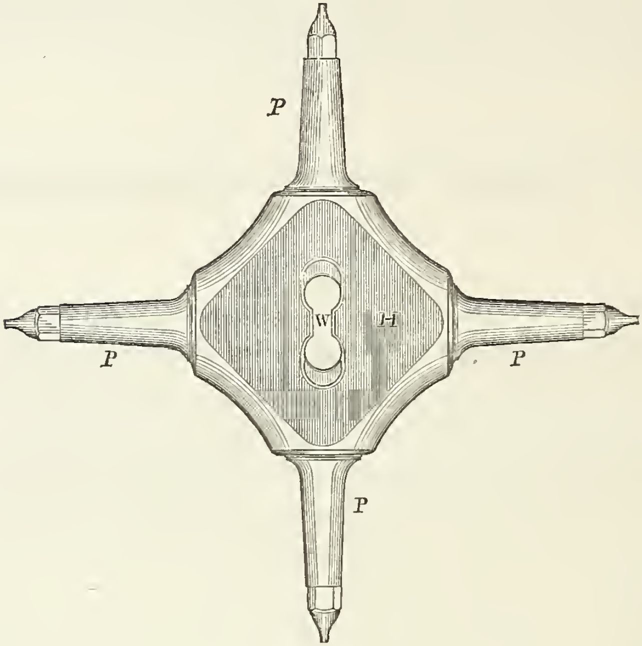


FIG. 82.

ture in the inner end of the movable sockets, AA, embraces the cylinders, so that when the wedge is moved forward or backward, the sockets are projected or withdrawn.

The tapering of the wedge has a certain known proportion to its length, so that if it is moved in either direction a given distance, a proportional movement is imparted to the sockets. The sides of the wedge incline 0.35 inch in a length of 2.2 inches, so that by pushing it the thirty-fifth part of this distance (about 0.06 inch), the distance between the two sockets is increased .01 inch.

553. There are four steel measuring-points, P, for each calibre, fitted with strong shoulders at one end, below which threads are cut for screwing into the sockets in the head. A wrench is made to fit the shoulders, so as to turn the points

firmly into their places; when two of these are screwed into the fixed sockets, the distance between their extremities is equal to the true diameter of the bore.

554. A square steel sliding-rod, R, is connected with the wedge in the head, and runs through the whole length of the staff, projecting some inches beyond the outer end. This rod has as many parts as there are joints in the staff (three), and, like them, connects by screws.

555. *The Handle* (Fig. 83) is attached to the projecting end of the sliding-rod. It is a short hollow tube of brass, MB, made to fit over the outer end of the staff, S, and connect with the sliding-rod, R, by a screw at its outer extremity fitted with a large milled-head, M. The handle is divided into two parts,

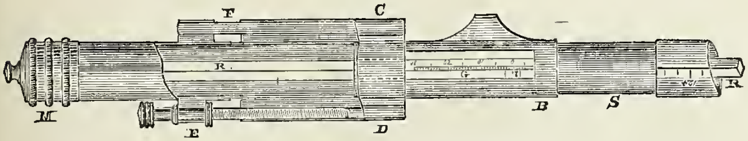


Fig. 83.—Handle of Star-gauge.

one fitting and working closely over the other. On each side of the inner part is a small tube, CD; a thread is cut in one, D, through which a fine screw, held by a stud on the outer part, E, works and gives it motion; a guide, F, runs through the other. A slit, G, through the inner part of the handle permits a part of the staff near the end to be seen beneath, and a scale is placed on one side of the slit graduated with the distance that the wedge moves to throw the points .01 inch apart.

556. *Adjusting the Instrument.*—There is a steel *adjusting-ring* (Fig. 84) for each calibre, reamed out to the exact minimum diameter of the bore. The fixed measuring-points of the head will just pass into the adjusting-ring of the corresponding calibre; the movable points are made to touch the inner circumference of the ring by pressing in the wedge; and this is accomplished by moving in the *handle*, which works the *sliding-rod*. Seen through the slit of the handle, G, is a small plate of silver, I, inserted in the staff, and a fine mark upon it to show the place of zero when the measuring-points are adjusted.

Fig. 84.

The zero-mark on the scale along the slit is made to correspond with it by means of the fine screw, ED.

557. *A Muzzle-rest* in the form of *T* is employed to keep the staff of the star-gauge in the axis of the bore while it is being used (Fig. 85). It contains a groove, A, in the centre of the transverse branch, to receive the lower half of the staff, and can be used with any calibre, as there is a movable slide on each branch, S, which can be adjusted to marks for the calibre, so that points projecting from the rear will enter the muzzle and hold the *rest* in place. In this position the upper edge of the transverse branch coincides with the diameter of the bore. A hook is secured on the inner side of the transverse branch, on one side of the groove, and so fitted that when the star-gauge is in the gun, it embraces one-half of that portion of the staff which is above the groove. Therefore, if the transverse branch be placed so as to coincide with the axis of the trunnions, the hook thrown over the staff, and the latter turned so that the centre-line just meets the end of the hook, two of the measuring-points will be in a plane perpendicular to the axis of the trunnions (Art. 550). If the staff is then drawn out carefully, without turning, measurements may be taken in the same plane. A notch in the end of the hook, made to coincide with the face of the muzzle, will mark the distances on the staff.

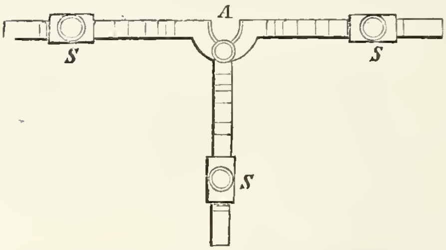


FIG. 85.—Star-gauge Rest.

558. *A disk* for circular measurements is employed when it is desired to take the diameter of the bore at many points of the circle. There is a brass tompion, V, to fit the muzzle of the gun, with a hole through its centre to receive the staff of the star-gauge (Fig. 86).

It is turned to fit snugly the bore of the piece, into which it enters two or three inches, to hold it firmly in place: and has a projecting flange or face to prevent it going in too far. The face is a plane surface with its circumference divided into as many equal parts as may be thought desirable, and numbered in regular order.

559. On the staff of the star-gauge a brass slide, X, is fitted, having a thumb-screw to hold it in any position; from its inner

end an arm, Z, extends at right angles to the staff, of sufficient length to meet the points on the circumference of the disk and having a centre-line marked upon it. This slide is secured at any distance on the staff at which a circular measurement is desired, and with the centre-line of the arm coinciding with the centre-line of the staff; when the arm will indicate the direction of the pair of measuring-points; being in the same plane with them.

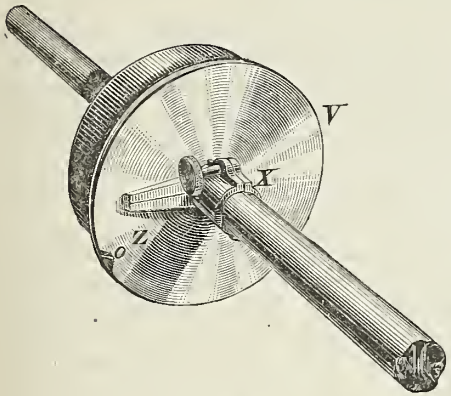


FIG. 86.

560. The disk is secured in the muzzle, with its zero-mark coinciding with a light punch-mark on the muzzle-face directly below the *line of sight*, so that it is in a plane passing through the axis of the piece and perpendicular to the axis of the trunnions. To take the measurements, press the staff home until the arm of the slide comes in contact with the face of the disk, and turn it to coincide with the various divisions of the disk at which measurements are desired.

561. The disk is divided into halves, and the centre-hole is reinforced on the inside by a projection, which is turned to receive a collar that fits closely around it, and holds the two halves together when they are placed on the staff.

562. *Use.*—The star-gauge is used to obtain the exact diameter of the bore. It is obvious that the determinations will not be absolutely accurate, for when the gun is worn, should the stationary points be perpendicular, the movable points, being then horizontal, would fall below the true horizontal diameter, and measurements would be more in error than it would be with the points in any other direction. Still if care is taken to preserve the points at the greatest length possible, a very tolerable degree of accuracy may be attained.

563. In the inspection of guns arranged on skids, the gun itself should be turned, which will insure accurate measurements. Care must also be taken not to allow the joints of the staff to become so loose that the coincidence of the centre-line

is destroyed when they are screwed together. If this should occur, however, a few turns of thread, placed between them at the time of putting the instrument together, would remedy the difficulty.

564. The bore must be measured at intervals of one-quarter inch from the bottom of the cylindrical part to the seat of the projectile; of one inch from that point to the trunnions; and of five inches from the trunnions to the muzzle. If any marks of the *reamer*, or other defects are seen in the bore, they are to be searched for, and their depths and positions noted.

These results are to be tabulated according to the blank forms furnished by the Bureau of Ordnance.

565. In recording the measurements of the bore in extreme proof and after service, it is necessary to distinguish between "indentation," that is, the depression at the "seat of the shot," which is always below, the "wear of the bore," which is generally above, and the increase of bore, or "enlargement" from any other cause (Art. 608.)

566. A Vent-guide, to be used with vents in guns of the Dahlgren pattern (Fig. 87).

This instrument is made of bronze or composition. When placed upon the gun, one of its branches coincides with the curve of the cylinder, and the other, starting from its centre, lies along the cylinder in contact with it longitudinally. The lower edges of the branches are a right line and a curved line, making two right angles with each other. The length of that of the transverse branch is equal to the distance between the centre of the two vents. The rear surface of the transverse branch is curved and quadrilateral. Its sides are inclined so that their rear edges, VV, show the exact direction of the vents. Every point in the upper edge lies in the same horizontal plane. The height is sufficient to permit the edges to give an accurate direction to the drill. The upper edge of the other branch runs off in a sloping curve to its extremity.

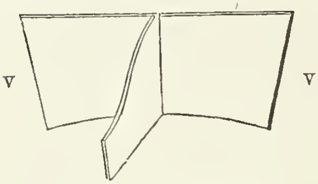


Fig. 87.—Vent-guide.

A centre-line is drawn through the lower edge of the longitudinal branch, and is continued upwards on the rear surface of the transverse branch to the top.

567. *Use.*—The guide being placed with its centre upon the centre-mark of the gun, and the centre-line of the longitudinal branch being made to coincide with the centre scribed upon the cylinder, the rear lower end of the transverse branch will then

coincide with the base-line, its extremities will indicate the centres of the vents, and the rear edges of the sides will show their true direction.

568. *An instrument for verifying the interior position of vents.*

A head of well-seasoned wood, which fits the chamber, is attached to a wooden disk of the diameter of the main bore. The surface of the head corresponds with a longitudinal central section of the chamber; at the point where the projection of the vent would meet it a piece of hard wood is inserted. A central line drawn through its length, crossed at a right-angle by another line at any known point from the smaller end, will afford convenient points to measure from.

A stout wooden staff is attached to the axis of the head; at a distance equal to the length of the bore, the end is jogged into the centre of a half-disk of wood, which is fitted to the bore.

The whole is so constructed that the straight edge of the half-disk (or the cord) is in the same plane as a horizontal section of the head. A few holes are bored through the disk attached to the half-head, to allow the instrument to pass freely into the gun and out of it.

569. A *wire* of untempered steel, of the size of the vent, with a sharp, well-centred point, and a small *spirit-level*, are required to use with this instrument.

570. *Use.*—The gun being levelled, and the instrument being pushed to the bottom of the bore, the upper edge of the half-disk near the outer end of the staff is then brought to a level.

The surface of the half-head then corresponds with the horizontal central section of the chamber. The point of the wire being pushed gently to meet it, will show very accurately the interior position of the vent.

571. Vent-gauges of untempered steel-wire, with shoulders to prevent them from slipping into the vent (Fig. 88). One should be of the proper diameter of the vent, one of the greatest, and one of the least, diameter allowed.

572. *Use.*—The diameter of the vent is measured by the gauges, the smallest of which must enter freely, and the largest not at all.

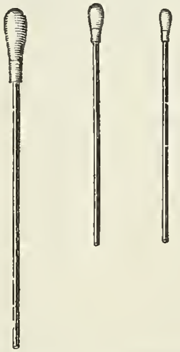


Fig. 88.—Vent-gauges.

573. A Vent-searcher, a steel wire of the length of the vent, bent to a right angle at the lower end and pointed.

Use.—The vent is examined for roughness or for cavities in the metal by means of the searcher, the point of which should feel every portion of it carefully.

574. A SEMICIRCULAR PROTRACTOR of metal for measuring the inclination of vents, or for ascertaining their deviation from the guide.

575. PROFILE-BOARDS, for distances in front and rear of base-line.

Their lower edges are adapted to the shape of the gun, and the upper ones are parallel to the axis of the bore.

The distances from the base-line of the several parts, and of points at which diameters are to be measured (Fig. 24), are laid off accurately on the upper edge, and then marked in lines perpendicular to it on the sides and lower edges of the profile. An iron strap is attached to the upper edge to prevent warping, and the whole is well coated with shellac-varnish to keep it from absorbing moisture.

576. The following instruments are used in connection with the profile-boards:

A *rule*, for verifying the marks, of such a length that not more than one fleeting may be necessary, to be graduated decimally according to the standard.

A small *square* of steel, to be used in referring the marks on the board to those on the rule.

A *steel straight-edge*, long enough to extend across the muzzle-face and several inches on the board, to ascertain the extreme length from base to muzzle. It is also used for the same purpose at the extreme end of the cascabel.

A steel *scratcher*, to mark the gun at points, not otherwise indicated, where diameters are to be measured.

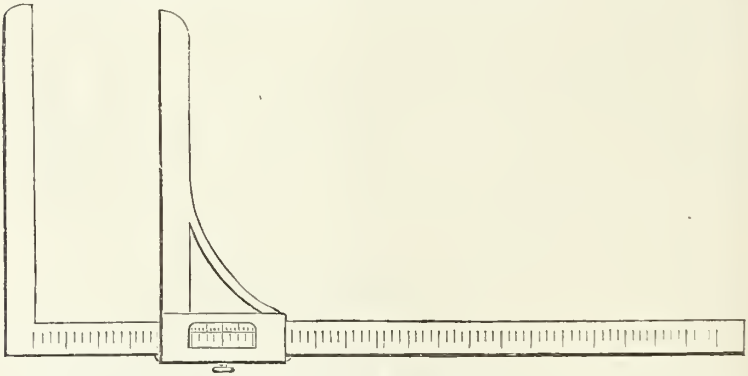


FIG. 89.—Beam-calipers.

577. A BEAM-CALIPER, for measuring diameters, is a square

of steel or iron (Fig. 89), with two branches, one of which is fixed and the other sliding.

The inner edges of the two branches, when pushed together, lie, of course, in contact with each other throughout their length. The beam is graduated to inches and tenths. A vernier is attached to the sliding-branch, graduated to hundredths of an inch.

The latter is provided with a thumb-screw to fasten it at any point.

The length of the beam must be rather greater than the diameter; and that of the branches than the semi-diameter of the guns to be inspected, at their largest points.

578. A Cascabel-block is a wooden cylinder of the proper diameter of the breeching-hole, the size of which it is used to verify.

The opening between the jaws may be ascertained by measuring the iron block which is fitted to go between them, or by a template.

579. A Trunnion-gauge is an iron ring of the proper diameter of the trunnions (Fig. 90). Its outer edge coincides with the diameter of the rim-bases.

Use.—To verify the position and alignments of the trunnions of a gun, it is first necessary to ascertain, by means of the trunnion-gauge and of the calipers, their cylindrical form and their diameters, which should be the same, or allowance must be made for half the difference in measuring their axial distances from the base-line, by the *trunnion-rule*, which should next be done. These distances should be equal, or their axes do not coincide, an error not tolerated.

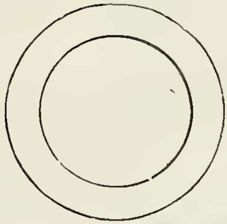


Fig. 90.—Trunnion-gauge.

The lengths of the trunnions are measured with the foot-rule, and the diameters of the rim-bases by that of the exterior rim of the trunnion-gauge.

580. A Trunnion-square (Fig. 91) of steel or iron for ascertaining the position of the trunnions, with reference to the axis of the bore. This instrument is a square, with two branches, one of which is fixed, and the other movable.

The foot of each branch, TT, is in the same plane, and is parallel to the upper edge of the main piece which connects them. The latter is graduated to inches and tenths. The movable branch, B, slides on the main piece, and may be secured to it by two thumb-screws, S. It is provided with a vernier-scale graduated to hundredths of an inch.

Between the branches there is a slide, R, also provided with a vernier, graduated as before, with a thumb-screw to secure it firmly; in its centre there is a sliding point, P, moving vertically, with a thumb-screw to fasten it. Above the foot of each branch there is a slit to receive the shank of a plate, H, on the end of which a thread is cut; the lower edge of the plate forms a right angle with the branch, and the plate is fastened to the branch by a nut, at a point from the end equal to the semi-diameter of the trunnion which is marked on each branch.

A graduated steel wedge, W, is used to measure the deviation of the trunnions from the feet of the square.

581. *Use.*—When the feet of the branches, or the lower edge of the plates, rest upon the trunnions, the upper edge of

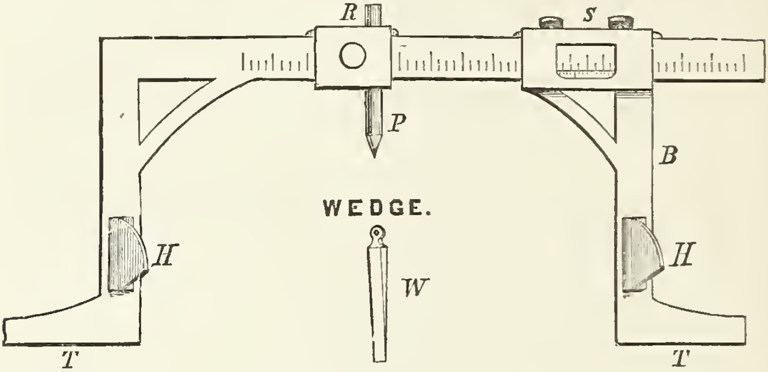


Fig. 91.—Trunnion-square.

the main piece is parallel to their axis, if their alignement is correct. When in the latter position, the edges of the feet will lie close against the sides of the trunnions.

The trunnion-square is placed upon the trunnions in the plane of their axis. The feet of its branches should coincide with the surfaces of both trunnions, throughout their length, above and in rear, and their inner edges with the faces of the rim-bases.

582. Then, with the *beam-compass* (Fig. 92), scribe on the

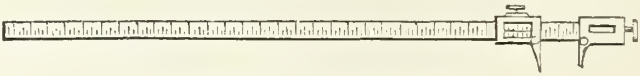


Fig. 92.—Beam-compasses.

upper surface of the gun the distance of the axis of the trunnions from the base-line, and push the sliding-point of the square down, till at that distance it touches the surface of the gun, and screw it fast.

Turn the gun over, and again scribe on it the same distance from the base-line. The square, being again applied, will determine whether the trunnions are above or below the axis of the bore, which will coincide with that of the gun, if accurately bored, and turned on the same centres and bearings. If the branches rest upon the trunnions before the point of the slider touches the gun at the scribe, their axis is below, but if the point touch first, above the axis of the bore by half the space between. The graduated wedge, being placed under the vertical sliding-point, will determine the amount. If both touch at once, both axes are in the same plane.

No gun can be received, the axis of the trunnions of which is above the axis of the bore.

583. A Trunnion-rule (Fig. 93).—To measure the distance of the trunnions from the base-ring or line. This is an iron rod

Fig. 93.—Trunnion-rule.

with a head at one end, through which passes one branch of a small square, A. The centre of the rod is marked on the end, and the square is set so that the inner edge of the branch which is parallel to the rod is at a distance equal to the semi-diameter of the trunnion from the centre. It is secured in this position by screws and clamps.

The upper side of the rod is graduated to inches and tenths. A slide, B, with a slot through it, to show the graduation beneath, traverses upon it, and is kept from turning by a guide on the lower slide. There is a vernier on the slide, graduated to hundredths of an inch; a thumb-screw serves to secure the slide at any point on the rod. That end of the slide from which the graduation of the rod commences has both of its sides drawn out, to form knife-edges; the knife-edges and the end of the slide are in the same plane.

584. *Use.*—When the square at the end is placed on the trunnions, the end of the rod will touch its side at the point of its greatest diameter. The rod being held parallel to the axis of the bore, with the side of the head pressing the rim-base, the

knife-edge will be in a proper position to fall into the base-line when moved to find it.

585. *Line of Sight.*—If the alignement of the trunnions be correct, it will serve as a means of determinating the correctness of the *line of sight*, which, before the gun is removed from the lathe, should be distinctly traced on the sight-masses and the swell of the muzzle, and should be at right angles to the base-line, to the axis of the trunnions, and to the connecting-piece of the trunnion-square, when its branches rest against their rear, with the plates across their upper surfaces.

The Inspector will further satisfy himself of the correct tracing of the line of sight on the gun, by examining the lathe and the manner of tracing it in the plane of the axis of the bore, at right angles to the axis of the trunnions, as by it are placed the sights and vent, and in their absence it serves as a line of metal sight.

586. A Set of Templates (Fig. 94), for verifying the shape of lock-lugs, the angle of the rear *sight-mass*, the curve between the base-line and the front of the rear sight-mass, that at the end of the cascabel, the bevel of the breeching-hole, the opening of the cascabel, and the shape of the muzzle-swell.

Fig. 93.—Templates for Sight-masses.

If the inspection should take place at the foundry, the templates used for chipping might be verified and used for inspection.

For guns of Dahlgren's pattern, a bronze model, showing the shape of the *lugs* and rear sight-mass, and the position of the vents, is furnished as a guide to the contractors.

587. *A standard foot-rule* for verifying measures.

A foot-rule of steel for measuring the masses, the length of the trunnions, and for other purposes. The graduation should be extended to each end.

588. *A set of ring-gauges*, large, medium, and small, for inspecting the projectiles used in proof.

589. *A small beam-caliper*, with outside edges, for examining the adjusting-rings and the ring-gauges.

The measures are to be taken by scales corresponding with the standard measures of the United States.

If two or more cavities should be near each other on the exterior, the gun may be rejected, though the cavities should be of less depth than tolerated in the table.*

590. If the trunnions are placed within the limits of tolera-

* Ordnance Instructions.

tion, the preponderance must not vary more than five per cent., more or less, from that fixed in the contract.

591. Impression-taker for Vents.—This consists of a wooden head, one half of which is cylindrical, and the other half is of the shape of the chamber, both being rather smaller than the parts of the bore for which they are intended. A staff, flat on its upper sides, and rounded on its under side to fit the curve of the bore, is mortised into the cylindrical portion of the head. A mortise is cut through the chamber part of the head, extending several inches in rear and front of the position of the vent. Into this mortise a loose piece is fitted, capable of free motion upwards and downwards, the top of which is pierced with holes to secure the wax or composition which is spread over its surface. This movable piece rests on a wedge attached to a flat rod running through a slot in the head; there is a slot in this rod about four inches long, a pin passing through it into the staff.

592. *Use.*—To use the instrument, withdraw the rod as far as the slot will permit, which will allow the movable piece upon which the composition has been spread to drop below the surface of the head, and protect it. Push the head to the bottom of the chamber and arrange the position of the staff, so that the movable piece will cover the vent, then press the end of the rod home. This motion will throw out the composition, and a distinct impression of the vent and of *fire-cracks* (should there be any) will be left upon its surface; draw the rod back as far as the slot will allow, and withdraw the instrument; the impression, being protected thereby, will come out uninjured. Impressions of injuries or cavities in the bore may easily be taken by a similar contrivance.

593. Gutta-percha Impressions.—Impressions are also taken of the interior of the bores of cannon on softened strips of gutta-gercha.

The following method is used in the English Service: *

A set of instruments are provided consisting of a semi-cylindrical iron frame, about two feet long, connected with an iron tube in such a manner that by screwing up a rod which passes through the tube, the frame can be worked up or down; upon this frame an iron plate, corresponding to each calibre of gun, is screwed, and when an impression is taken gutta-percha is spread on the plate, and by means of the rod is pressed against the defective part.

594. In the absence of special instruments for the purpose, the following method may be used:

* Text-book of Rifled Ordnance.

The blocks of wood, as shown in Fig. 95, are of a wedge-shape, they can be made by any carpenter, but require some practice to work with them so as to get perfect impressions.

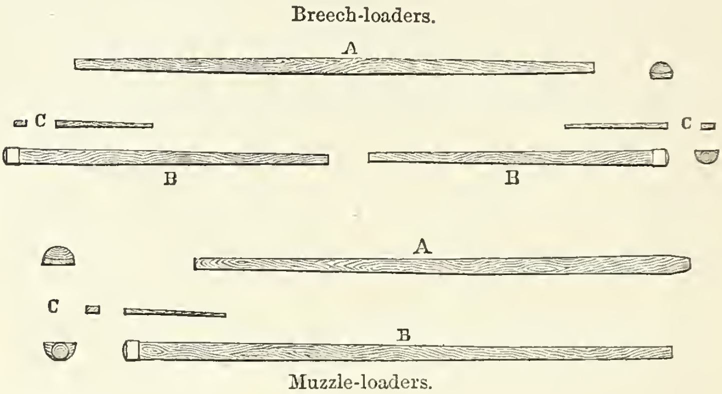


FIG. 95.—Wood Blocks for taking Impressions of the Bores of Guns.

The blocks, A, tapering from the centre for breech-loading guns, and from the breech for muzzle-loading guns, with their wedges, B, should be made to suit the diameters of the bores to be taken, leaving room for about .25 inch of gutta-percha, when the wedge or wedges are driven home, and proceed to take the impression as follows:

A sufficient quantity of gutta-percha, having been softened in water just below the boiling-point, is well kneaded and worked to expel the air and water, and is laid along the block, A, which has been previously prepared by rubbing it over with a little soft soap.

The gun is so placed that the impression required will be taken upwards, the block, A, is inserted into the bore, and the wedge, B (if a breech-loading gun, by simultaneous blows at both ends), is driven well home with mauls: a small wedge, C, is then forced between the ends of the blocks A and B.

This can be easily withdrawn in about ten or fifteen minutes, according to the weather, when the impression has become cold, and thus gives slackness to the wedge, B, and the block, A, which are withdrawn in the order named, together with the impression, which can be readily removed from the block, being prevented from sticking by the soft soap.

Before impressions are taken the bore should be clean, but slightly greasy; if quite dry the gutta-percha will adhere to it, and the impression be damaged in the removal. The impression should be reduced to the smallest dimensions compatible with showing the whole of the defect.

595. The impressions of any defects are cut off, the position in the gun is marked on the back, and they are registered and preserved for future reference.

The defects are noted in the following manner:

The distance is recorded in inches from the muzzle, and the position round the gun is recorded in all cases according to the diagram (Fig. 96), looking from the muzzle, as "up," "D," "R," "L," or in intermediate positions, as "R of D," "L of up," etc., etc. If a defect extends any length it is noted as in the following examples: "36 in., D to L," which means a defect thirty-six inches from the muzzle running round the bore from "down" to "left;" or "49 inches to 56 in. up," meaning a defect running along the top of the bore from forty-nine inches to fifty-six inches; or, in other words, seven inches long.

FIG. 96.

596. VENT IMPRESSIONS.—The implements required for taking permanent vent impressions in lead are a *soft wire* about 0.07 in. in diameter, and 3 or 4 fathoms long.

A *lever* about twice the length of the bore, about 3 inches in diameter, and shod to suit the curve of the bore nearly. A small *button* of soft lead, judged to be of sufficient size to fill the vent at least one inch from the bore. This is to be pierced lengthwise to receive the wire.

597. *To Take the Impression.*—Shove the wire through the vent; let it pass along the bore and out at the muzzle; put it through the leaden button and tie a knot at the end.

Draw the wire back through the vent until the leaden button is introduced firmly into the inner orifice. Apply the lever, making its shoe bear on the button, and force it well in by repeated blows, the muzzle being the fulcrum. This done, disengage the button by pushing in the priming-wire.

In taking impressions of the vent and cracks, each button in turn is used as a pattern for molding its successor, allowing for the progressive enlargement of the vent or the cracks emanating from it. When the crack shows itself, the head of the button should be so enlarged as to include it.

These examinations should take place after every twenty fires, at least, and more frequently when any unusual enlargement of the vent or extension of cracks are developed, and indicate its speedy destruction. Before each examination the bore of the gun is carefully washed and dried.

598. POWDER-PROOF.—The powder-proof is based on the highest charge which the gun will fire in service, and bears a certain relation to it.

The proof-charges are as follows:

CALIBRE AND CLASS OF GUN.	CHARGE OF POWDER, LBS.	PROJECTILE.	NO. OF FIRES.
	Pounds.		
XV-inch......43,000 lbs.	35	Shell............330 lbs.	3
	45	" ...." "	3
	55	Cored Shell......400 "	3
XI-inch......16,000 "	25	Solid Shot.......166 "	1
	15	Shell............127 "	10
X-inch......12,500 "	18	Solid Shot.......124 "	1
	12	Shell............ 95 "	10
IX-inch.......9,000 "	15	Solid Shot....... 90 "	1
	10	Shell............ 68 "	10
VIII-inch of.....6,500 "	10	Shot............ 65 "	10
32-pdr. of...... 4,500 "	8	Shot............ 32 "	10

The cannon-powder for proof is of not less than 1,500 feet initial velocity. It is filled in service-cylinders and well settled.

For chambered pieces the increased charges should fill the chamber and necessary portion of the bore.

The projectiles are of full weight, and not below the mean gauge; the shells filled with a mixture of sand and ashes, to bring them up to the weight of the filled shells. Sabôts for the shell, and a grommet wad over the shot.

The gun should be fired on skids or a proving-carriage to test the trunnions.

If five per cent. out of any lot offered for ordinary proof under a contract fails to sustain it, the whole may be rejected, as may be stipulated in the contract.

599. WATER-PROOF.—The pressure to be applied in the water-proof is two atmospheres, or thirty pounds to the square inch.

The penetration of water in this proof through the metal of the piece, in any place, will cause the rejection of the gun; and if, on examination after the water-proof, there are any defects indicated by weeping or dampness in the bore, the gun is rejected.

The water-proof is alone to be depended on to detect minute clusters of cavities in the bore, which for this purpose should be perfectly dry, and examined by sunlight. All inspections, consequently, should take place in fair weather, and when the temperature is above the freezing-point.

600. *Hydraulic Pump and Apparatus for the water-proof.* —Any of the various patterns of this machine may be applied to the proof of guns. An iron cross-head is secured to a stout wooden block which fits into the muzzle, and which has a flange or shoulder to cover the muzzle-face; rings of gutta-percha are placed between them; an iron rod with a ring in one end, to fit over the trunnion, and with a thread cut on the other end, is used on each side of the gun, to connect the trunnions with the cross-head. The whole is set up with nuts, and the pressure on the rings makes a tight joint; a coupling on the cross-head receives the hose, and the water is forced into the gun through a hole in the wooden block. Care should be taken that the valve is loaded with the proper weight for proof.

In the construction of the *built-up* steel-lined cannon of the English service, the steel tubes are subjected, after toughening in oil, to a water-pressure in the interior of 8,000 lbs. per square inch, to detect any latent cracks; and after the powder-proof they are subjected to a pressure of 120 lbs. on the square inch, to make sure that the end has not been split at proof.

601. Extreme Proof of Trial-guns.—The extreme proof of guns intended for trial of metal is conducted as follows:

A suitable butt is erected to arrest the flight of the projectiles used in proof, and to admit of their easy recovery, and a bomb-proof, readily accessible, for the protection of the firing-party.

After undergoing the ordinary proof established for its calibre and class, the gun selected for extreme proof is subjected to at least 1,000 rounds with service-charges.

It may be fired from skids or suspended.

During the trial the gun is frequently and critically examined, inside and out, for cracks or defects, especially about the interior orifice of the vent, of which impressions are taken in wax at regular intervals.

If they show that the vent is corroded in furrows, and enlarged considerably in diameter at its juncture with the bore, a permanent impression is to be taken in lead, to show the conical enlargement.

602. Enlargement of Vents.—When, from the appearance of the bore at the interior orifice of the vent, it is evident that the latter has enlarged beyond the limit of safety, and especially when a crack or cracks appear to be extending rapidly, the vent so enlarged may be filled with melted tin or zinc; a

tight-fitting sponge-head being pushed to the bottom of the chamber to close the interior orifice—and the other vent being drilled through for the purpose of continuing the firing. The precise time at which this is to be done will vary according to circumstances; such as quality of metal, charge, and elevation.

603. The endurance of a smooth-bored gun with service-charges may be surely predicted by observation of the progressive wear of the interior orifice of the vent. There are certain general forms in which this enlargement takes place. They may be classed as triangular, lozenge, quadrilateral, star, circular, and elliptic. (See Plates in Ord. Ins.)

With the lateral vent of the Dahlgren system, it usually takes the lozenge form, the cracks extending from the opposite angles lengthwise of the bore.

With those rifled-cannon in which the vent is bouched, the cracks appear around the bouching, and although the bouching preserves the vent, yet the formation of fissures around the enlarged orifice, when once commenced, causes a greater tendency to rupture. With the vent not bouched, the wear in rifle-cannon is about double that of the smooth bore.

So long as the wear of the vent is regular and without cracks, a mere enlargement is not indicative of danger; but when it reaches a diameter of four-tenths of an inch, the vent should be closed and a new one opened.

604. A gun of large calibre should not in service be expected to stand more than 400 or 500 rounds before it will be necessary to open the new vent, which, however, will be of no advantage unless the old one be closed at its interior orifice, on which the gases otherwise would continue to act as a wedge.

The first distinct appearance of the cracks, as shown by the button, is the proper limit.

After the gun bursts, a sketch or draft is made showing the lines of fracture, and specimens are reserved for trial of density and tensile strength; and, if practicable, a photograph is taken.

605. Endurance of Guns in Service.—The principal injuries caused by service are internal, arising from the separate action of the powder and the projectile. They increase in extent with the calibre, whatever may be the nature of the gun, but are modified by the material of which it is made.

606. Injuries from the Powder.—The injuries from the powder generally occur in rear of the projectile. They are, 1st. Enlargement of that portion of the bore which contains the powder, arising from the compression of the metal. This

injury is more marked when a sabôt or wad is placed between the powder and the projectile, and is greatest in a vertical direction. 2d. Cavities produced by the melting away of a portion of the metal by the heat of combustion of the charge. 3d. Cracks arising from the tearing asunder of the particles of the metal at the surface of the bore. At first a crack of this kind is scarcely perceptible, but it is increased by continued firing until it extends completely through the side of the piece. It generally commences at the junction of the chamber with the bore, as this portion is less supported than the others. 4th. Furrows or scoring produced by the erosive action of the inflamed gases. This injury is most apparent where the current of the gas is most rapid, or at the interior orifice of the vent, and on the surface of the bore, immediately over the seat of the projectile.

607. *Scoring* commences very early in large guns; at first, it is only a mere roughness, which gradually increases in depth and forms lines along the bore; but it is not until a gun has been fired very considerably that it becomes of importance.

The impressions of deep scoring resemble the bark of an old elm-tree, the metal being eaten away into irregular furrows and ridges. Even when it has reached this extreme case, however, scoring has not caused the destruction of the gun, though in some instances, acting like a wedge, it has split the bore at that part.

Some experimental guns, excessively scored on the upper side of the bore, have been turned over, vented and sighted on the under side, but this has not been found necessary until the gun has been used more than is probable under ordinary circumstances.

608. Injuries from the Projectile.—The injuries arising from the action of the projectile occur around the projectile and in front of it. They are:

1st.—Indentation in the lower side of the bore, produced by the pressure on the projectile by the escape of gas through the windage, before the ball has moved from its seat. The elasticity of the metal, and the burr, or crowding up, of the metal in front of the projectile, cause it to rebound, and, being carried forward by the force of the charge, to strike against the upper side of the bore, a short distance in front of the trunnions. From this it is reflected against the bottom, and again reflected against the top of the bore, and so on until it leaves the piece.

The first is called "indentation," and the others are called "enlargements."

In pieces of ordinary length, there are generally three enlargements when this injury first makes its appearance, but their number is increased as the "indentation" is depressed and the angle of incidence increased. The effect of this bounding motion is alternately to raise and depress the piece in its trunnion-holes, and to diminish the accuracy of fire, until finally the piece becomes unfit for service.

It is principally from this injury that bronze guns become unserviceable. Mortars and howitzers are not much affected by it.

The principal means used to prevent this injury are to wrap the projectile with cloth or paper, and to shift the seat of the projectile.

The latter may be done by a wad or lengthened sabôt, or by reducing the diameter and increasing the length of the cartridge. The last of these methods is considered the most practical as well as the most effective; and it has the additional advantage of decreasing the strain on the bore, by increasing the space in which the charge expands before the ball is moved.

2d. Scratches or furrows made upon the surface of the bore by rough projectiles, or by case-shot.

3d. Cuts made by the fragments of projectiles which break in the bore.

4th. Wearing away of the lands of rifle-cannon, especially at the dividing edges. A little rubbing of the side of the grooves from the friction of hard bearings is of little importance.

5th. Enlargement of the muzzle, arising from the forcing outward of the metal by the striking of the projectile against the side of the bore as it leaves the piece. By this action the shape of the muzzle is elongated in a vertical direction.

6th. Cracks on the exterior. These are formed by the compression of the metal within, generally at the *chase*, where the metal is thinnest. This portion of a bronze gun is the first to give way by long firing, whereas cast-iron guns usually burst in rear of the trunnions, and the fracture passes through the vent, if it be much enlarged.

609. Descriptive List of Guns.—Before sailing, the Inspector of Ordnance furnishes the Commander with a descriptive list of his battery, together with a statement of the number of times each gun on board has been fired, in the following form (a copy of which the Commander transmits to the Bureau of Ordnance before sailing; this list is returned to the Inspector of the yard to which she may return, with all additional firing, noted opposite the number of each gun, certified correct by the Commander):

Class of Gun.	Marks on base-ring.			Trunnions.		Pivot or Broadside.	Where Received.	No. of fires to date.
	Regr. No.	Weight.	Foundry.	Right.	Left.			

610. *Set of Vent Impressions.*—The Inspector also furnishes the Commander with a set of leaden impressions of the interior orifice of the vents of the guns, secured in a suitable box, that he may be able to compare the wear and gradual enlargement. These are transferred with the guns to other ships, or when landed. (Fig. 97.)

611. INSPECTION AT TERMINATION OF A CRUISE.—At the termination of a cruise the guns are carefully examined by the Ordnance Officer of the Yard, and such others as may be directed, with the view to discover and report any injuries which they may have sustained in service, or any defects which may not have been developed in the original proof.

FIG. 97.—Vent Impressions.

Before proceeding to examine a gun the bore should be thoroughly cleaned; it will generally be sufficiently prepared for examination by washing, sponging, and drying.

If, however, there be hard rust or a coating of any kind on the surface of the bore, it may be cleansed either by firing, if circumstances admit, one or two sealing-charges, about one-third the full charge, without projectiles, which will usually loosen the scale; or the bore may be scrubbed out with hot water and potash.

No sharp-edged or pointed scraper should be employed for cleansing the bores of rifled-guns, as they are unnecessary and liable to injure the rifling.

612. In this examination the attention of the Inspecting Officers is directed to the following points, viz.:

Enlargement of the interior orifice or exterior orifice of the vent.

Indentations or hollows produced by the projectile *balloting* against the surface of the bore, or by the action of the gases.

Cuts or scratches in the bore, produced by fragments of broken, or roughness of imperfect, projectiles.

Roughness or corrosion of the metal on the exterior, produced by neglect or exposure.

Similar injuries in the bore, or any enlargement of the bore, which is to be ascertained by measuring with the star-gauge, at every one-fourth of an inch, from the bottom of the cylindrical part to the seat of the projectile, every inch from that point to the trunnion, thence every five inches to the muzzle, and the results recorded in the usual form, and reported to the Bureau, that they may be compared with those noted at the original inspection.

In rifled-cannon, cracks or injuries produced by firing, or the rupture of shells, are to be sought for, around and in the rear of the vent bouching; on the top of the bore, between the trunnions and reinforce-band; on the lower side of the bore, near the seat of the projectile, at the junction of the lands and the grooves; near the inside of the muzzle, caused by explosion of shells.

Care is to be taken that the distinguishing marks and numbers are always accurately noted, that the correct history of each gun may be preserved.

613. Inspection of Vents.—As the best indication of the amount of firing to which any smooth-bored gun has been exposed, when it is not otherwise known, is given by the enlargement of the vent; particular attention is paid, in the re-inspection of the guns, to this point. The standard gauge is used to ascertain the general enlargement, and the searcher to detect defects which may have been developed in firing. Impressions are taken of the lower orifice of the vent with softened wax, and if they show that the vent is corroded in furrows and enlarged considerably in diameter at its junction with the bore, a permanent impression is to be taken in lead to show the conical enlargement.

614. When the number of rounds fired is not known, an estimate may be made from an examination of the vent by cylindrical gauges, differing from each other by .01 inch, passed through it.

In all the guns of the Dahlgren pattern the vents are two-tenths of an inch in diameter.

Observation of the wear of the vent in proof-firing of smooth-bored guns gives the following as the average diameter of the vent, after the under-mentioned number of fires:

No. of Rounds.............	100, 200, 300, 400, 500.
Diameter of Vent...........	.24, .26, .30, .35, .40.

These combined with examination of the interior orifice, will enable a very correct judgment to be formed of the probable number of fires sustained and duration of the gun.

The larger the calibre and the heavier the charge, the more promptly the wear is manifested on the interior and exterior.

The enlargement does not extend very far from the lower orifice until the enlargement of the exterior has reached a diameter of .3 of an inch. So long as the wear is regular, and the cracks, although numerous, do not exceed .5 of an inch in length, the indications are good. If the cracks are but few or diminish in number, running into each other and extending rapidly, it is a very unfavorable sign. In the rifle-cannon (Parrott's) cracks athwart the bore, either running into the bouching or into the rear of it, are very unfavorable to the gun's endurance.

CHAPTER IV.

BUILT-UP GUNS.*

Section I.—Principles of Construction.

615. GENERAL CONSIDERATIONS.—No modern theory of constructing guns can be called new, since guns are in existence that have been either recovered from wrecks, or preserved in other ways, showing every variety of coils, hoops, casting, wire-binding, and so on, as far as the appliances then in use could furnish the quondam inventors with means of carrying their inventions into effect.

That in which novelty has been attained, is the improvement of processes by which large castings or forgings, accurate turning and boring, can be secured, or by which chemical knowledge can be brought to bear on the manipulation of metals; but no such progress can make a built-up gun, or machine of any sort, stronger than a perfectly homogeneous one, in which the varying strains are closely calculated and properly met by the scientific disposition of the necessary strength.

616. DEFINITION.—The terms "*built-up*" and "*hooped*" are applied to those cannon in which the principal parts are formed separately, and then united in a peculiar manner. They are not necessarily composed of more than one kind of metal; some of the most important are made of steel alone; and they may be made by welding or by screwing the parts together, and by shrinking or forcing one part over another.

617. OBJECT.—The object of this method of manufacture is to correct the defects of one material by uniting with it opposite qualities of the same or other materials. The defects which follow the working of large masses of iron or steel, such as crystalline structure, false welds, cracks, etc., are avoided by first forming the parts in small masses of good quality and then uniting them separately.

618. NATURE OF THE FORCE TO BE RESTRAINED.—In considering the effect upon a yielding material of any force which may be applied, the rate of application of the force, or the time which elapses from the instant when the force begins to act, until it attains its maximum, should not be neglected; for, with equal ultimate pressures per square inch of surface, that force

* Compiled by Lieutenant J. C. Soley, U. S. Navy.

will be most severe upon the gun which attains this pressure in the shortest period of time. (Chap. II.)

619. HOW TO INCREASE THE STRENGTH OF A GUN.—The most obvious method of enabling a gun to sustain a greater elastic pressure is simply to thicken its sides, thus increasing the area of the parts to be torn asunder. This rule has been found to work practically with guns of small calibre, but in larger guns it does not work, from the fact that, in cast guns, of whatever metal, the outside helps but very little in restraining the explosive force of the powder, the strain not being communicated to it by the intervening metal. The consequence is that, in large guns, the inside is split while the outside is scarcely strained. This split rapidly increases, and the gun ultimately bursts.

620. *Example.*—If we make equidistant circular marks on the end of an India-rubber cylinder (Fig. 98), and stretch it, we can plainly see how much more the inside is strained than the outside, or even the intermediate parts; the spaces between the marks will become thinner, each space becoming less than that outside of it; but the inner spaces, much thinner than the others (Fig. 99), showing that when the inside is strained almost to breaking, the intermediate parts are doing much less work, and those far removed almost none.

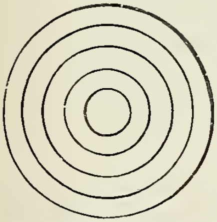


FIG. 98.—India-rubber cylinder, with equidistant concentric marks.

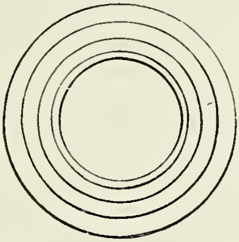


FIG. 99.—The same cylinder, stretched by internal pressure; the concentric marks show the inferior stretch of the exterior.

621. LIMIT TO THICKNESS OF METAL.—Now, if we take any transverse section of a gun, any unit in length, and suppose the metal to be divided into any number of concentric rings, it will be evident that the greater the distance of any ring from the axis of the gun, the less will it be stretched by the expansion of the bore when the piece is discharged, and consequently the less will it contribute to the general strength of the gun. If the strain upon the bore from the discharge be considered merely as a pressure,—statical force,—the resistance offered to it by any two rings will be inversely proportional to the square of their circumferences or distances from the axis of the gun.

622. It will, therefore, appear that there is a certain limit beyond which it would be useless to increase the thickness of the metal, viz.: When the force exerted on the surface of the bore would be sufficient to rupture the interior portions of the metal before the strain acted to any extent upon the exterior parts. Any arrangement of the parts by which the explosive strain is distributed equally over the entire thickness of the piece, necessarily brings a greater amount of resistance into play. In order to obtain the requisite resistance, and with a moderate thickness of metal, it is desirable to equalize, as far as possible, the strain upon every portion of the metal.

623. METHODS OF EQUALIZING THE STRAINS.—There are two general methods of accomplishing this, viz.: *First*, by giving the exterior portions a certain *initial tension*, gradually decreasing and passing into compression towards the interior, which is done by shrinking heated iron bands or tubes around the parts to be compressed, or by slipping a tube into the bore, which has been slightly enlarged by heat.

Secondly, by means of the system of *varying elasticity;* this is accomplished by placing that metal which stretches most within its elastic limit around the surface of the bore, so that, by its enlargement, the explosive strain is transmitted to the other parts.

These two methods of equalizing strains without an inordinate increase of thickness, are so important that they deserve more than a passing notice. They are called the systems of Initial Tension and Varying Elasticity. Some gun-makers use the one, some the other, some a combination of the two, and even in our own hollow-cast guns the idea of Initial Tension is one of primary importance.

624. PRINCIPLES OF SYSTEM OF INITIAL TENSION.—The system of Initial Tension consists in making a gun of concentric tubes, by putting on each successive layer, proceeding outward from the centre, with an initial tension exceeding that of those below it; in other words, so that each hoop shall compress the one within it. The inner layer is thus in compression while the outer layer is in the highest tension. The inner layer is able to sustain the first and greatest stretch, and the outer layer, although stretched less by the explosion of the powder, has already been stretched into high tension, and thus has to do an equal amount of work. The intermediate layers bear the same relation to the initial strain, and to the strain of the powder, so that, in short, all the layers contribute equally of their tensile strength to resist the strain of the explosion.

625. DEFECTS OF THE SYSTEM.—Each hoop, or tube, has this

element of weakness that its inner circumference is more stretched than its outer one. Absolute perfection would necessitate infinitely thin hoops, and, practically, the thinner the layers the greater will be the strength, provided the mechanical difficulties in constructing, and more especially in applying, a great number of thin strata with the proper tension do not outweigh the advantages.

626. Methods of Application.—The two principal methods of applying the system are by *shrinking* on, or by *forcing* on, the hoops.

627. *Shrinking.*—If the hoops are put on by shrinking, two embarrassments arise: *First*, the hoops must be accurately bored, and after each layer has been put on, the gun must be put in a lathe and the outside turned. Great accuracy of labor is required—labor of the most expensive class.

Secondly, the process of shrinking on is not to be depended upon; not only is there a difficulty in insuring the exact temperature required, but scarcely any two pieces of iron will shrink identically. The fitting of hoops with nice adjustment would be difficult, theoretically; practically, it would not be done. But the chief embarrassment is the unequal effect of heat.

In the first place, heating the layers over a fire to expand them subjects one part to more heat than another; the temperature of the surface and interior are unequal, thus causing irregular strains. This may be remedied by boiling the hoops in oil, which would toughen as well as expand the hoops. In the second place, the hoops are often heated to redness when oxydation takes place. The internal diameter of the hoop is increased, and scale is left between some parts and not between others. In the third place, cast-iron and steel sensibly and permanently enlarge in proportion to the amount of carbon they contain when subjected to the heat.

628. *Forcing on.*—Whitworth and Blakely advocate the method of forcing the hoops on with hydrostatic pressure. The forcing of a slightly conical ring over a correspondingly conical tube obviates the necessity of great accuracy in the diameter of either pieces. The truth of the cone depends upon the correctness of the lathe. The truth of the surfaces is also a question of good tools. The tension of the ring depends on the distance to which it is forced in the conical tube, and this may be regulated by the safety-valve of the hydrostatic press. With special tools, and when correctness depends upon the mechanical appliances, which can be adjusted with the utmost nicety, an inexpert workman could hardly fail to do well.

629. Principles of System of Varying Elasticity.—Let us now suppose the hoops or tubes forming a gun to be fitted together accurately, but without tension. If the inner hoop is very elastic, and the next less elastic, and so on throughout the series, the outer hoops being the least elastic, and the degree of elasticity being exactly proportioned to the degree of elongation by internal pressure, all the hoops will be equally strained by the powder, and none of their strength wasted. If the inner hoops be stretched by the powder-pressure $\frac{1}{10}$ of an inch, and the outer hoop $\frac{1}{100}$ of an inch, the material of the inner hoop should have such elasticity that it should be no nearer its breaking-point when stretched $\frac{1}{10}$ of an inch than the less elastic outer hoop when stretched $\frac{1}{100}$ of an inch. Both hoops would then be equally strained by the powder, and oppose an equal resistance to it.

630. Defects of the System.—It has been found difficult to obtain materials having the respective ranges of elasticity necessary to perfectly carry out this system. For this reason the outer tube or tubes are sometimes put under an initial tension equal to the working load, in order that the work done may be equal for all. This severe and permanent strain on the outer tube, of course, tends to relax it; but if the inner tube can stretch very much without injury, and the outer tube can only stretch a little, the permanent strain upon all parts of the gun, in order that it may be uniformly strained under fire, will be slight, and the tendency to relaxation limited.

631. Longitudinal Strength.—Care must be taken to have sufficient longitudinal strength. The theoretical resistance of a cylinder under internal pressure to cross fracture is four times as great as its resistance to splitting longitudinally, if the tenacity of the metal is the same in all directions. To obtain strength in this direction, some circumferential strength may be sacrificed by making one part the length of the entire gun, and of adequate thickness. It is probably better that this single large piece should be inside, and this is the general practice.

632. Length of Hoops.—Hoops of considerable length are desirable to add to the frictional surface, thus giving longitudinal strength to the gun. But length or continuity is chiefly desirable to transfer the strain upon one point to a large resisting area.

633. Number of Hoops.—An obvious disadvantage of a large number of hoops is that the transverse strength of the gun is much reduced.

634. Want of Continuity.—A hooped gun must always

possess the defect of want of continuity of substance. However perfect the workmanship at first, in large guns the jar of repeated firing would soon shake them loose. The great defect in the Armstrong guns was developed in the shaking loose and fracturing of some of the hoops under the tremendous vibration due to firing large charges.

635. VIBRATION.—Both the means, that have been considered, of increasing the resistance of a gun to *mere pressure*, are perfected only in proportion to the number of separate tubes or layers employed; but on the other hand, increasing the number of parts lessens the resistance of the body to the effect of *sudden strain*. When a gun is fired the shock is propagated from layer to layer in a wave; if the layers are already detached tubes, the outer one has no help from the rest in resisting the vibration, and the only way to modify the effect of the wave of force upon the outer layer is to give that layer great mass and thence inertia.

636. CONCLUSIONS.—To sum up briefly the principles of gun construction, merely thickening the walls of a gun beyond a certain point adds very little to its resistance to internal pressure. A homogeneous gun, in a state of initial repose, however thick it may be, cannot sustain permanently a pressure per square inch greater than the tensile strength of a square inch of the metal of which it is composed. The reason is that the inner layers of metal are more stretched and strained by an internal pressure than the outer layers, in the inverse ratio of the squares of their diameters. Therefore, the layers must be placed under such initial strain, or must possess such varying elasticity that all parts of the gun will be equally worked at the instant of firing.

Both these conditions are perfectly carried out in proportion to the number of separate layers or tubes thus treated; but the wave of force (in distinction from statical pressure), and the effects of unequal vibration, *distress* a gun in proportion to the number of its parts, so that the building-up principle cannot be carried far without depriving the gun of the necessary mass and continuity of substance.

637. The system of hoops with initial tension, although theoretically perfect and an acknowledged improvement in the construction of ordnance, involves certain practical difficulties. When several thicknesses of hoops are used, it is difficult to maintain the proper longitudinal strength, and it has been found that a gun composed of two or three tubes, although not so strong to resist statical pressure as one composed of five or six tubes, would resist a greater number of heavy charges of gunpowder and prove a more trusty weapon.

638. With the present materials, it would be almost impossible to insure uniformly a degree of elasticity in the different layers, exactly proportional to their respective elongations under fire. The Initial Tension system, slightly modified, may be brought to the aid of the system of Varying Elasticity. If the internal tube of a gun cannot stretch to the extent required without injury, placing the external tube in slight tension will remedy the defect; then the inner tube will have a greater range of safe elongation, and the outer tube will take a greater share of the strain.

Section II.—The Parrott Gun.

639. General Description.—The Parrott Guns used in the United States Navy are chiefly the 100-pdr. and 60-pdr. They were fabricated exclusively by Capt. Parrott, at the West Point Foundry; none have been manufactured since 1865.

The peculiarity consists in the fact that the gun is a cast-iron piece strengthened by shrinking a coiled hoop of wrought-iron over that portion of the body which surrounds the charge.

640. The Barrel.—The cast-iron main portion, or body, A (Fig. 100), is made like any ordinary cast-iron gun, except that it is a little lighter at the breech. The body of the 100-pdr. is cast on a core, that of the 60-pdr. is cast solid. The

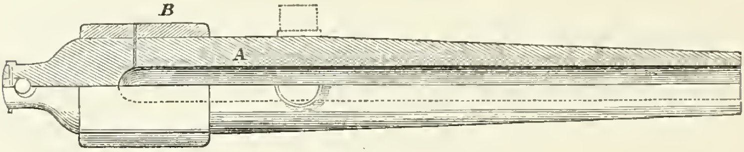


Fig. 100.

body having been bored, has that portion of its exterior which is to receive the reinforce turned to a cylindrical form, and of a diameter about $\frac{1}{10}$ of an inch to a foot larger than the interior diameter of the reinforce when cold.

641. The Hoop, B, is formed by bending a rectangular bar of iron spirally round a mandrel and then welding the mass together by hammering it in a strong cast-iron cylinder. In bending the bar, the outside, becoming more elongated than the inner one, is diminished in thickness, giving to the cross section of the bar a wedge-shape which possesses the advantage of allowing the cinder to escape through the opening, thereby securing a more perfect weld.

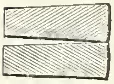


Fig. 101.

642. Placing the Reinforce.—The body is placed in nearly a horizontal position upon bearings which permit it to be rotated on its axis, and which will permit the reinforce to be put on when sufficiently expanded by heating it; a pipe is introduced into the muzzle for conveying a constant stream of cold water to the bottom of the bore. When the reinforce has been properly heated, and so expanded as to enable it to pass loosely on to the body, it is placed in its position on the body, and cold water is introduced into the bore and the body is rotated on its axis. By this rotary movement, the reinforce, while hanging loosely on the body, is prevented from remaining in contact with it at any one point, and so prevented from cooling first at this point. By the introduction of the water which likewise passes out at the muzzle, the heat, imparted to the body by the reinforce, is carried off, and the body is prevented from being materially expanded, and so lessening the pinch or force with which the reinforce finally binds upon it.

643. As soon as the reinforce is found to bind upon the body, it is covered with sand or some other non-conductor of heat, the flow of water continuing until the gun is entirely cold. The object of so covering up the reinforce is to prevent the outer portion from cooling and contracting quicker than the inner portion, and to cause the reinforce to bind more firmly upon the body. The thickness of the reinforce when finished by boring the interior and turning the exterior is about equal to from .4 to .5 the calibre of the gun, and its length sufficient to cover the usual charge of powder extending a distance of one calibre in rear of the bottom of the bore and one calibre in front of the seat of the charge. The principle of construction is that of Initial Tension.

644. *The Vent* is bored perpendicularly, and enters the bore at the distance of half a calibre from the bottom of the bore. It is made in a bouching of pure copper screwed into the gun. The upper portion of the copper is replaced by steel $\frac{3}{4}$ in. thick, to obtain a harder surface for the blow of the hammer.

Section III.—British Naval Guns.

645. THE ARMSTRONG SYSTEM.—To Sir William Armstrong is undoubtedly due the merit of employing wrought-iron coils shrunk together to form a gun.

His main principles of gun architecture consist essentially:

646. *First*, in arranging the fibre of the iron in the several parts of the gun so as best to resist the strain to which they

are respectively exposed; thus the walls or sides of a gun are composed of coils with the fibre running round the gun, so as to enable the gun to bear the transverse strain of the discharge without bursting; whilst the breech is fortified against the longitudinal strain or tendency to blow the breech off, by a solid forged breech-piece with the fibre, running along the gun.

647. *Secondly*, in shrinking the successive parts of the gun together so that not only is cohesion throughout the mass insured, but the tension may be so regulated that the outer coils shall contribute a fair share to the strength of the gun.

With regard to the first principle, a gun may be destroyed either by bursting the barrel or by blowing off the breech. Now wrought-iron in the direction of its fibre is about twice as strong as it is in the cross-direction; hence the best way to employ it to resist the transverse strain, is to wrap it round and round the piece like a rope. This is the foundation of the Armstrong Coil System.

For a similar reason the best way to resist the longitudinal strain is to place the fibre lengthways; so a breech-piece was made from a solid forging with the fibre in the required direction.

With regard to the second principle, it has been shown that the strength of a gun is not proportional to its thickness, and the gun should be constructed so that each part of its mass would do its proportion of work at the instant of firing.

648. The Armstrong Gun.—The Armstrong System is the basis of the system now in use in Great Britain, and a description of the 9-inch, 12-ton gun is given, as a type of the Armstrong System, although it is nearly obsolete. It was the method of construction up to April, 1867, for all heavy guns. (Fig. 102.)

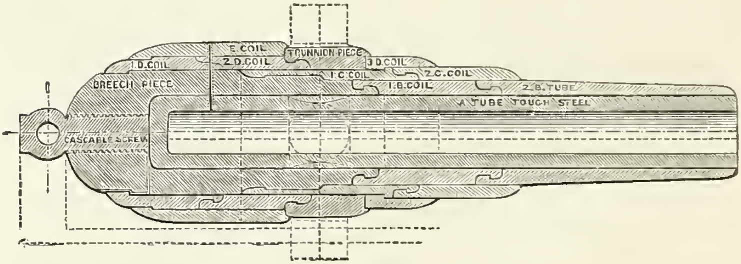


Fig. 102.

649. *Number of Parts.*—The gun consists of a solid ended

steel barrel, a forged breech-piece, a cascabel, a B tube, a trunnion-ring, and seven coils: twelve separate parts.

650. *The Barrel, or A Tube.*—The steel cylinder, having been bored for a barrel, and toughened in oil, is turned on the exterior to suit the interior of the breech-piece.

651. *The Breech-piece* is built by a series of wrought-iron slabs being successively molded together, and then drawn out, bored, and turned. The breech-piece will not fit on the steel tube when both are cold, the difference in size being the designed shrinkage. The breech-piece must then be expanded by heat until it is sufficiently large to go over the end of the steel tube, where it is allowed to cool and shrink.

652. *Cascabel.*—The screw is then cut for the cascabel in the breech-piece, the end of the screw fitting evenly against the end of the barrel. The cascabel is a solid forging of wrought-iron.

653. SHRINKING ON THE COILS.—The mass is now turned down for the B coil, which is shrunk on. The coils are heated over a wood-fire and placed in position as soon as they are sufficiently expanded, jets of water being turned on to assist in shrinking them. The B tube is then shrunk on, and so on, coil by coil, until the whole gun is shrunk up.

654. COILS AND TUBES.—To make a coil, a bar is taken of the shape shown in the figure (103), heated, and drawn, while hot, upon a revolving mandrel and coiled into a close spiral of any required diameter, the narrower side of the bar being placed next to the mandrel; in winding, the section of the bar is changed to rectangular. The spiral is heated, placed on end under a hammer, and *upset* into a hoop (Fig. 104), the sides of all the adjacent coils being thus welded together. The hoop is also patted on the outside to preserve its cylindrical form. The rear coils are flanged to hook over the breech-piece. Two coils or hoops form the B tube; one of these is turned down at one end forming a shoulder half an inch long, and the other has a corresponding recess (Fig. 105). This last, having been expanded by heat, is fitted to the other, and the recess contracts on to the shoulder (Fig. 106). They are then heated, slipped over a loose

FIG. 103.

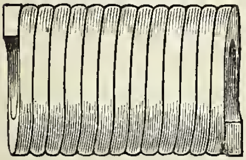


FIG. 104.—Bar coiled to make a hoop.

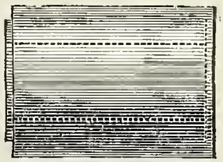


FIG. 105.—Hoop recessed to fit others.

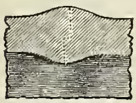


FIG. 106.—Section of weld.

mandrel, and hammered to perfect the weld, thus forming the B tube.

655. THE TRUNNION-RING is made of slabs of iron consecutively welded together on the flattened end of a *porter-bar*, and gradually formed into a ring by slitting the pile with a small iron wedge, and then with a series of taper mandrels. The trunnions are hammered at the same time out of the ends of the pile. It is then cut off from the end of the porter-bar, the ring bored and slightly recessed to fit a corresponding projection on the coil beneath it, and is slipped over when sufficiently expanded by heat.

656. THE FRAZER SYSTEM.—Mr. Frazer's plan is an important modification of Armstrong's, from which it differs principally in building up a gun of a few long double and triple coils, instead of several short single ones, and a forged breech-piece. (Fig. 107.)

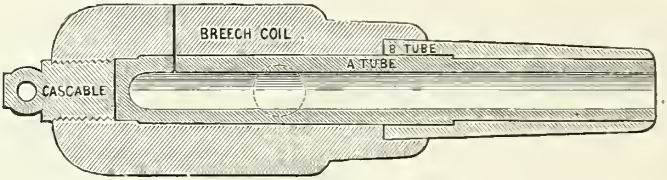


FIG. 107.—Frazer 9-inch.

657. Great expense is saved by this means, as there is much less surface to be bored and turned. With respect to theory, it may be urged in its favor, in the first place, that a forged breech-piece (which is comparatively expensive and liable to fly into fragments, should the gun burst) is not required with a solid ended steel-barrel and long thick coils, although it is necessary with several short coils to compensate for the longitudinal weakness of their joints. The whole of the wrought-iron, therefore, can be coiled round the barrel, and thus give extra transverse strength. Again, the trunnion-ring, which was shrunk on in the original construction, is welded on to the breech coil in the Frazer plan, so that there is no fear of slipping.

658. With regard to the second Armstrong principle, although a series of thin coils helps us to distribute the induced strain upon a gun by shrinking on each coil separately, the method is open to the serious objection, that it is practically difficult to calculate the respective proportionate amount of extension, and, consequently, the greater the number of pieces in a gun, the more likely that some weakness will exist in the mass owing to the undue strain on some of its parts.

659. Shrinking on the coils successively was adopted by Sir William Armstrong, as a convenient mode of adhesion, and not on the distribution theory. In the formation of a triple coil, it is generally a manufacturing necessity to have the first coil cold before the second bar is wound round; but the third bar is wound on while the second coil is hot; the second and third layers, therefore, contract nearly simultaneously, and are kept in a state of tension, by the first which they compress to a certain degree, thus carrying out the theory of Initial Tension.

660. But the grand decisive fact bearing upon this question, was the favorable result of the trials for comparative endurance, which the 64-pounder and 9-inch specimen guns underwent, and in virtue of which the Frazer system superseded the original single coil system of Armstrong, towards the close of 1866.

661. THE WOOLWICH GUN.—The name "Woolwich Gun" is the term applied to all the guns manufactured in England since 1866. The term is a comprehensive one, and might be expanded into "Wrought-iron-muzzle-loading-guns, built on Sir William Armstrong's principle, modified by Mr. Frazer, improved by Mr. Anderson's method of hooking the coils with solid-ended steel tubes toughened in oil, rifled on the French system, modified as recommended by the Ordnance Select Committee, for projectiles studded according to Major Palliser's plan."

662. Details of the Gun.—The gun consists of:

(1.) An A tube.
(2.) A B tube.
(3.) A breech-coil.
(4.) A cascabel.

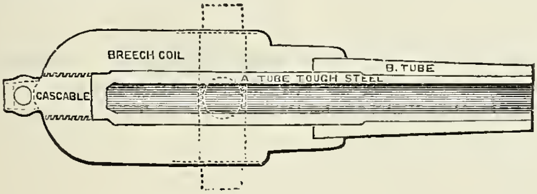


Fig. 108.

663. (1.) *The A tube*, or inner barrel (Fig. 109), is made from a solid forged cylinder of cast-steel, which is supplied to the Royal Gun Factory by Messrs. Firth, of Sheffield. Casting is necessary, not only for the purpose of obtaining a sufficiently large block of steel, but also of making the block homo-

geneous and uniform in density. Forging imparts to it the properties of great solidity and density.

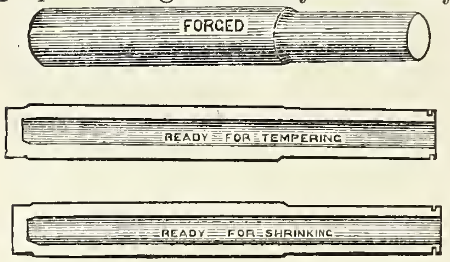


Fig. 109.

A piece is cut from the block at the breech end, and divided into small pieces which are tested for tensile strength and elasticity in the natural state, and also to ascertain at what temperature the block can be immersed in oil to the best advantage.

A steel-block which stands all the tests, is rough-turned, in which operation a lip is formed on the muzzle to facilitate lifting the tube into or out of the furnace or oil-bath. It is then bored roughly from the solid.

The tube thus formed is heated from four to six hours to the approved temperature in a vertical furnace, and then plunged into an adjacent bath of oil, in which it is allowed to cool and soak, generally twelve hours. It must then be turned and bored to make it straight inside and outside, and to remove any flaws.

It is then subjected to the water-test of 8,000 pounds per square inch, and, if no flaw is detected, the barrel is considered safe, and remains in this condition until the B tube is ready to be shrunk over it.

664. (2.) *The B tube* is composed of two single and slightly taper coils united together (Fig. 110). The two coils, being made and welded in the usual manner, are faced and reciprocally recessed to the depth of about one inch, and then united together endways by expanding the recess of a coil by heat, and allowing it to shrink around the shoulder of the other (Fig. 111). This holds the two coils together enough to allow the tube thus formed, to be placed upright in a furnace; when it arrives at welding-heat, it is removed to a steam-hammer, and receives on its end six or seven blows,

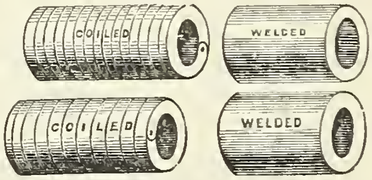


Fig. 110.

Fig. 111.

which weld the joint completely. The tube is next rough-turned, in which process a rim is left near the muzzle for convenience in lifting, and then rough and fine bored (Fig. 112). The interior of the B tube having been brought to the required smoothness for contact with the steel barrel, it is gauged every twelve inches down the bore, and at the shoulder.

Fig. 112.

To the measurement the calculated amount of shrinkage is added, and the exterior of the A tube is turned so that it shall be exactly larger than the interior of the B tube by the required amount of shrinkage.

665. (3.) *The Breech-coil* is composed of a *triple-coil*, a *double-coil*, and a *trunnion-ring*. The triple-coil (Fig. 113) is made of three bars, all of the same section, but differing, of course, in length; the middle one is coiled in a reverse direction so as to break joints. To weld the folds, it is raised to welding-heat in a furnace, and hammered on end; then a mandrel is forced down inside from either end, and it is hammered on the outside, being heated before each operation. When cold, the ends are faced, and the outer coil is turned down at the muzzle end to form a shoulder for the reception of the trunnion-ring.

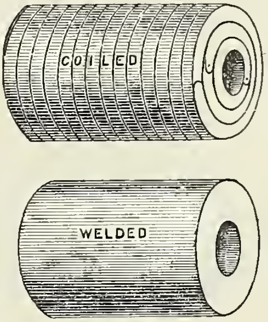


Fig. 113.

The double coil (Fig. 114) is made of two bars of the same section as those of the triple coil, but of different lengths. It is made in the same manner as the triple coil, and it has a shoulder formed at its lower end, so that it may overlap the trunnion-ring.

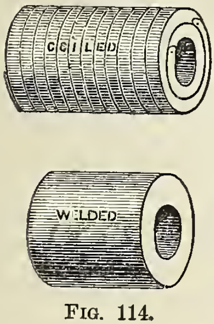


Fig. 114.

The trunnion-ring (Fig. 115) is made like all wrought-iron trunnion-rings, being built up on the end of a porter-bar.

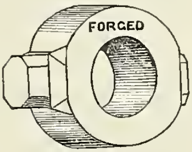


Fig. 115.

All these parts, triple-coil, double-coil, and trunnion-ring, being thus prepared, the trunnion-ring is heated to redness and dropped on the shoulder of the triple-coil, which is placed upright on its breech end for this purpose; while the trunnion-ring is still hot, the double-coil is dropped down on the front of the triple-coil through the upper portion of the trunnion-ring, which thus forms a band over the joint, and in cooling grips the two coils (Fig. 116) sufficiently to admit of the whole mass being placed bodily in the furnace, where it is raised to welding-heat. It is then placed on its breech end under a heavy hammer; six or seven blows suffice to amalgamate all the parts; but to make the weld more perfect in the interior, a cast-iron mandrel is forced down the bore to within 20 inches of the breech. The mass is then reversed, and the mandrel driven out again. It is then turned and bored. The front of the double coil is recessed to a distance of nine inches, and deep enough to overlap the B tube. Finally the thread is cut for the cascabel. (Fig. 117.)

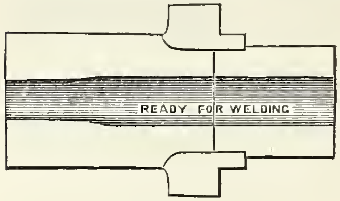


Fig. 116.

666. (4.) *The cascabel* is made of the best scrap-iron. It is first forged into a single cylinder, then turned, and a bevel thread cut on it. A hole which is afterward enlarged to a loop is drilled through the end. (Fig. 118.)

One round of the thread is turned off at the end of the cascabel, so that there may be an annular space there, which, in connection with the channel now cut along the cascabel and across the threads $\frac{1}{16}$ inch in depth, forms the gas-escape which comes out at the right side of the loop. This will give notice, in case the steel tube should split.

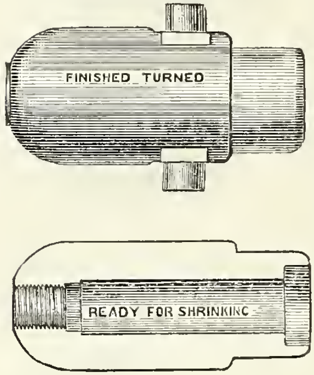


Fig. 117.

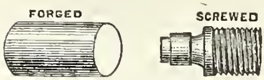


Fig. 118.

667. Building up the Gun.—The A tube and the B tube, being prepared as described, are shrunk together in the following manner: the B tube is placed over a grating, and heated for about two hours by a wood-fire, for which the tube itself forms the flue, until it is

sufficiently expanded to drop easily over the muzzle-end of the A tube, which is placed upright in a pit ready to receive it. The B tube is then raised, the ashes brushed from its interior, and it is dropped over the steel barrel (Fig. 119). During the process of shrinking, a stream of cold water is poured into the steel barrel by means of a pipe and syphon—to keep it as cool as possible. A ring of gas is placed at the muzzle-end of the B tube to prevent its cooling prematurely, and jets of cold water play on the other end, and are gradually raised to the muzzle for the purpose of cooling the whole tube consecutively from the breech end, which it is desirable should grip first. The method of cooling the tube prevents it from being drawn out into a state of longitudinal tension.

FIG. 119.

The A and B tubes, shrunk up, are placed in a lathe, and while one cutter fine-turns the B tube to its proper shape, another cutter fine-turns the breech end of the A tube according to the plan of the breech-coil.

The half-formed gun, composed of the A and B tubes, is placed on its muzzle in the shrinking-pit, and the breech-coil is heated and shrunk on in the same manner as the B tube; it is, however, being nearly of the same thickness throughout, allowed to cool naturally, and cold water is forced up into the bore of the gun by a jet round which the muzzle rests.

The cascabel is next screwed in, which operation requires great care, as the front of it must bear evenly against the steel barrel. After it is screwed in, it is splined to prevent it from turning.

668. The above method of construction is now applied to

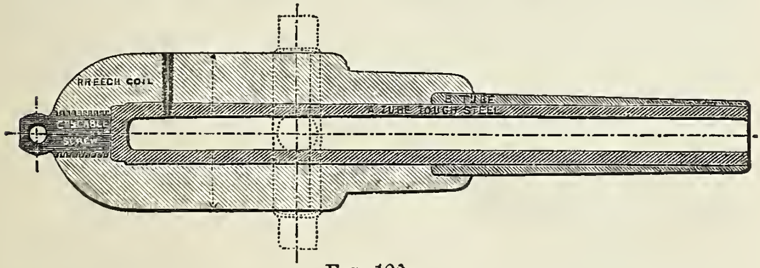


FIG. 120.

the 7-inch and 8-inch guns (Fig. 120). It has been modified for the 9-inch guns (Fig. 121), and upwards, by using a slightly thinner steel tube and two double coils on the breech instead of one triple coil.

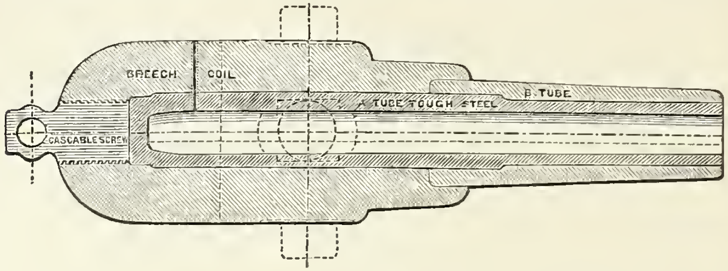


FIG. 121.

The higher natures have an intermediate B coil in addition (Fig. 122), and the 12-inch 35-ton gun has a button instead of a cascabel hole.

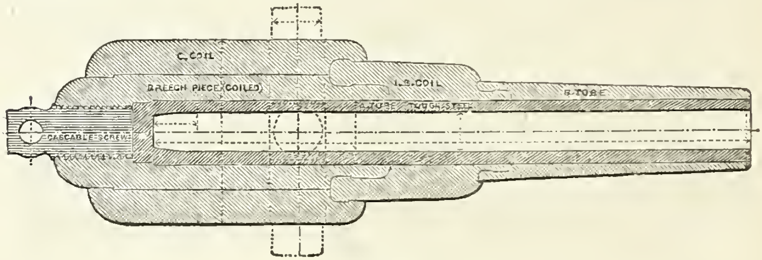


FIG. 122.

669. VENT.—The vent enters at a point two-fifths the length of the service-cartridge from the end. The vents are lined with copper, specially hardened, and bored vertically in the 7-inch, 8-inch, and 9-inch guns; but in the 10-inch and 12-inch guns they are bored at an angle of 45° with the vertical, and on the right side of a broadside gun, but on the most convenient side in a turret-gun.

670. *Nomenclature.*—The guns are named as follows:

The 12-inch	35-ton	700-pdr.
12-inch	25-ton	600-pdr.
10-inch	18-ton	400-pdr.
9-inch	12-ton	250-pdr.
8-inch	9-ton	180-pdr.
7-inch	$6\frac{1}{2}$-ton	115-pdr.

671. PALLISER SYSTEM OF CONVERSION.—This system of Major Palliser depends on the principle of Varying Elasticity, and recourse has been had to it in order to utilize the smooth-bore cast-iron guns. Some smooth-bore 64-pdrs. are the only ones which have been converted.

672. *Theory of the System.*—A barrel or hollow cylinder of coiled wrought-iron is introduced into a cast-iron gun, the barrel being of such thickness in proportion to its calibre that the residual strain borne by this tube shall bear a relation to the strain it transmits to the surrounding cast-iron which shall be best proportioned to their respective elasticities. The precise proportions will depend on various circumstances, the principal of which are the excessive expansion of wrought-iron due to heat, and great range between the limits of elasticity and rupture.

The cast-iron will have to do nearly all the longitudinal work. By varying the thickness of the tube, the transmitted strains can be regulated to the greatest nicety.

673. METHOD OF CONSTRUCTION.—The gun having been bored, a coiled wrought-iron tube is inserted (Fig. 123). The

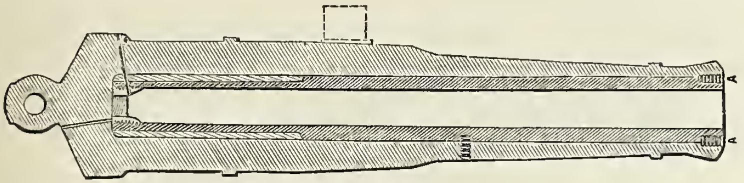


FIG. 123.

tube consists of two thin wrought-iron barrels, the outer one being much shorter than the inner one, and shrunk to it at the breech end. Two are used for the purpose of obtaining the benefit of the tension, and also to break the continuity of any internal fracture. The end of the tube is closed by a solid wrought-iron breech-screw. The tube is made slightly taper, and the bore of the gun is tapered correspondingly; the tube is placed in the bore, and as soon as it comes in contact throughout its length, a screw-locking-ring A, which takes against a shoulder on the tube, is screwed into the muzzle, and sets the tube home; and since in practice it has been found that the elasticity of the wrought-iron inner tube is not proportioned to its greater elongation, the deficiency is supplied by putting the tube under a slight compression, which is effected by permanently stretching the wrought-iron in the gun by heavy proof-charges. The tube is further secured in the gun by means of a screw which passes through the cast-iron shell a short distance before the trunnions at right-angles to the bore, and screws into the tube.

674. PARSON'S SYSTEM OF CONVERSION.—Mr. Parsons has proposed that the tube should be made of steel, having a solid breech, A (Fig. 124), the ingot not being bored

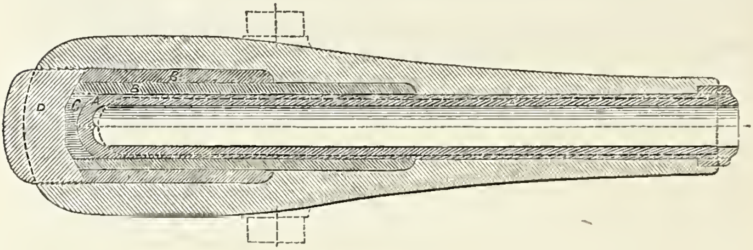


FIG. 124.

through its entire length. He proposes to reinforce the tube with jackets of steel shrunk on, B, and to insert the whole, tube and jacket, from the rear of the iron casting, the cast-iron gun being so bored out as to require force to insert the tube in its place. The tube being inserted, a steel plug, C, is to be screwed in from the rear, which presses against the rear of the tube, and the breech is then closed by a cast-iron plug representing the cascabel of the piece, D.

Various projects have been brought forward to convert our present smooth-bore guns into rifles, but these are all makeshifts. All of our smooth-bore guns are of too high a calibre, relative to their length of bore and weight, to be usefully converted.

675. EXPERIMENTAL GUNS.—THE WHITWORTH GUN is made of a substance called *compressed steel*, which is said to be obtained by melting short bars of Swedish iron with a small quantity of carbonaceous matter in crucibles, after which it is cast into round ingots and compressed by hydraulic presses while fluid. The smaller Whitworth guns are forged solid; the larger ones are built up with hoops (Fig. 125). The barrel is made by casting an ingot hollow. A taper mandrel is inserted in the hole, and the whole tube is hammered until it is of the desired size and shape. The hoops are first cast hollow, and then hammered over a steel mandrel or rolled in a revolving-machine. Before receiving their final finish they are annealed. The hoops are screwed together to form a tube, and

the tubes are bored with a slight taper and forced on over each other by hydraulic presses, in order to secure initial tension. In the larger guns the breech is hooped with a harder and a

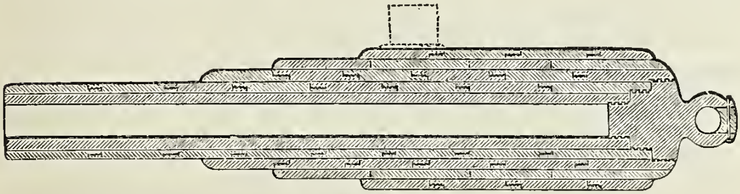


Fig. 125.

higher steel than the barrel. The breech-plug is made with offsets in such a way as to screw into the barrel and the two adjoining hoops.

676. The Blakely Gun.—The most approved pattern of the Blakely Gun combines in its construction the principles of Initial Tension and Varying Elasticity, in order to call all the metal of the piece into simultaneous play (Fig. 126). The

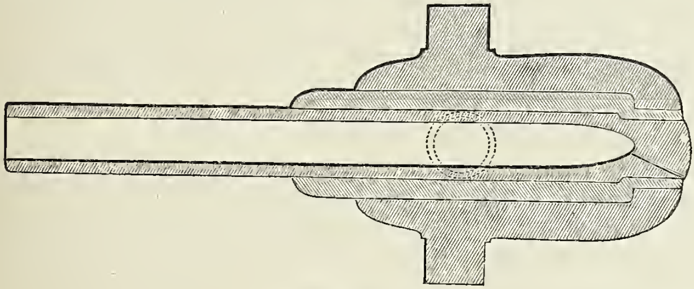


Fig. 126.

inner tube is made of low steel having considerable elasticity, but not quite enough. The next tube is made of high steel with less elasticity, and is shrunk on to the inner tube with just sufficient tension to compensate for the want of elasticity. It is hooked at the breech end over the inner tube. The outer cast-iron jacket, to which the trunnions are attached, is the least elastic of all, and is put on only with the shrinkage obtained by warming it over a fire. It is hooked over the tube within. The steel tubes are cast hollow and hammered over steel mandrels, by which the tenacity of the metal is much increased. All the steel parts are annealed.

677. The Vavasseur System consists of a steel tube with hoops of the same material. The strength is cast more upon the hoops and less upon the tube, which is quite thin and jacketed from the breech to a short distance in front of the trunnions, with a second tube shrunk upon it; the hoops encircle the jacketed and unjacketed parts, extending to the muzzle. (Fig. 127.)

The figure represents a 7-inch gun of this make. It is built entirely of Firth steel, except the trunnion-band, F, which is

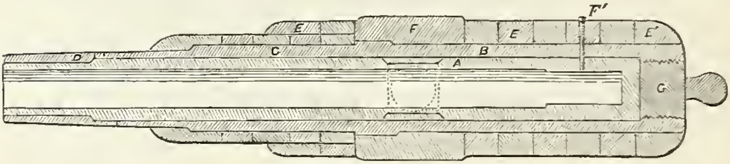


Fig. 127.—Vavasseur 7-inch [steel].

made of wrought-iron. The tube, A, the jackets, B, C, D, and the breech-plug, G, are of cast-steel, the tube, A, being oil-tempered. The exterior rings, E, are forged and rolled like railway tires (Art. 706). The vent is at a distance from the bottom of the bore equal to two-fifths length of the cartridge.

Section IV.—French Naval Guns.

678. General Description.—Breech-loading, rifled cast-iron guns hooped with steel were introduced into the French navy about 1860. On these being considered deficient in power, efforts to obtain increased strength were made, which resulted, in 1871, in the adoption of the system now in use.

679. *Model of* 1871.—The model of 1871 comprises the calibres of 12.48 inches, 9.36 inches, 7.32 inches, and 5.46

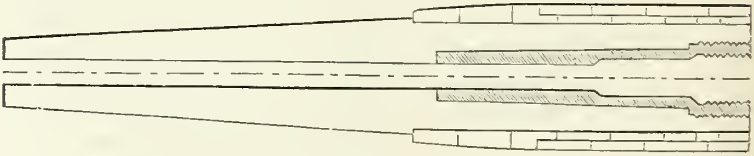


Fig. 128.

inches. They are all cast-iron breech-loading guns, hooped and lined with steel.

680. Casting.—Second-fusion gray cast-iron is used exclusively in the manufacture of these guns. They are cast in a mold with a hollow core, and cooled from the interior. The chase occupies the lower part of the mold.

681. Lining.—The tubes to line the bore are made of Bessemer steel, forged and tempered in oil, furnished by Messrs. Petin & Gaudet. The tube is introduced into the gun from the rear or breech end, and has welded on its after-end a collar having a thread on the outside which screws into the metal of the gun; on the inside of the collar is the thread for the breech-screw.

The tube is introduced into a lodgment about .007 inches less in diameter than the exterior diameter of the tube; the length of the lodgment is also about .007 inches less than that of the tube.

682. To insert the tube, that part of the gun which is to contain it, is raised to a certain heat which will insure the right amount of expansion. The tube is inserted cold and screwed up, and the cast-iron in cooling compresses it, both longitudinally and transversely. The greatest objection is the difficulty of making the joint tight. Tubes extending the whole length of the gun have been used, but without such good results.

683. The Hoops.—The hoops are rings of puddled steel, very strong and elastic; mild steel, homogeneous, with a regular fibre, is generally chosen. The body of the gun is turned perfectly cylindrical, and of a diameter slightly greater than the interior diameter of the hoops; they are then heated and shrunk on, and the gun is cooled interiorly by running water through the bore.

684. The gun is cast without trunnions, and they are built upon one of the hoops, which is called the *trunnion-hoop.* The larger calibres have a double row of hoops breaking joints.

685. Gas-check.—*The Broadwell Ring* forms the gas-check for these guns. This is the invention of Mr. Broadwell, an American, and it is adopted generally as the gas-check in all successful breech-loading systems.

686. The Broadwell Ring is an arrangement illustrated by Fig. 129. It consists of a curved ring, I, and flat bearing-plate, H. The curved ring is fitted in a correspondingly shaped chamber, and like a steam-valve, for instance, may be made perfectly gas-tight, independently of the expansive force of the gas, by being pressed tightly into the chamber by the breech-closing apparatus.

The curved self-adjusting gas-ring and adjustable bearing-plate are exceedingly simple,—the ring completely filling the chamber, and being free to move in any direction that may be necessary in order to bear accurately upon the plate, without in the least impairing its mechanical fit in its chamber.

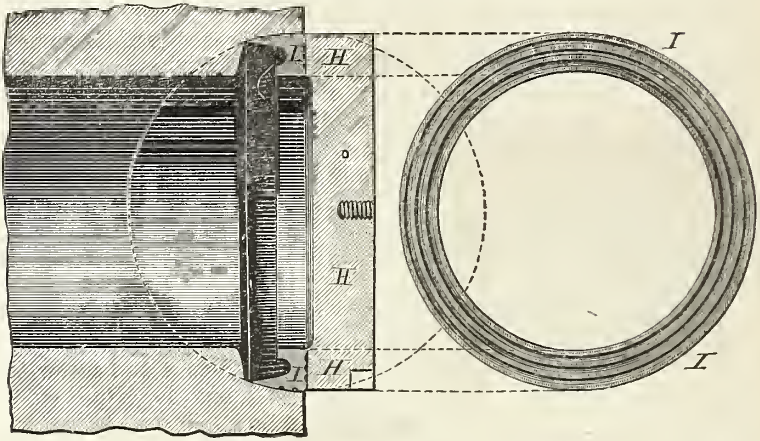


FIG. 129.

687. *The French Guns* of old model had the gas-check fixed to the axis of the breech-plug, but this led to difficulties of working, particularly when using very quick powder, and when the initial velocities became considerable. These guns had two lodgments for the gas-check, the one nearest the breech being reserved for the time when degradations of the bore at the other, had occurred sufficiently to prevent a complete closure.

This change was very efficacious in prolonging the life of the piece, and only required a shorter axis for the new gas-check.

688. In the model of 1871, only one lodgement is made in the gun; the gas-check, DE (Fig. 130), is of the same shape, but is placed by hand in the lodgement, and driven up by the breech-screw, S. It remains in place throughout the firing. The central opening is made of the same diameter as the powder-chamber, and the side is strengthened by a projection. It freely admits the passage of the ammunition. In the large guns the gas-checks are made of copper, and in the small ones of steel. If destroyed, they are easily renewed.

689. BREECH-SCREW.—The breech is closed with a screw-plug of cast-steel, having fourteen threads, which is screwed into the rear part of the bore.

Were it necessary in firing to screw and unscrew the whole length of this plug at every round, much time would be wasted; but this is obviated by dividing the screw into six parts, in the direction of its axis, the threads being removed

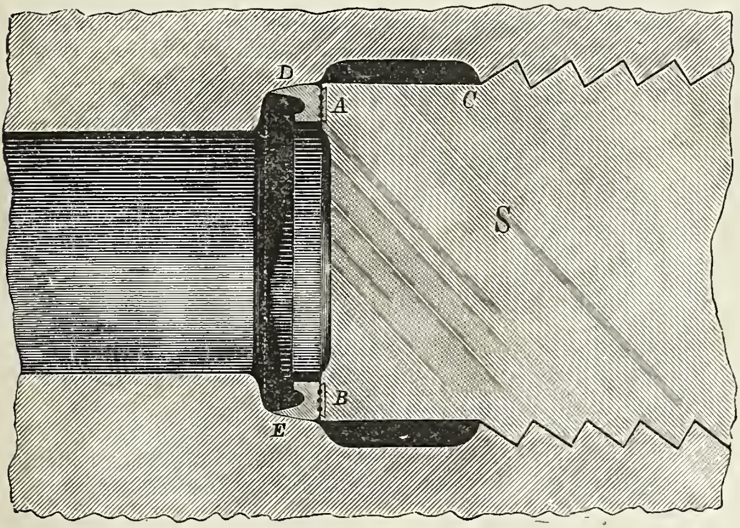


Fig. 130.

from every other one, both from the plug and from the breech of the gun. When the breech is to be closed, the threaded portions of the plug are presented so that they come opposite the smooth parts of the breech-hole. The plug is then pushed in, when a sixth of a turn with a handle brings the screw of both parts together. (Fig. 132.)

690. This system of closing the breech by means of a slotted screw, or one having interrupted threads, was first proposed by an American named Eastman, and has been adopted by the French with excellent results.

691. In the model of 1871 the threads are inclined so that the plug will be better supported from the rear. (Fig. 130.) There is a slight hollow in the front end of the plug opposite the central opening of the gas-check. To make the closure still more complete, a copper ring, AB, projecting .01 inches, is sunk into the front end of the plug. This ring, on which the bottom of the gas-check rests, offers a surface of softer metal, and assists in making the contact more perfect.

692. The ring, as well as the base of the gas-check, has three concentric grooves, .05 inches wide and deep, which furnish lodgements for any gas that may escape, and prevent it from

reaching the metal of the gun. To reserve a place of deposit for the residuum from the bore, the part, AC, between the lodgement of the gas-check and the threads of the collar, is bored out to the same diameter as the bottom of the threads.

693. *To close the Breech.*—A strong cranked lever serves to manipulate the breech-plug, by turning which the threads of the screw enter the corresponding grooves. The movement in the contrary direction disengages them.

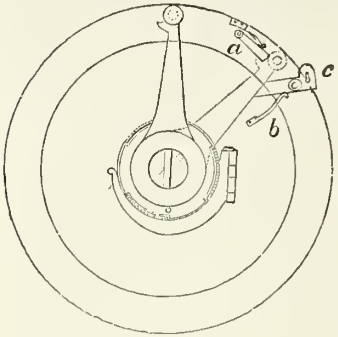


Fig. 131.

694. The breech being closed, the lever-handle is prevented from moving back, and thus allowing the plug to be unscrewed by a short metal catch, *a* (Fig. 131), working freely on a stud placed in the upper part of the right side of the breech. This catch lifts as the lever-handle reaches it, and allows it to pass, but drops by the action of a spring when the handle has passed, and thus prevents the lever from moving to the left, a stud on the breach prevents it from moving to the right.

695. *To open the Breech.*—The weight of the breech-plug for a $9\frac{1}{2}$-inch gun is about 500 pounds; therefore a support, or collar, is used to hold it, when withdrawn. This is a metallic frame carrying a bracket, A (Fig. 132), hinged to the side of the breech near the opening. It has a kind of gutter in which slides the screw portion of the plug. This support being placed in a line with the bore, the hand gripe at the middle of the breech-plug is seized, and the screw being disengaged, a strong pull will bring the whole to the rear. The impulse given swings it open, the breech-screw remaining fixed in its support, or collar. A safety-catch held by a spring secures the collar fair in a line with the bore.

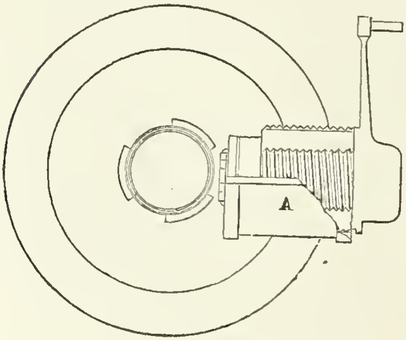


Fig. 132.

696. Loading.—The breech-plug being swung round at right angles to the bore on its support, an iron bearer is introduced to facilitate the loading of the projectile, and prevent the cartridge from being torn by the threads of the screw. It is kept in position by a lever and stud fixed to the under side of the breech. The bearer has a groove to guide the projectile, and it is long enough to clear the tapped portion of the breech. It is readily moved in and out by hand. The projectile is placed on this bearer and pushed into the bore; a wad of dried sea-weed is then pushed in, and afterwards the cartridge; the plug is then pushed in, and screwed up.

697. *Safety-catch.*—To obviate the danger resulting from a neglect to screw up the plug when the breech is closed, the lock-lanyard, which has a bob on it, is made to pass through the eye, *c* (Fig. 131), of a piece of iron fixed to the breech. When the handle is not in its place, that is, when the plug is not properly screwed in, a spring, *b*, closes the eye and does not allow the bob to pass. When the handle is in position with the plug screwed up, it opens the eye and allows the bob to pass, when the gun can be fired.

698. The Reffye Gun.—This is a small bronze breech-loader, introduced during the war of 1870 by Col. De Reffye. Its distinctive feature seems to be its metallic cartridge, which is interesting because it is proposed to introduce in our service a breech-loading 3-inch rifled howitzer using a metallic cartridge-case.

699. *The Reffye Cartridge.*—This is composed of compressed powder enclosed in a metallic case. The rigidity of the cartridge-case offers the valuable advantage of permitting the employment of powder pressed in cakes, which preserve that form and condition calculated to produce the best effect from the expanding gases. Besides, the case furnishes a lining to the chamber, and also serves as a gas-check. (Fig. 133.)

The cartridge cylinder is made from a sheet of tin, rolled on a mandrel and covered with several layers of paper rolled on, using glue between all surfaces.

The head, AB, is a brass cup contracted at the open end and slightly enlarged at the bottom. A depression is formed in its base, called the *priming-chamber*, which also serves as a compartment for the vent gas-check arrangement, CD. A hole is drilled in the centre of this indentation, E, for the rivet of the gas-check, and the sides are pierced at the point where the bottom joins with six holes, *hh*, to permit the passage of the flame to the charge. A brass disk or gas-check, CD, is riveted to the bottom of the priming-chamber, and it is chamfered at the edges, so as to avoid closing the holes communicating with the charge. A brass cup fits snugly in the depression of the head, forming a part of the priming-chamber, and it is pierced to correspond with the axis of the vent.

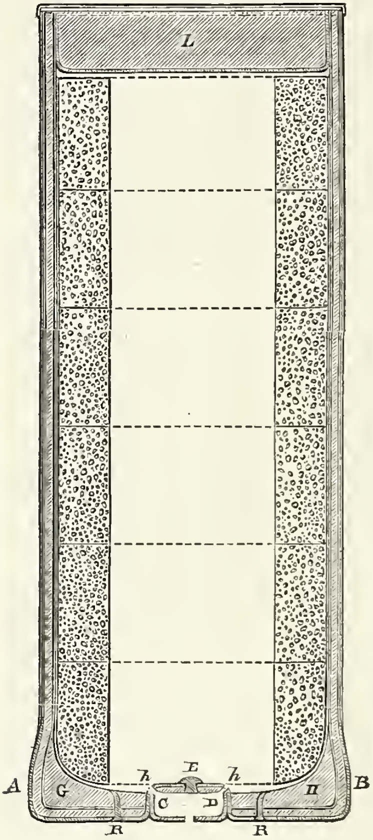


FIG. 133.

The wad, GH, is made by rolling sheets of paper in cylinders, which are then cut up into the required sizes. These serve as wedges, binding the tube and head close together.

In making up the case, the lower edge of the cylinder, having been slit with hand-shears, is inserted in the head and shoved down until the edge takes against the priming-chamber.

The cylindrical paper wad is now dropped in the case, just fitting over the priming-chamber, and pressed down with a punch, which forces it against the sides and upon the bottom of the bent tin. The head is secured by rivets, RR, to the bent edges of the tin, and to the wad, securing all firmly together.

The charge is made up of six cakes or rings of compressed powder having central holes. The bottom cake is slightly convex at its lower surface, to take the form of the pressed paper wad. The cartridge is charged by rolling the six cakes in a paper envelope, and inserting the cylinder thus formed in the case.

By a certain degree of compression a greater force is developed, when an appropriate surface of ignition is presented, by the explosion of a given quantity of gunpowder, than in a loose state; therefore a charge of powder when compressed should give a greater velocity than an ordinary charge fired in the ordinary way.

A pasteboard cup, L, is placed over the powder and filled with lubricating material, having first inserted a wad of tow. The end of the case is covered with a cloth patch secured with a ribbon, to keep the pasteboard cup in place. The edges are then slightly crimped.

The priming-chamber, CD, is filled with musket-powder, the vent-hole being closed with a small patch, one corner of which is left free.

The gas-check arrangement operates as follows: The powder in the priming-chamber being ignited by the primer, the flame will immediately reach the charge through the small holes pierced for the purpose, when the gases from the latter pressing in the opposite direction flatten out the indented brass, which carries with it the gas-check, and the whole closes down upon the vent, forming a metallic obstruction to the escape of the gases.

700. In the forward face of the breech-screw of this gun, a cupped recess 0.4 in. in depth is sunk to receive the head of the metallic case. This recess has three left-handed spiral grooves, in which the head of the case is firmly grasped, and as if embedded after firing. On opening the mechanism and withdrawing the movable breech, these projections bring with them the cartridge-case. The latter strikes with its open end at the rear opening in the breech, and falls to the ground. In case it is too firmly held, it may be readily detached by unscrewing. The Eastman breech-closing arrangement operates well in this gun, except a slight upsetting will sometimes appear in the threads of the screw-box. In our gun several important modifications will be made in the details of the screw-breech by increasing the length of the screw, adopting a better form of thread, and the insertion of a steel thimble containing the screw-box, in the rear of the gun. At the centre of the recess, in the body of the breech-screw, is the vent, by which the flame from the primer passes to the centre of the cartridge.*

Section V.—German Naval Guns.

701. Nomenclature.—The heavy rifled guns for vessels are breech-loaders, of Krupp's cast-steel, all hooped, and with round breech closure and axial vent. The calibres of the guns, that is, diameters of rifled part of bore from land to land, are as follows:

* U. S. Naval Ordnance Notes, 1873.—*The Reffye Gun.*

11-inch, or 28 centimetre,		....	96-pdr.
10-inch, or 26	"	....	
9-inch, or 23½	"	....	96-pdr.
8-inch, or 21	"	....	72-pdr.
6.6-inch, or 17	"	....	36-pdr.
5.7-inch, or 15	"	....	24-pdr.

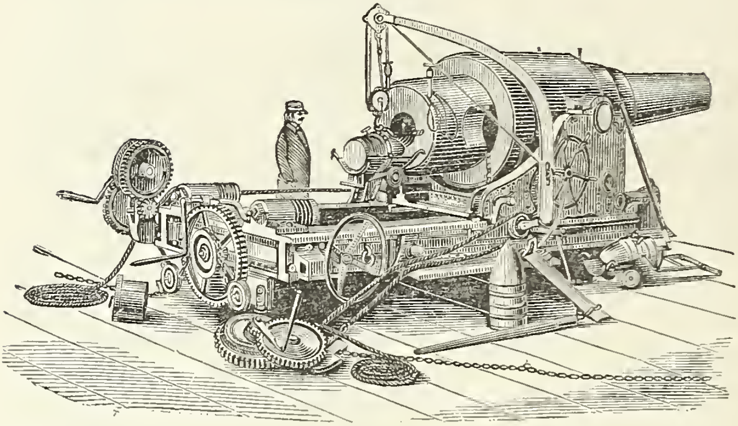


Fig. 134.

702. Features of the Manufacture.—The great features of the manufacture are the forging of large masses from single homogeneous ingots without seams or welds, the forging and rolling of hoops without welds, the use of very heavy hammers, and the quality of the steel which contains one-half per cent. of carbon and a considerable quantity of silicon.

703. Old Krupp Construction.—The guns are made at the factory of Krupp, at Essin, in Prussia. He supplies all the cast-steel guns that are used in the German service. Until within a few years, he made all his heavy guns of a single ingot, cast, forged, and turned; but this method left the gun open to the serious objection of liability to bursting explosively or without warning. No matter what care has been used in the manufacture, cast-steel is a treacherous metal, likely to burst without warning; and in many instances the failure of Krupp's guns have been attended with disastrous consequences.

704. New Krupp Construction.—Mr. Krupp has abandoned the preceding method, and now builds up all his large guns by shrinking hoops of steel over a central tube with initial tension.

The guns consist of a central tube, and the single (in guns of 9-inches calibre, and upwards double) layer of hoops protecting those parts most exposed to damage by the expansion of the powder-gas.

The 6.6-inch and 8-inch guns of the old construction have been altered to the new on account of its greater durability. The outside parts are named: the breech or bottom-piece, R

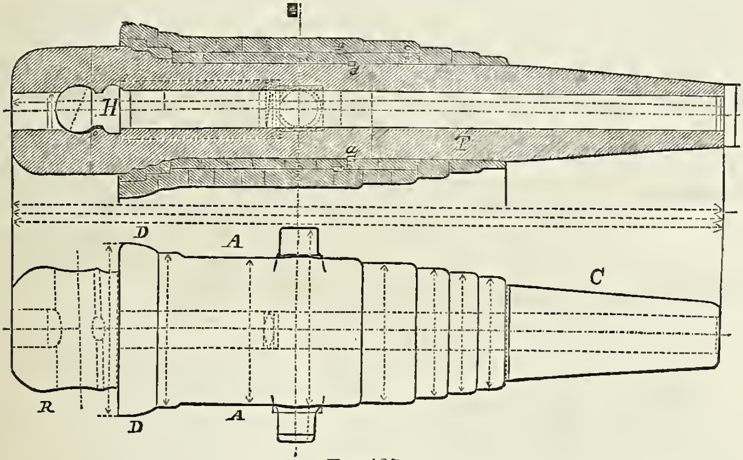


FIG. 135.

(Fig. 135), the hooped or middle piece, A, and the cone, or chase, C. The length is measured between the planes of the base of the breech and the muzzle. The breech-piece immediately abaft the hooped piece contains the wedge-hole, H, cutting through at right angles to the axis of the bore. In the base of the breech is the hole for loading, L (Fig. 140); on each side of the hole is a hook, V, with two slots for the hinges of the loading-box, and hooks of shell-bearer; farther forward are the holes for the sights.

The hooped piece, diminishing in front by steps towards the chase, has in its rear the protruding *end-hoop*, D (Fig. 135). In its front part, on a broad hoop, are the rim-bases and trunnions, whose axes pass through the axis of the piece. On top of the trunnions are the screw-holes for sights. The after-edges of the end-hoop and of the bottom-piece are considerably rounded off. The bore extends to the wedge-hole, and includes the chamber, the seat of the projectile and rifling. The chamber is equal in diameter to the diameter of the bottoms of the grooves.

705. The Central Tube, T, is very massive; almost a gun by itself. It is forged and turned from a single ingot, and loses half its weight in the lathe. The gun-blocks are cooled slowly by throwing them, after hammering, into the hot ashes and cinders from the furnaces, where they are allowed to remain. This tube supplies all the longitudinal strength, and projects far enough to the rear to accommodate the breech closure. It is not tempered. The walls are 0.8 of a calibre thick from a point over the middle of the charge to the point where the rings terminate.

706. Hoops.—The hoops are made with an endless fibre by forging an ingot into the shape shown in Fig. 136, with a slot through the middle ending in holes. This slot is pressed with wedges into a ring, which is half the diameter and twice the thickness of the finished ring. The ring, having been heated, is put over the central roll of a machine like the tire-rolling-machine (Fig. 137). The rolls, while revolving, gradually approach each other, and thus the hoop is rolled to its proper size, and at the same time an endless fibre is developed in the direction of the circumference; they are cooled by a jet of water while on the rolls; this prevents distortion. They are then heated and shrunk on with initial tension. They are kept from working on the gun by key-rings, *a* (Fig. 135), which are half-hoops laid into scores cut to receive them.

Fig. 136.

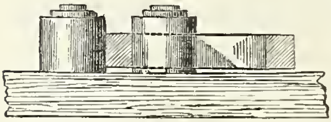


Fig. 137.—Machine for Rolling Hoops.

707. Breech-plug.—For the hooped guns which with heavy charges had not sufficient durability, the cylindro-prismatic wedge, P (Fig. 139), has been adopted. It slides in a

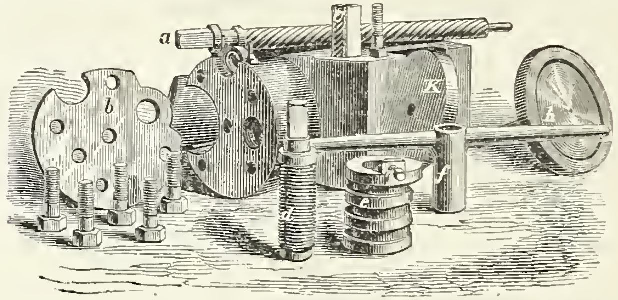


Fig. 138.

horizontal mortise of the same shape in the breech-piece. The plug is made of steel, the wedge and cylinder forming one body; the rounded part is on the rear side, as that gives a greater bearing-surface. It is generally drawn out on the left side, except in turrets or when the position of the guns may require a change. The front side is flat and forms the bottom of the bore. The wedge has small grooves parallel to its after-edge on the top and bottom for the *leading-lasts*, which keep it in position while it is being moved out and in.

In the guns of 8-inch calibre and upwards, the plug is moved in and out by a *transporting-screw*, *a*. In the smaller guns it is moved by hand. The transporting-screw rests in a groove on the upper side of the wedge, and has a shoulder which takes against the locking-plate, *b*, and a rounded end which turns in a ring at the other end of the wedge and keeps the screw in position. The screw works in a nut, *c*, on the upper side of the wedge-hole. (Fig. 139.)

The transporting-screw has a square end to which a crank,

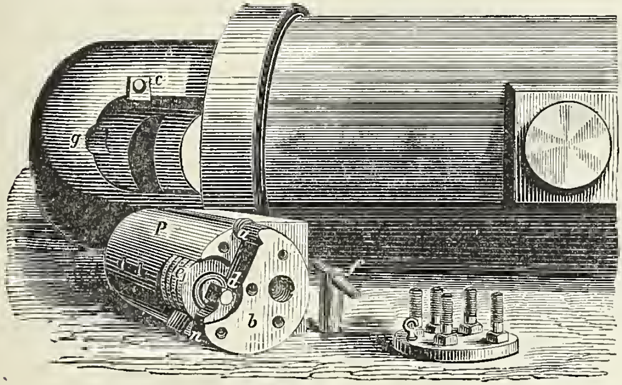


FIG. 139.

f, is fitted for turning it. The end projects through a plate, *b*, called the locking-plate. This plate is screwed on to the extreme end of the wedge.

In a hollow on the after-side of the wedge is the *locking-screw*, *d*, with its joint against the locking-plate, out of which one end protrudes square, for shipping the crank, while the other end rests in the wedge and is held by a pin. It may be turned, but cannot be moved in the direction of its axis. Upon it is the nut, *e*, shorter than the hollow, with several rings cut away on one side, but with one full end ring at the outer end. Upon the latter a projection, *u*, is formed, which, coming out of a segment of the locking-plate, may be turned about one-third of a circle. As soon as the projection stops the turning of the nut, it can be pushed forward or back. With closed breech, the ring parts of the nut fit into cuts, *g*, *g*, *g*, in the gun; but when open, the part not having rings turns to the rear. The same crank, *f*, fits both screws.

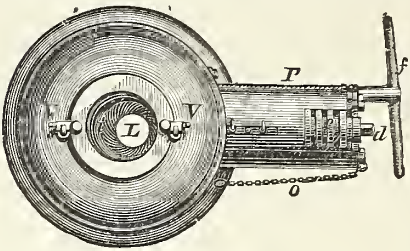


FIG. 140.

The locking-chain, *o*, on the gun, with the hook on the locking-plate, limits the movements of the wedge.

708. GAS-CHECK.—To prevent the escape of gas breechwards without a perfect mechanical fit of the parts of the breech, a *Broadwell-plate*, *h* (Fig. 129), and ring, *i*, are used. The ring is a circle of steel, which fits into a groove or chamber at the bottom of the bore close to the wedge-mortise. As an aid to the steel Broadwell-ring of the chamber, a circular, slightly hollowed out Broadwell-plate, *h* (Fig. 138), is entered into the wedge, which is cut out for this purpose on its front side at *k* (Fig. 138), so that, at the closing of the breech, its rim, projecting a little over the wedge, meets the ring, which also projects over the front side of the wedge-hole. At the discharge this check is closed by the action of the powder-gas, which presses the thin edges of the ring against the gun and plate. The plate has circular plates of thin brass behind it, for an equalizing spring support; and the plate is kept

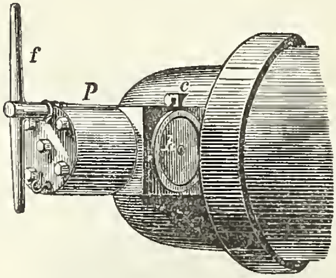


FIG. 141.

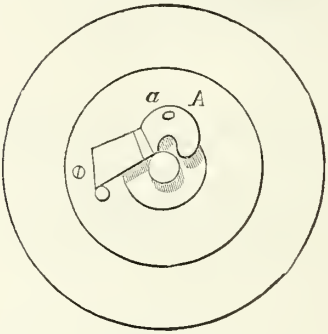


FIG. 142.

in position by a pin which is screwed into the wedge at the centre, for which the plates of brass are pierced.

709. The Vent-tube.—The vent is in the direction of the axis of the bore, and is filled with a vent-tube; this is made of steel, cylindrical, and is lined with copper, more or less conical, and fits exactly into its place in the wedge; this place is enlarged at the rear, and fitted with a thread for the *primer-tube screw*. It has also a broad flange upon whose rear side the lock for confining the friction-primers is placed, *A* (Fig. 142). This consists of a flat cover which has a cut in it for the wire of the friction-primer, and it has a button on top for handling it, *a*. It turns easily on its hinge, and is hollowed out on the side of the vent, so that it may be raised by the escaping gas, and thrown aside. The whole lock is placed in a hollow of the wedge, so that it can be moved at pleasure without interfering.

CHAPTER V.

RIFLING.

Section I.—Principles.

710. Definition.—A rifle is a fire-arm which has certain spiral grooves or "rifles" cut into the surface of its bore, for the purpose of communicating a rotary motion to a projectile around an axis coincident with its flight.

711. Origin of Rifling.—The rifle-principle was first developed in small-arms. With the smooth-bore gun the windage which allowed the ball to be entered freely at the muzzle of the piece gave rise to great inaccuracy of flight, from the fact that the projectile was thereby caused to ballot along the bore, and be projected in a direction due to its last contact, and this deviation was complicated by a motion of rotation generated at the instant of the last contact of the ball with the bore, and perpetuated throughout the entire flight of the projectile.

712. To avoid the bad effects of the shocks in the bore, windage was suppressed, the ball made of a calibre equal to that of the piece, and straight grooves cut in the barrel; which diminished the surface in contact with the projectile, thus enabling it to be pushed home with slight pressure. By accidentally making these grooves inclined, it was immediately seen that increased accuracy was given to the weapon; but the science of the day was unable to assign a reason for this superiority.

713. About the year 1600 the rifle-musket began to be used as a military weapon for firing spherical bullets. It is well known, however, that this means of obviating the effects of the irregular rotary movement of the projectile was applied long before the nature of the difficulty which it remedied was itself apprehended.

714. The rotation of the ball upon a given axis, by means of the tight-fitting spiral groove, and the consequent invariable presentation to the resistance of the atmosphere, of the surface originally placed in that direction, would seem to indicate beyond the possibility of misconception, the advantage that was to be obtained from it. And yet it is only in our own time that the round ball has given way in the rifle to the conical or

elongated projectile. The great merit of the arm was consequently of little account, because the resistance experienced by the round ball from the atmosphere was nearly the same, whether fired from one piece or another; while with light charges there was a certain decrease of initial velocity from the friction in the rifle. But with the conical or elongated projectile the surface of the transverse section was decreased, while the weight remained; therefore there was less resistance to overcome with the same power.

715. It is obvious, however, that the introduction of elongated projectiles would follow that of rifled-bores; and, indeed, it is very doubtful if cannon would ever have been rifled were it not for the sake of firing such projectiles—for the advantage of such accuracy as might be given to a spherical projectile would very probably be counterbalanced by the curved and irregular ricochet that rotation imparts to it, and the increased strain on the gun. Thus rifling being necessary for the employment of elongated projectiles, and such projectiles being essential to the success of rifled cannon, the two have become inseparably connected in the mind.

716. *Difficulty of Loading.*—The great difficulty of loading the rifle prevented it for a long time from being generally used in regular warfare, but the improvements which have been made of late have entirely overcome this difficulty, and rifles are now used almost universally in place of smooth-bored small-arms.

717. INTRODUCTION OF RIFLE-CANNON.—The general adoption of rifled small-arms necessitated the introduction of rifled-cannon. It is plain that the principle has application to all sizes of projectiles, and would therefore be used for the heaviest ordnance as well as for the smallest. Contemporaneous attempts so to adapt it have not been wanting, but they are in many cases isolated in point of time and connection.

The first persevering and rational efforts to apply the rifle-principle to cannon were initiated some twenty years since, and the names of Wahrendorff, Cavalli, Lancaster, and others, are identified with the first efforts to overcome the difficulties—of no ordinary character—that beset the question.

718. DIFFICULTY OF CONSTRUCTION.—The yielding nature of lead renders the application of the rifle-principle of easy accomplishment in the case of small-arms; but such is not the case with rifle-cannon, where the projectiles are made of iron.

The application of this principle to cannon also required an increase of strength in the piece.

719. The greater the weight and the length of a projectile, the greater is the opposition from inertia and friction which it

offers in the bore to the expansion of the ignited charge, and this opposition is considerably augmented if the projectile is constrained to travel through the bore in a spiral course. Hence it is not difficult to comprehend why a rifled-gun must be of a stronger, tougher, and more elastic material than is necessary for a smooth-bore gun in which the spherical projectile yields promptly to the first impulse of the powder-gas to which it presents half its surface, and bounds freely forward through the bore, almost unimpeded by friction; while the strain on the gun is immensely relieved by the comparatively great windage.

720. Again, as the explosive power of a cartridge, as well as the inertia and friction of a projectile, increase as the cubes of their respective weights, while the surface of the chamber and the base of the projectile against which the powder-gas acts increase only as the squares, it follows that the larger the charge and the heavier the projectile, the harder and stronger must be the inner barrel, or else the slower must be the combustibility of the powder used.

721. The difficulty of perfecting more powerful guns for rifle-cannon than previously existed, has been very great; nor have we by any means reached perfection in the construction of such guns. The successful application of the rifled principle and the possibility of throwing enormous shells with the greatest initial velocity have exhibited the importance of the strongest cannon and the utility of the largest calibres, but their development must be in harmony with the progress of the manufacturing arts.

722. Progress in Construction.—The progress of the art of war depends essentially upon that of the sciences and manufactures, for the manner of fighting depends upon the character of the arms which we possess. These will be more effective, as their mode of construction is more perfect, and as the means employed in their manufacture produce greater strength and precision.

This is particularly the case with reference to cannon, in evidence of which we have only to call to mind the great revolution in warfare which has taken place since their introduction, and which is continually taking place as the means of perfecting cannon increase.

It is only of late years that our knowledge of the metallurgy of iron, and our ability to manufacture and handle large masses of that metal, have rendered possible the fabrication of the enormous pieces of the present day.

But now the great improvements which have been introduced in the manufacture of iron, in the fabrication of cannon, and in the facilities for the transportation and handling of heavy guns, render possible the success of cannon of mammoth proportions.

723. Designing Rifle-cannon.—In designing rifle-cannon, the practicability of manufacture and the durability of structure must be ascertained. The weight, calibre, length, system of rifling, weight and shape of projectile, etc., etc., must be all scientifically calculated so as to ensure excellence in range, accuracy, and penetration; and then each and all of these constructional details are liable to alteration, should the thorough trial of a specimen gun render any amendment advisable.

724. Early Experiments.—The first comprehensive experiment with rifled-cannon appears to have been made in Russia, about 1836, on the invention of a Belgian, but did not prove successful.

In 1845, Cavalli, a Sardinian officer, experimented with a breech-loading cannon which was rifled with two grooves, for a plain iron projectile, adapted to fit them. In the next year, Wahrendorff, of Sweden, fitted heavy projectiles to take the rifling by affixing lead to their elongated sides by means of grooves cut in them. And not long after this, Timmerhaus, of Belgium, invented an expanding *sabôt*, which, being fitted to the base of the projectile, was forced into the rifle-grooves and thus gave rotation.

In these early experiments we find the germs of the leading systems of the present day. The solid projectile, fitted to enter the grooves of the gun; the compression of a soft covering on the projectile by the lands of the gun; and the expansion of the rear of the projectile by the pressure of the powder to fill the grooves of the gun.

725. OBJECT OF RIFLING.—The object of rifling a gun is to increase its accuracy of fire, and, by enabling elongated to be substituted for spherical projectiles, to obtain from it longer ranges.

Rifling diminishes the deviations of ordinary projectiles, due to the following causes:

1st. Want of uniformity, in figure and weight, around the longitudinal axis of the projectile, passing through the centre of gravity.

2d. Position of the centre of gravity, before or behind the centre of figure.

3d. Resistance of the air.

I. By rotating the projectile around its longitudinal axis, the direction of these deviations is so rapidly shifted from side to side, that the projectile has no time to go far out of its course either way.

II. The velocity of this rotation is such as to make the axis stable on leaving the bore, and to counteract the pressure of the air tending to turn the projectile over, or render it unsteady in flight.

III. A given weight of projectile can be put into such a form as to oppose the least practicable cross-sectional area to the air, and thus to receive the least practicable retardation of velocity.

726. ADVANTAGES OF ELONGATED PROJECTILES.—Certain peculiar advantages follow from the rotation of the projectile, causing it to present the same part to the front throughout its flight.

It becomes possible to make a much simpler percussion-fuze, because it is only necessary to provide for action in one direction in place of every possible direction.

Shells required to act towards the front in any peculiar way have their bursting-charge and metal placed with a view to this object. So, again, the centre of gravity may be brought to any desired part of the shell; and this is an important feature in the construction of projectiles.

Rifling gives the power of altering the form of projectiles at will. The head may be made of any desired shape, for penetration or flight. The projectile may be elongated so as to give a diminished surface for any resisting medium to act upon: thus in flight, velocity is kept up and the range extended, or on impact greater penetration is obtained.

Weight for weight, the same effect may generally be produced with an elongated projectile by using a smaller charge of powder than with a spherical one.

It follows from the flight of an elongated projectile meeting with less resistance from the air, and keeping up its velocity better, that at all but very short ranges the trajectory is flatter; hence the probability of hitting an ordinary object is greater.

The power to vary the length of the elongated projectile enables all those for the same gun to be made of the same weight, and hence to require the same elevations with the same charge of powder. Or it is possible to make a projectile specially heavy if required. This obviously cannot be the case with spherical projectiles, which must be of the same size.

727. DISADVANTAGES OF ELONGATED PROJECTILES.—The chief disadvantages are, bad ricochet, increased complication. and expense of manufacture, liability to injury arising from the necessity of soft studs, expanding rings, or a soft lead coat; increased

strain on the gun, besides greater probability of jamming and injury to the bore, uncertainty of time-fuzes.

728. METHOD OF RIFLING.—To rifle a fire-arm, spiral grooves are cut in the surface of the bore, into which the projections or soft metal coating of the projectile are made to enter.

The grooves may be of any number, and may extend partially around the bore, or once, twice, or several times in its length. They may be of the same pitch or curvature throughout, or the twist, if desired, may increase in curvature towards the muzzle. It is essential, however, that all the grooves be of the same curvature, and exactly parallel to each other; their object being to impress upon the projectile a rotating motion about its axis of progression, and thus keep it in a straight line as it spins forward. The motion of a top holding itself upright while rapidly spinning, illustrates the principle of the rifle.

729. LANDS.—The spaces between the grooves are called "*lands*." Where the grooves are very wide, and the lands very narrow, they are termed "*ribs*."

730. *Calibre.*—The calibre of a rifle-gun is measured across the lands. In the case of a rib-rifled-gun, it is measured to the bottom of the grooves.

731. FORM OF GROOVE.—The form of the grooves and their number vary very much according to the method of rifling.

The form of the groove is determined by the angle which the tangent makes at any point with the corresponding element of the bore. If the angles be equal at all points, the groove is said to be *uniform*. If they increase from the breech to the muzzle, the grooves are called *increasing*, or the rifling has a *gaining twist*.

732. *Twist* is the term generally used to express the inclination of a groove at any point, and is measured by the length of a cylinder corresponding to a single revolution of the spiral. This, however, does not convey a correct idea of the inclination of a groove.

A correct measure of the inclination of a rifle-groove at any point, is the tangent of the angle which it makes with the axis of the bore; and this is always equal to the circumference of the bore divided by the length of a single revolution of the spiral, measured in the direction of the axis.

734. UNIFORM TWIST.—Let A B C (Fig. 143) be a right-angled triangle, in which—

$BC =$ circumference of the bore of a gun,
$AB =$ length of the bore.

Now suppose the triangle ABC to be wrapped around the surface of the bore as in Fig. 143, so that B and C meet. AC will be the *helix*, or curve of the groove. Now in Fig. 143 the groove makes a complete turn in the length of the bore; but in ordinary

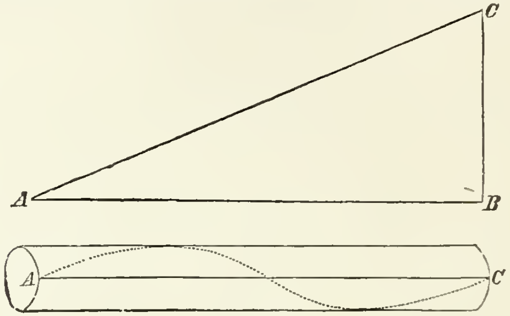


FIG. 143.

rifle-guns the *twist* is more gradual, making less than one turn in the bore.

In the case before us, AB equals the length of rifling due to one turn, that is, the distance travelled by the projectile while it is turning on its axis. AC is the total length of spiral and θ the angle of twist, or angle of the rifling. Let n = number of calibres in which the projectile makes one turn.

$$\tan\theta = \frac{BC}{AB} =$$

$$= \frac{\pi \times \text{calibre}}{\text{number of calibres} \times \text{calibre}} =$$

$$= \frac{\pi}{\text{number of calibres}} = \frac{\pi}{n}.$$

735. UNIFORMLY INCREASING TWIST.—When this system is adopted, the grooves start in a direction parallel to the axis of the bore, and the twist increases uniformly towards the muzzle.

In the Fig. 144, ABCO denotes the development of the bore, and OM that of a groove. The origin of the co-ordinate axes is taken at the commencement of the groove at the bottom of the bore; the axis of Y is parallel to the axis of the bore.

The curve OM is tangent to OA at O, since the projectile starts in the direction OA. Let φ denote the variable angle between OX and the direction of the curve OM. If the twist increases uniformily, tan φ will *decrease* uniformily as the ordinate *increases*, and we shall have $\tan\varphi = \frac{m}{y}$, m being an undetermined constant.

But $\tan\varphi = \frac{dy}{dx} = \frac{m}{y}$,

$\therefore$ $ydy = mdx$;

integrating, $y^2 = 2\,mx + K \ldots\ldots\ldots\ldots\ldots (a)$.

The constant of integration (K) is zero, since the curve passes through the origin. (a) is the equation to a parabola referred to the vertex and principal axes.

In the Figure, MT is the tangent at M, and MM′ equals AB $= \pi c$, c being the calibre of the gun.

Also M′T is put equal to nc, n denoting the number of calibres in which the projectile makes one turn after leaving the muzzle.

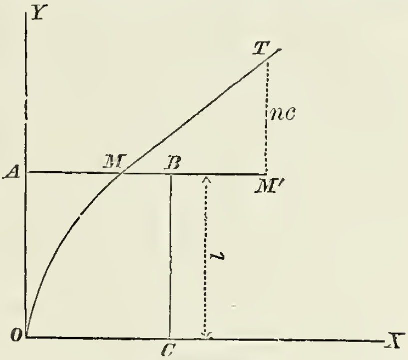


Fig. 144.

To determine m, putting φ' for the value which φ has at M we have

$$\tan\varphi' = \frac{m}{l};$$

$$\text{also } \tan\varphi' = \frac{nc}{\pi c} = \frac{n}{\pi};$$

$$\therefore \qquad m = \frac{ln}{\pi}.$$

Whence the equation to the curve is

$$y^2 = \frac{2ln}{\pi}x \ldots\ldots\ldots\ldots\ldots\ldots (b).$$

By means of equation (b) the curve is easily traced.

736. Comparative Advantages.—*The Increasing-Twist.*—The advantages claimed for this method of rifling are, that the projectile, not being forced to take the whole twist of the rifling at once, moves more readily from its seat, and thus the initial strain upon the breech of the gun is reduced, thereby prolonging its life; also that the bearings on the projectile are not liable to be torn off.

Theoretically it would seem that a system of rifling which permits the projectile to move directly forward from its seat, at the moment of ignition of the charge, must be more favorable to endurance than one which, by impeding the first movement of the projectile in the bore, narrows the space for the expanding gas, and consequently brings a greater pressure on the breech of the gun.

But practically this method does not appear to be successful, in the enormous cannon of recent construction.

737. The greatest objection to the increasing-twist is that it cannot be used with a long bearing of projectile. Indeed, the theoretical bearing, whether it is a soft metal ring, a strip, or a stud is infinitely short—a mere line—and practically, length of bearing is only obtained by a constant molding of the projectile to the new angle of rifling, so that the portion of the projectile intended to take the grooves, must be short and also soft. for if it cannot obtain, by changing it figures, more bearing on the grooves than on a mere line, it will undoubtedly cut the grooves, thus increasing friction, and soon ruining the bore.

In the absence of further experiments, it would hardly be safe to conclude that long bearings will not prove indispensable to the heavy projectiles and high velocities that are now required.

A projectile, if balanced on weakening studs in each groove (Art. 782), is liable to break up through the stud-holes, thereby injuring the gun.

To rapidly rotate an iron cylinder, say 12 inches in diameter and three calibres in length, weighing nearly a third of a ton, by a ring of such points, is very likely to produce a *wabbling* motion and unsteady movements in flight, with reduced range. Very rapid twist, although it conduces to steadiness of motion, cannot be given because small bearings will not endure the great effort necessary.

738. *The Uniform Twist.*—In this case the same angle of twist obtains throughout, from the seat of the projectile to the muzzle; it is more simple in construction, and as accurate in results.

The effort of rotation may be diffused over a long centring bearing, extending along the whole cylindrical body of the projectile, which is an advantage of great importance, and when the projectile is free to escape, its motion will be much more uniform than if it received, as it were, a severe wrench on leaving the muzzle, while it is not believed that the life of the gun is materially affected by differences of powder pressure within the possible limits which can obtain, between guns rifled with the same final angle of twist, on the uniform and on the increasing systems.

739. Initial Velocity of Rotation.—Let V be the initial velocity of the projectile or space which it would pass over in one second, in the direction of flight, moving with the velocity with which it leaves the piece, and l the distance passed over by the projectile in making one revolution; then $\frac{V}{l}$ will be the number of revolutions in one second and $2\pi\frac{V}{l}$ the *angular velocity* of the projectile at the muzzle.

The velocity of rotation of a point on the surface is given by the expression

$$r\,w = 2\,\pi\,r\frac{V}{l},$$

in which r is the distance from the axis of motion, and w is the angular velocity.

740. Velocity of Rotation.—The velocity of rotation required by a projectile will depend chiefly upon the *initial velocity*, the *form*, the *density*, the *distribution of the material*, and the *position of the centre of gravity* of the projectile; therefore, there is a particular inclination of grooves which is best suited to each calibre, form of projectile, charge of powder, etc.

This has not yet been fully determined by experience, and the consequence is that a wide diversity of twists is employed in different services and by different experimenters. A long course of very careful experiments is necessary to establish laws that could be generally applied.

741. *Initial Velocity.*—As the initial velocity of a projectile is increased, so will the resistance of the air tending to overturn the projectile be greater.

742. *Form.*—Long projectiles require a more rapid rotary motion than short ones of equal weight, for the resultant of the air acts with a greater leverage as the length of the projectile is increased, tending to give it a rotation round its shorter axis.

The cause of this tendency to turn over in flight, is apparent from the accompanying diagrams.* As the effect of the pressure of the air differs according to the shape of the head of the projectile, both a conoidal and a flat head are here given in Figs. 145 and 146.

In each of these Figures, R, representing the resultant of the air's resistance, acts below a, and is half-way between the dotted lines, which include between them a space representing

* Owen.

the opposing current of air; it is evident these lines should be parallel to AB.

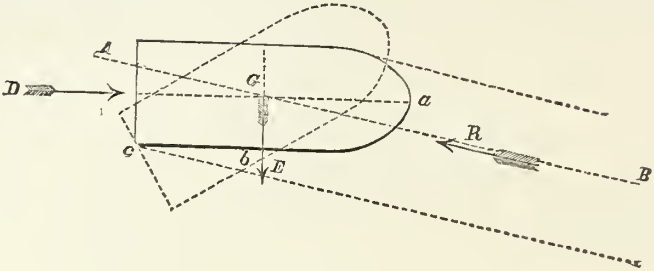


FIG. 145.

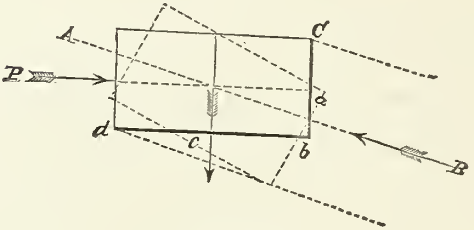


FIG. 146.

The effect of R in Fig. 145 is to give the projectile a rotation around one of its shorter axes, the head being turned up, as shown by the dotted lines. In fact a pressure exerted anywhere and at any angle between *a* and *b*, that is, before and be low the centre of gravity, G, will have a tendency to raise the head; and a force exerted behind and below G, between *b* and *c*, will have a tendency to depress it.

In Fig. 146, the pressure, R, will not raise but depress the head, as shown by the dotted lines; and if R acts anywhere between *a* and *b*, the same effect will be produced; but if R acts between *b* and *c*, the head will be raised as with the cylindro-conoidal projectile. (Fig. 145.)

It is necessary to give a flat-headed projectile a greater velocity of rotation than a conoidal or *ogival*-pointed projectile; for the current of air meeting the projectile, instead of having merely, as with the latter form, to pass around the pointed head, presses with the flat head upon a surface almost at right angles to the previous direction of the current, and consequently exerts a very much greater force proportionally, tending to overturn the projectile.

743. *Density.*—The greater the density of a projectile, the

less will its velocity of rotation be decreased by the resistance of the air during the time of flight, because of its greater momentum. For instance, a leaden shot would retain its velocity of rotation longer than one of iron; consequently, as the densities of projectiles are increased, so may their respective velocities of rotation be diminished.

744. *Distribution of the Material.*—A hollow, elongated projectile will be steadier during flight than a solid shot of equal weight, for, the mass being distributed farther from the axis, the radius of gyration is lengthened. Thus it is found in practice that elongated shells are steadier in flight than shot from the same gun, when the latter are of the same weight as the shell.

745. *Position of the Centre of Gravity.*—If the centre of gravity of a projectile is very far forward, as in Fig. 147,

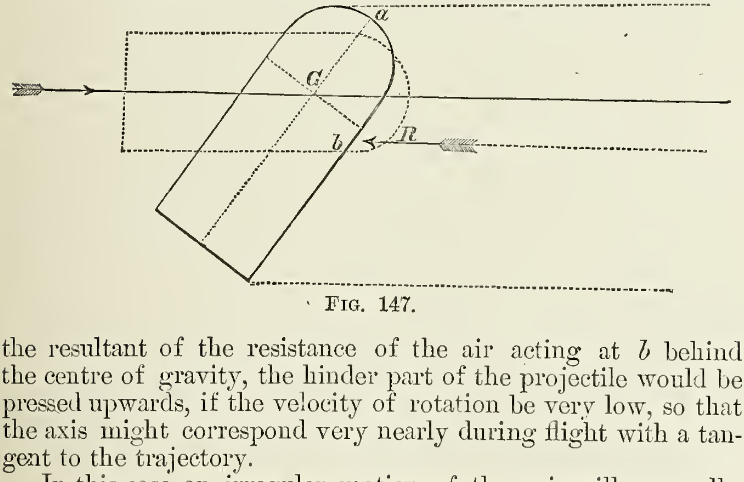


FIG. 147.

the resultant of the resistance of the air acting at *b* behind the centre of gravity, the hinder part of the projectile would be pressed upwards, if the velocity of rotation be very low, so that the axis might correspond very nearly during flight with a tangent to the trajectory.

In this case an irregular motion of the axis will generally result from the opposite tendencies of the forces which act upon the shot; the air endeavoring to press up the hind-part of the projectile, while the rotatory motion resists any change in the direction of the longer axis. With the centre of gravity in this position, there is little fear of the projectile turning over even with a low velocity of rotation; but, in order that the axis may be stable, a rapid rotatory motion must be given to prevent any "*wabbling*" which might arise from the cause just explained.

Should the centre of gravity be situated near the base, a very high velocity of rotation is requisite to compel the projectile to proceed head first. In Fig. 148, the pressure, R, of the air acting at *b* would doubtless turn up the point *a* and cause the projectile to rotate around its shorter axis, unless counterbalanced by a very rapid rotatory motion around the larger axis.

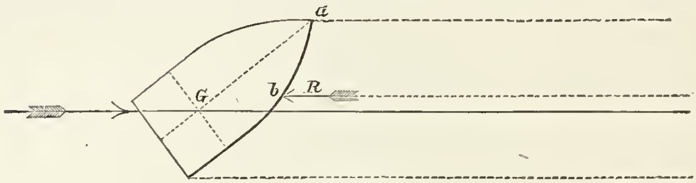


FIG. 148.

746. *Conclusions.*—A very high velocity of rotation is objectionable for the following reasons: That the strain upon the metal of the cannon will be very great, as the charge must be comparatively large, and the grooves will require a sharp twist, much resistance being thereby caused to the motion of the projectile; that the projectile, after grazing, will deflect considerably; and that, should the projectile be a shrapnel, the pieces would spread laterally to too great a distance to be effective.

It will generally be sufficient, as far as accuracy is concerned. to give an elongated projectile such a velocity of rotation that the axis may be stable during the whole time of flight for the longest required range; should the rotation be not sufficiently rapid at any part of the trajectory, the axis of the projectile will become unsteady, and inaccuracy of fire will be the result.

To determine theoretically the velocity of rotation which ought to be given to a projectile of definite form would be a very difficult problem, and therefore recourse must be had to actual experiment to obtain approximately the velocity required.

747. CHARACTER OF GROOVES.—The width of the groove generally depends on the diameter of the bore, and the peculiar manner in which the groove receives and holds the projectile.

Wide and shallow grooves are more easily filled by the expanding portion of a projectile than those which are narrow and deep; and the same holds true of circular-shaped grooves when compared to those of an angular form. An increase in the number of grooves increases the firmness with which a projectile is held, by adding to the number of points which bear upon it.

The effect of decreasing the depth of rifle-grooves is, generally, to increase the accuracy but diminish the range. The increase of accuracy undoubtedly arises from the fact that the projectile is held more firmly by the grooves as it passes along the bore; while the diminution of range arises from an increase of friction between the projectile and the grooves.

The depth of the grooves has an obvious influence upon the strain brought upon the gun, and the extent of the bearing-surface required to rotate the projectile will depend upon its velocity and the angle of twist. With a high velocity or a sharp twist, shallow grooves would strip a soft metal bearing, or cut a hard one.

748. *Loading and Driving Edge.*—A rifle projectile both on entering and leaving the bore, is driven by a force acting along its axis, and rotation is given by the projections coming against the spiral formed by the edge of the groove. Thus, in Fig. 149, if the projectile was pushed base first, the studs would move against the *loading-edge*, CC, of the grooves, while if pressure were applied to the base so as to move it head first, the studs would meet the *driving-edge*, DD, and work along it.

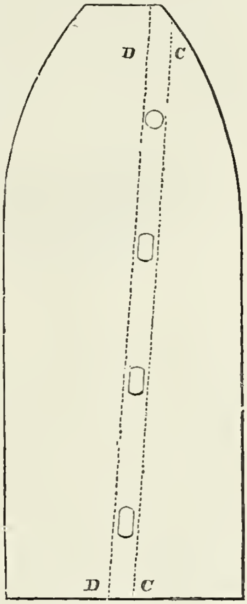


Fig. 149.

749. *Advantage of Radial Bearing.*—A great source of strain from rifling is due to the wedging of the projectile in all grooves of which the bearing-sides do not lie in the plane of the diameter of the bore. For instance, the inertia of a projectile rotated by the groove CD, Fig. 150, tends only to rotate the gun in the opposite direction, but the greater part of the pressure imposed in the groove LMNP assists the powder in enlarging the diameter of the bore. In addition to this direct rupturing strain, the friction of the projectile is increased by the same cause.

The slightest inclination of the bearing-surfaces from being truly radial, causes increased friction, as at G, where the pressure, acting in the line GH, can be resolved into two forces: GI, useful, and GK, the reverse.

In the form of groove LMNP, the force is applied to the projectile by the surface MN in the direction RS, whereas motion is intended to be given in the direction RT.

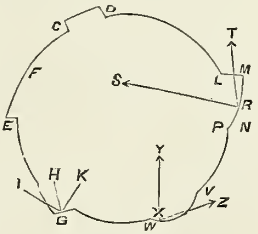


Fig. 150.

750. *Advantage of Rounded Angles.*—The angle of the side

of the land with the bottom of the groove has the usual relation to strength generally observed in mechanical construction. A sharp angle in a part subjected to strain and vibration is considered the beginning of a fracture. For this reason, Parrott and others who understood the advantage of a radial bearing side, nevertheless rounded the angle of their grooves.

Another reason for rounding the groove, especially in the case of the *Centring System* (Art. 754), is to prevent the violent shock of the projectile when its bearing-edges strike the rifling. Figs. 151 and 152 are exaggerated to illustrate this.

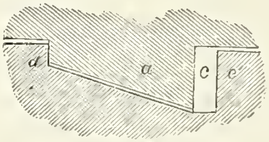


Fig. 151.

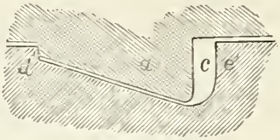


Fig. 152.

The projection *a* bears and remains upon the side *d* of the groove going in, and so leaves the windage, *c*, on the other side. In going out the projectile will have acquired considerable velocity before it strikes the side *c*, so that the blow will be violent and the commencement of the rotation instantaneous. But the projection (Fig. 152) not only slides up the rounded groove without a blow, but lifts the projectile into the centre of the bore, thus centring it.

751. Cutting the Grooves.—The practical method of cutting the grooves consists in moving a rod, armed with a cutter, back and forth in the bore, and at the same time revolving it around its axis. If the velocities of translation and rotation be both uniform, the grooves will have a uniform twist; if one of the velocities be variable, the groove will be either increasing or decreasing, depending on the relative velocities in the two directions.

All the grooves are first cut roughly in succession, and then finely. The distance between the grooves is regulated by a disk fastened securely to the breech of the gun, having its periphery equally divided by as many notches as there are to be grooves.

The gun is held each time by a pawl, and when a new groove has to be cut, is turned round to the next notch.

The rifling-machine is horizontal, and permanently placed in position; the gun to be operated upon is fixed in front of it, in line with the rifling-bar, which has a motion of translation along its bed as well as a certain amount of rotation on its own axis, regulated to the required pitch. An automatic reverse motion is contrived for the bar, so that when once set in motion the machine is self-acting.

Section II.—Systems.

752. A System of Rifling consists essentially in the *means of giving rotation to the projectile.*

The twist of the grooves, the length, diameter, or form of the projectile, must depend upon the purpose for which a gun is required, no matter upon what system it may be rifled. Inventors often claim principles which are as applicable to one as to another system. As regards precision of fire, one system will give as good results, for all practical purposes, as another, provided the conditions of charge, projectile, and twist of grooves are alike, and the rifling of the bore and the manufacture of the projectiles have been performed with the same amount of care and skill in both cases.

The conditions that are especially desirable in a system of rifling for ordnance are:—Accuracy of fire, simplicity and durability in both projectile and gun, non-liability of projectile to jam in the bore in loading or firing. It must not cause too great strain, and for heavy ordnance, must allow of the use of large charges.

It will be observed that in many of the systems of rifling in use, one or more of these conditions have been sacrificed to some extent, to secure a closer compliance with others thought to be of greater importance, or of easier attainment.

753. Great numbers of rifled guns, with projectiles to correspond have been proposed, but most of the *systems* of rifling that have been adopted by any service, or tried on the practice-ground, may be divided into the following classes, each of which has its advantages and its disadvantages, and none are without objections.

First. Muzzle or breech-loading guns, having projectiles of hard metal, fitting the peculiar form of the bore mechanically.

Second. Muzzle or breech-loading guns, with projectiles having soft metal studs or ribs, to fit the grooves.

Third. Muzzle-loading guns, with projectiles, having a soft metal envelope or cup, which is expanded by the gas in the bore.

Fourth. Breech-loading guns, with projectiles having a soft metal coating larger in diameter than the bore, but which is compressed by the gas into the form of the bore.

754. First Class.—In this class, the hard metal projections are so shaped as to fit the peculiar form of the bore mechanically. The gaining-twist is obviously impracticable with this form of rifling.

Centring.—In consequence of windage, which is necessary in all muzzle-loading guns, the axis of the projectile does not always coincide with that of the bore; in firing, this leads to inaccuracy of fire.

In order to secure accuracy of fire, it is essential that the axis of the projectile should correspond with that of the bore of the gun; for, otherwise, the axis of rotation will be variable, and the deflection of the projectile uncertain. Should the axis of the projectile on leaving the bore be unsteady, the projectile will have the *wabbling* motion so frequently observed in experimental practice.

A projectile is said to be *centred* when the grooves of the rifling are so constructed as to bring the axis of the projectile in line with that of the bore when the piece is fired.

Centring may embody the compressing or expanding systems in any required degree.

While the projectile is rotated by the solid projections formed upon it, and fitting into the grooves of the gun, the exterior of these projections, or of the whole projectile, may be covered with a soft substance which may, in the case of a breech-loader, be larger than the bore, and thus be compressed while passing out of the gun; or which may be expanded, by the pressure of the powder, to fill the gun.

When the projectile is well centred, windage cannot affect its straight passage through the bore.

Usually, in the first class, the hard surface of the projectile is dressed to bear directly on the surface of the bore, leaving a little windage. The systems of *Whitworth*, *Vavasseur*, *Scott*, and *Lancaster* are examples of this practice.

755. Whitworth's System.—The Whitworth gun has a hexagonal spiral bore, the corners of which are rounded off. The form of the bore is not, however, strictly hexagonal.

The interior of each gun is first bored out cylindrically, and when the rifling is completed, a small portion of the original cylindrical bore is retained along the centre of each of the sides of the hexagonal bore, and the other parts of each side recede or incline outwards towards the rounded angles; hence the diameter of the hexagonal bore is greatest at the rounded angles.

This description will be readily understood by reference to Fig. 153.

The reasons for thus modifying the general form of the rifling are, to facilitate loading, and thus allow of a reduction of windage, and also to ensure, if possible, the bearing of the sides of the projectile on surfaces instead of on mere lines, as would be the tendency with a plain hexagonal bore having windage.

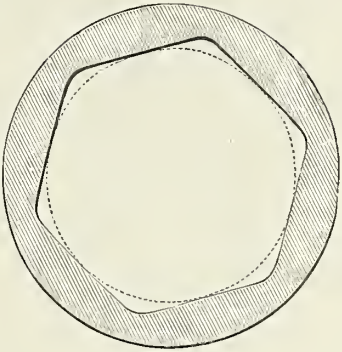


FIG. 153.

A hexagonal bolt revolved on its axis within a slightly larger hexagonal orifice would not bear upon its side, but only upon its six corners. The points of contact would be mere lines.

In this system, the bore must obviously be slightly larger than the projectile. In Fig. 154, while the face, *a e*, of the projectile is flat, the face, *d e*, of the bore is so inclined, that the

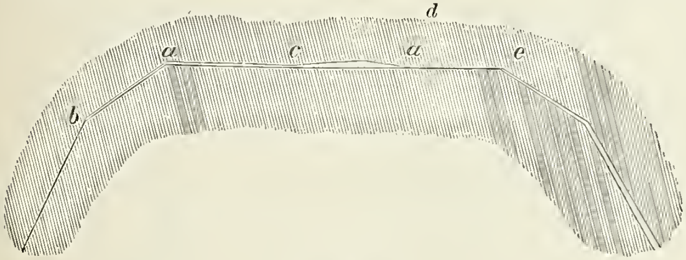


FIG. 154.

projectile in coming out will bear upon the whole of it, as shown. If the face, *a e*, of the bore was also plain, the projectile would bear only on the corners *e b*, etc.

The following table gives the particulars of the Whitworth guns and rifling:

Particulars and Charges of Whitworth Guns.

Name of Gun.	Bore.		Length.	Windage on going in, half sides.	Weight.	Twist of Rifling.	Weight of Charge.	Weight of Projectile.	Length of Projectile.	Bursting-charge of Shell.
	Across Flats.	Across Angles.								
	Ins.	Ins.		Ins.	Lbs.	1 turn in inches.	Lbs.	Lbs.	Ins.	Lbs.
120-pounder* .	6.4	7	144	.06	16660	1 in 130	27†	151†	20.5	5
70-pounder .	5	5.5	118	.055	8582	1 in 100	13†	81†	19	3 lbs. 12 oz.
12-pounder . .	2.75	3	104	.02365	1092	1 in 55	1.75	12 lbs. 2½ oz.	7	6 oz.

The 80-pounder has 118 in. length, and 5 in. diameter of bore, with 1 turn in 120 in. Charge 10 lbs.
The 3-pounder has 72 in. length of bore, 1.5 bore across the flats, and is rifled with 1 turn in 40 in. Charge, 8 oz.

* Made at Woolwich, on the Armstrong principle.
† Iron targets at Shoeburyness. Maximum charge.

The peculiarities of this system are the polygonal rifling and comparatively small bore. It has great range and penetration, but has never been adopted for heavy guns by any nation except Brazil.

The polygon has twenty-four surfaces with six grooves, each .4 inch deep.

Though the long iron bearing diffuses the strain over a large surface, and enables a rapid twist with great rotation to be

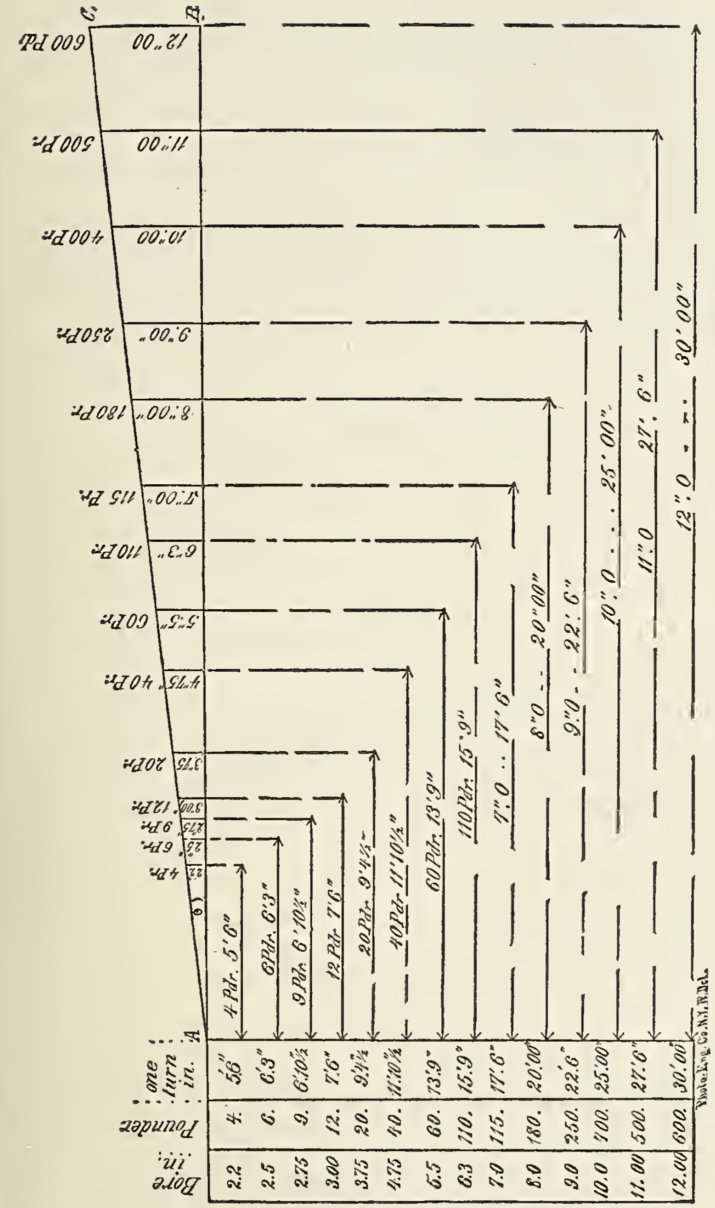


FIG. 155.--Diagram of Rifling.

given, yet the bearing is really on a mere line in each groove, and is much nearer the axis of the projectile than in systems with projecting flanges, and the leverage for rotating is therefore much less.

In muzzle-loading guns of this system it is difficult to thoroughly sponge the bore.

A patent lubricating cartridge in a metallic case is used with the breech-loaders.

756. VAVASSEUR'S SYSTEM.—This method comes under the head of *rib-rifling* (Art. 729)—the rotation being given by means of raised ribs in the bore, while the projectile itself has corresponding grooves cut along its cylindrical surface.

The ribs are three in number; their shape, and also that of

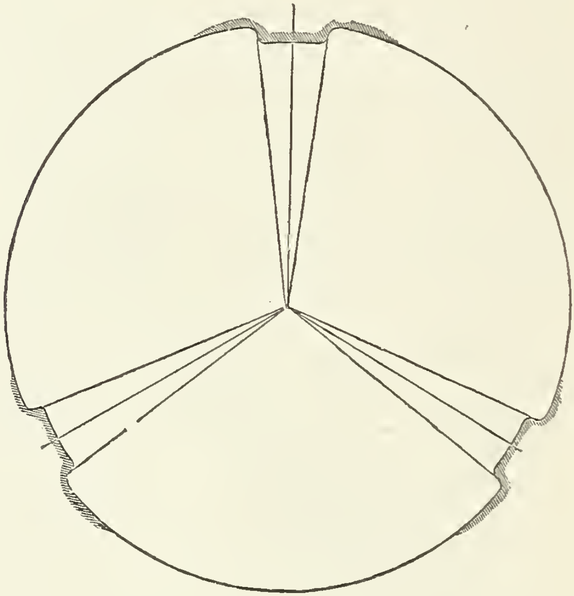


FIG. 156.

the corresponding grooves, are shown in Fig. 156. There are no sharp angles either in the projectile or the bore of the piece.

The dimensions and particulars concerning the guns and rifling are given in the following tables:

	GUN.					PROJECTILE.				WINDAGE.		
a	*b*	*c*	*d*	*e*	*f*	*g*	*h*	*k*	*l*	*m*	*n*	*o*
Pdr.	Diam. bore in.	Diam. inside ribs.	Depth of ribs.	Breadth of rib at point.	Radii joining bore and rib.	Body mean Diam.	Bottom of groove Diam.	Width of grooves at bottom.	Radii at corners of grooves.	Body of projectile.	Over grooves.	At sides of grooves.
4	2.2	2.	0.1	0.26	.03	......	......	......	.03	......	......	......
6	2.5	2.2	0.15	0.29	.05	......	......	......	.05	......	......	......
9	2.75	2.45	0.15	0.32	.05	......	......	......	.05	......	......	......
12	3.00	2.65	0.175	0.35	.05	2.95	2.6	0.39	.05	.05	.04	.04
20	3.75	3.35	0.2	0.44	.05	3.685	3.31	0.48	.05	.065	.04	.04
40	4.75	4.35	0.2	0.57	.05	4.685	4.31	0.61	.05	.065	.04	.04
60	5.5	5.10	0.2	0 67	.05	5.43	5.05	0.71	.05	.07	.05	.04
110	6.3	5.90	0.2	0.78	.05	6.22	5.85	0.82	.05	.08	.05	.04
115	7.0	6.6	0.2	0.87	.05	6.92	6.55	0.91	.05	.08	.05	.04
180	8.0	7.6	0.2	1.00	.05	......	......	......	.05	......	......	......
250	9.0	8.6	0.2	1.13	.05	......	......	......	.05	......	......	......
400	10.0	9.5	0.25	1.25	.08	......	......	......	.08	......	......	......
500	11.0	10.5	0.25	1.38	.08	......	......	......	.08	......	......	......
600	12.0	11.4	0.30	1.5	.10	......	......	......	.10	......	......	......

The twist of the rifling is one turn in thirty calibres for all sizes. The angle of the twist is $5°, 58', 41''.6$, and is thus obtained:

In the right-angled triangle ABC (Fig. 157), let $AB = n =$ the number of calibres in which the projectile makes one revolution $= 30 =$

BC = circumference of bore,
θ = angle of rifling;

$$\text{Then } \tan\theta = \frac{BC}{AB} = \frac{\pi}{n} = \frac{3.1416}{30} =$$

nat. no. 0.10472 log 9.020029 = 5°.58′, 41″.6.

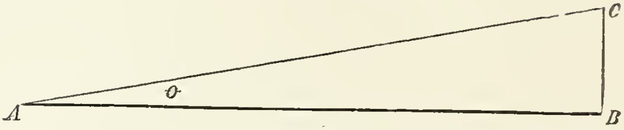


FIG. 157.

To find the Width of Rib.—Having width of rib for one gun, to find that of another gun, when r' of the latter is known.

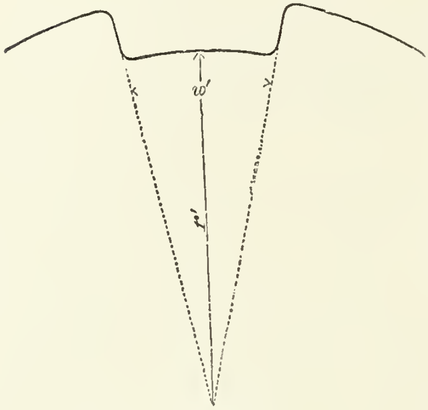


FIG. 158.

w^1 = width of rib.

v^1 = $\frac{1}{2}$ diam. inside of rib (col. *c.* of Tab).

1.5 = width of rib of 12-in. gun.

5.7 = r′ for 12-in. gun.

Then w′ : 1.5 = r′ : 5.7.

Suppose w′ is required for 10-in. gun, when r′ = 4″.75,

$$w' = r' \times \frac{1.5}{5.7} = .263r'$$

$$= .263 \times 4.75 =$$

1″. 24925, or 1″.25 (col. *e* of Table).

In this system the bore of the gun is not weakened by having grooves cut into it, and the projectile is also considerably stronger than those fitted with studs, because the metal cut out of the body of a twelve-inch projectile, for instance, by the countersinks for fixing the studs (Art. 782), is more than that cut out of the same projectile by the three grooves.

There is also considerable less scoring in the bore, as the part most affected by the rush of the gas in the part between the ribs, nearly one-third the whole circumference in width; the scoring is, therefore, much less local and takes place in a part not weakened by grooves cut into it, as is the case in grooved guns, where the grooves being the highest part of the bore act as channels along which the gas rushes.

It is claimed that as the ribs in this system project from the surface of the bore, they are much more effectually cleaned than are grooves, by sponging, so that much less windage can be allowed.

Late experiments to determine the relative values of long and of short rifle-bearings have demonstrated the great superiority of the system.

This arrangement necessarily involves a considerable amount of friction, the more so as both the metals which come into contact are hard. It is necessary that the projectiles should be fitted with peculiar precision, so as to preclude jamming on the one hand, and too much windage on the other.

757. Scott's System.—In this method the bore is rifled with narrow, shallow grooves (Fig. 159), deeper on the driving than on the loading side. The projectile is one iron casting having ribs almost triangular in section, extending the whole length of the cylindrical body, and set to the angle of the rifling. In cross section the ribs give a deep bearing-surface on the driving-side. (Fig. 160.)

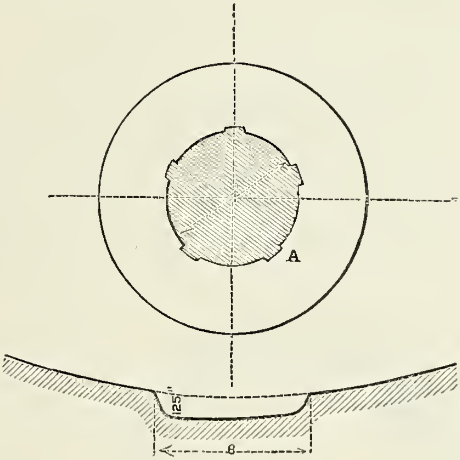


Fig. 159.

By shallowing the loading-side of the groove, the ribs rest on inclined planes so that the projectile, when forced into its seat, has a natural tendency to slip round so as to cling to the driving-side before the gun is fired, to start easily, and to mount into the centring position the moment it begins to move out.

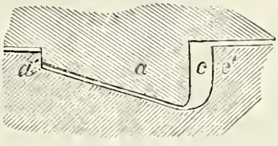


Fig. 160.—Scott's Groove and Rib.

Less windage is given to the ribs on the projectile than to its body, so that it rests upon its projections, and its body does not touch the bore at all.

The ribs almost fill up the grooves, and check the escape of the gas, with its consequent erosion of the bore, and unequal action on the projectile. While by striking the curve of the cross section of the groove and of the rib with two different radii, the latter is driven up into the centre of the bore at once, causing the axis of the projectile and of the bore to coincide. (Fig. 161.)

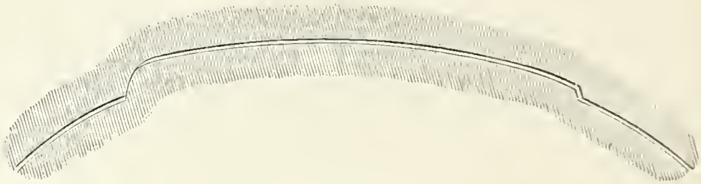


Fig. 161.

In this system there are 3 grooves for 9-ton guns and under; 5 grooves for 12 and 18-ton guns; and 7 grooves for 25-ton guns and upwards. The grooves are of the same size for all guns. Width, 0.8 inch; depth, 0.125 inch. This system has not, as yet, been generally adopted by any nation.

758. Lancaster's System.—This method may be described as that of the usual circular bore with two wide grooves, each about one-third the circumference in width, the shoulders of the grooves being shaved off so as form an ellipse. (Fig. 162.) The cross section of the bore is oval, only a trace of the original bore being left at the minor axis.

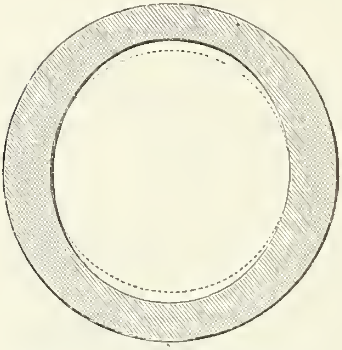


Fig. 162.—Lancaster's Rifling.

The absence of shoulders to the two grooves converts the two places of contact of the projectile with the rifling, into circular wedges tending to burst the gun or to compress the projectile.

This system has much to commend it, on account of its simplicity, but it has never obtained success; on the contrary, it has been very unsuccessful in competition with other systems.

759. Comparative Advantages of the First Class.—The advantages of this class are: economy, simplicity, and durability of projectile. The rifle-motion is communicated with great certainty and regularity. The projectile does not expand

by the explosion, and hence gets more windage as the bore warms, so that its safety-valve gets larger as the guns expands and gets weaker.

The chief objections are, that both projectile and bore being hard, fracture of one or the other is liable to occur from a projectile *jamming*, and that unless the bore be made of very hard material, it will be rapidly worn by the friction of the projectile on it.

The obvious mechanical advantages of the *Centring System* recommend it. It decreases the strain upon the gun by allowing windage without affecting the accuracy of the flight of the projectile; and when so applied as to bring the minimum wedging-strain and friction upon the gun, and to place and hold the projectile in the centre of the bore without shock, and to allow its centre of gravity to be in the centre of figure, and to support the projectile at or on both sides of its centre of gravity, thus promoting velocity and accuracy, it would seem that this system must be the best to be adopted for heavy ordnance.

760. Second Class.—In this class the body of the projectile is composed of a hard metal, as cast-iron, and there are attached to it projections of soft metal in the form of ribs, or rounded buttons so arranged as to enter the grooves of the rifling. The *Woolwich* or *French* rifling, and the Shunt system are examples of this class.

761. The Woolwich System.—The present English service rifling is called by this name. It is a modification of the French System, and consists of deep broad grooves (Fig. 163), each of which receives two soft metal circular studs attached to the projectile.

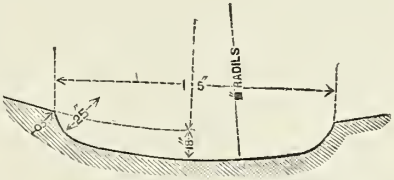


Fig. 163.—Woolwich Groove.

The grooves are three or more in number, according to the calibre of the piece; they are 1.5 inches wide, and 0.18 inches deep, with curved edges, both the loading and driving edges being struck with the same radius. The bottom of the grooves is eccentric to the bore, being struck with a radius of 3 inches; they are of the same width for all natures of heavy guns, but are a little deeper for the 10-inch gun and upwards; the grooves are also widened at the muzzle in the larger guns, in order to faciliate loading by cutting away the loading side slightly for two inches from the muzzle.

This system embraces uniform and increasing twists, the latter being preferred.

Both the direction and twist are given by the bearing of the studs on the grooves, the body of the projectile never being intended to come into contact with the bore. The windage is 0.8 inch in all calibres.

The projectiles have two studs for each groove in all instances; both studs in the case of the uniform twist, and the rear one where the twist is increasing, are nearly of the size of the groove, with their faces corresponding to the curved bottom of the groove.

The rear stud is four inches from the bottom of the projectile, and the studs of each groove are equidistant from the centre of gravity. (Art. 783.)

Particulars of the Rifling:

12-inch gun, 9 grooves; twist increasing from 1 in 100 to 1 in 50 calibres at muzzle. 10-inch gun, 7 grooves; twist increasing from 1 in 100 to 1 in 40 calibres at muzzle. 9-inch gun, 6 grooves; twist increasing from 0 to 1 in 45 calibres at muzzle. 8-inch gun, 4 grooves; twist increasing from 0 to 1 in 40 calibres at muzzle. 7-inch gun, 3 grooves; twist uniform 1 in 35 calibres.

The 7-inch gun has a uniform twist because, at the time of its introduction, the uniform was preferred to the increasing spiral.

762. The Shunt System.—This is one of Armstrong's systems of rifling. The peculiarity of this system is that the depth and width of the grooves vary at different parts, the object aimed at being to provide a deep groove for the studs of the projectile to travel down when the gun is being loaded, and a shallow groove through which they must pass when the gun is fired, so that the projectile may be gripped and perfectly centred on leaving the muzzle. This is obtained by making one side of the groove (the driving-side) near the muzzle, shallow, as shown in Fig. 164, the unshaded portion representing the shallow part, or grip.

The projectiles have soft copper studs, which fit easily with a windage of 0.025 inch into the deep portion of the groove; when the gun is loaded, the studs travel down this deep portion until they reach about the middle of the bore, where they meet with an incline, by which they are "shunted," or switched off, into a narrow part of the groove, still of the same depth, down which they travel to the chamber.

On discharge the studs bear against the other side of the groove, until they come to the incline, up which they travel, the studs being thereby compressed. With this compression they pass through the remaining part of the bore.

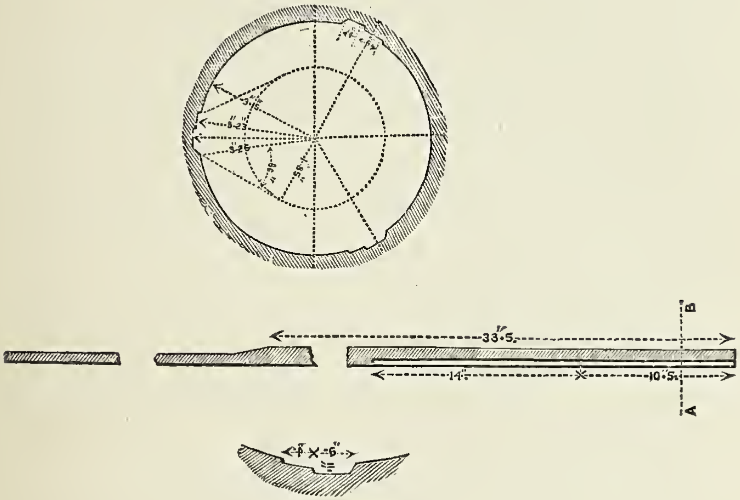


Fig. 164.

There are three grooves with a uniform pitch of one turn in 40 calibres, the edges being angular.

This system was introduced with certain guns of the Armstrong pattern in the English service, after the repeated failures of his heavy breech-loading guns, because, it carried out two favorite theories of Sir William Armstrong, viz., the centring of the projectile and its retardation. The last is now generally conceded to be a disadvantage. It has been abandoned, because it was not found to answer well in practice.

It was complicated; the projectile was gripped at the muzzle when at its highest velocity, thus greatly straining the piece, and the sharp angles at the edge of the grooves rendered the tube liable to split.

763. Comparative Advantages of the Second Class.—In this class the studs being soft, the bore is not liable to injury from the projectile, if, as should always be the case, the height of the stud is rather greater than the depth of the groove, so that the projectile moves through the bore on the studs alone. Also if a jam should occur, the studs will give away, and so prevent injury.

Studs in the middle of the projectile instead of long bearings on its cylindrical portion, or expanding material at its base, allow the rifling to stop farther away from the chamber; so that the gun is not weakened by it, at the point of greatest powder-pressure.

On the other hand, the studs cause additional expense in manufacture, and they are liable to injury in transport or store. And they are a frequent cause of injury to the bore from overriding the grooves.

764. Third Class.—In this class the body of the projectile is composed of a hard metal, and there is attached to it, generally at the base, a cup, band, or other arrangement of soft metal, by the expansion of which into the grooves of the gun the projectile is given rotation.

The expansion system is carried out on the most extensive scale in this country. The plan of rifling which has heretofore been almost universally adopted in the United States consists of lands and grooves of the same or nearly equal width. As the standard Army and Navy projectiles are of the expanding class, they may all be used in any gun of the proper calibre, irrespective of the width or depth of the groove.

The Parrott, Hotchkiss, and Shenkle, and many other projectiles, belong to this class. The Parrott system will illustrate it. (Art. 785.)

765. The Parrott System.—In the rifling of the Parrott guns the grooves and lands are of equal width, the former being one-tenth inch deep for all calibres. The bottom corners of the grooves are rounded to facilitate cleaning and to do away with the mechanical disadvantage of a sharp corner. (Fig. 165.)

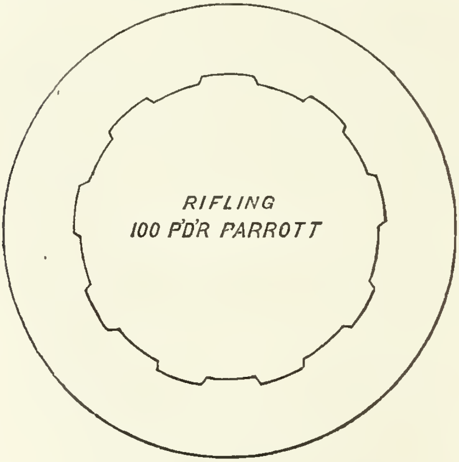


Fig. 165.

The projectiles are recessed around the corner of the base to receive a brass ring which is expanded into the grooves of the gun by the explosion of the powder.

All calibres are rifled with an increasing-twist.

The following table gives the particulars of the Parrott guns and rifling.

The calibres in use in the naval service are the 100-pdr. and the 60-pdr.

The 30-pdrs. and 20-pdrs. have been withdrawn, and a new bronze 20-pdr. rifle substituted.

Round shot can readily be used in these guns when advantageous, as for the ricochet. They should be wrapped in canvas or other suitable material, with the object of bringing their centre as nearly in the axis of the bore as practicable.

PARTICULARS AND AMMUNITION OF THE PARROTT GUNS.

NAME OF GUN.	Length of Bore.	Diameter of Bore.	Diameter over Reinforce.	Weight.	No. of Grooves.	Depth of Grooves.	Twist of Rifling. (Increasing.)	Charge.	Weight of Projectile.
	Ins.	Ins.	Ins.	Lbs.		Ins.	1 turn in ft. at muzzle.	Lbs.	Lbs.
10-pdr......	70	3	11.3	890	3	$\frac{1}{10}$	10	1	Shot, $10\frac{1}{4}$; Shell, $9\frac{3}{4}$
20-pdr......	79	3.67	14.5	1750	5	$\frac{1}{10}$	10	2	Shot, $19\frac{1}{2}$; Shell, $18\frac{3}{4}$
30-pdr. Army.	120	4.20	18.3	4200	7	$\frac{1}{10}$	12	$3\frac{1}{4}$	25 to 30
30-pdr. Navy.	96.8	4.20	18.3	3550					
60-pdr. Navy.	105	5.3	21.3	5360	7	$\frac{1}{10}$	15	6	55
100-pdr......	130	6.4	25.9	9700	9	$\frac{1}{10}$	18	10	70 to 100
8-inch.......	136	8	32	16300	11	$\frac{1}{10}$	23	16	132 to 175
10-inch......	144	10	40	26500	15	$\frac{1}{10}$	30	25	230 to 250

766. Comparative Advantages of Third Class.—Expanding projectiles cannot be fired with as heavy a charge of powder as others, for fear of breaking, nor are they always sure to receive the rifle-motion. The windage being greatly reduced or entirely stopped, the strain on the gun is increased, and an ordinary time-fuze will not always be lighted by the flame from the charge of the gun. Fragments of the expanding attachment are liable to fly off and injure those in advance. The centre of gravity is almost necessarily behind the centre

of figure, and the bearing of the projectile is usually behind the centre of gravity.

767. Fourth Class.—With this class the projectile is larger than the bore, and is squeezed or planed to fit the bore by the lands of the rifling. The projectile, therefore, must have a soft coating, and be entered at the breech into a chamber larger than the rest of the bore; and whatever escape of gas there may be around the breech-closing apparatus reduces its range and velocity.

This plan was early adopted and perfected by the Germans, who obtained great accuracy and range with charges of one-tenth weight of the projectile. The rifling consisted of numerous shallow rectangular grooves.

The Armstrong system of rifling for breech-loaders formerly used in the English service does not differ in principle from this. The rifling consists of a great number of shallow, narrow grooves (the 7-inch has 76), the object being to give the soft metal covering a very large bearing on the driving-side of the grooves, and thus prevent stripping, and make up for want of depth. This system has been abandoned.

The German system will illustrate this class.

768. The German System, or Krupp's Method.—In this system the grooves are thirty in number for all calibres, quite shallow, and of the form shown in Fig. 166, their sides being radial and forming sharp angles with the bore. The rifling has a uniform-twist of one turn in 25 feet.

The grooves are wider at the bottom of the bore than at the muzzle, so that the compression of the lead-coated projectile is gradual, and less force is expended in changing the shape of the projectile.

This change of shape is effected by making the whole groove of the same size as at the muzzle, and then cutting away gradually on the loading-edge of the groove. Of course, as the twist is uniform, the driving-side of the groove cannot vary.

The outer surface of the lead coating of the projectile is in raised rings with grooves between, to allow space for its being drawn down in passing through the bore. (Fig. 182.)

769. Comparative Advantages of the Fourth Class.—The compressing system unduly strains the gun by suddenly stopping windage, by fouling, and by forcing the projectile into a bore of smaller diameter. The compressed projectile must be fired from a breech-loading gun, and the increasing-twist is impracticable from the great length of the soft-metal bearing. The soft coating of the projectile is liable to injury in handling and in store; also to be stripped on firing.

Its advantages are that the projectile is centred during its passage through the bore, which prevents balloting; the angles of departure and the initial velocities are therefore more uni-

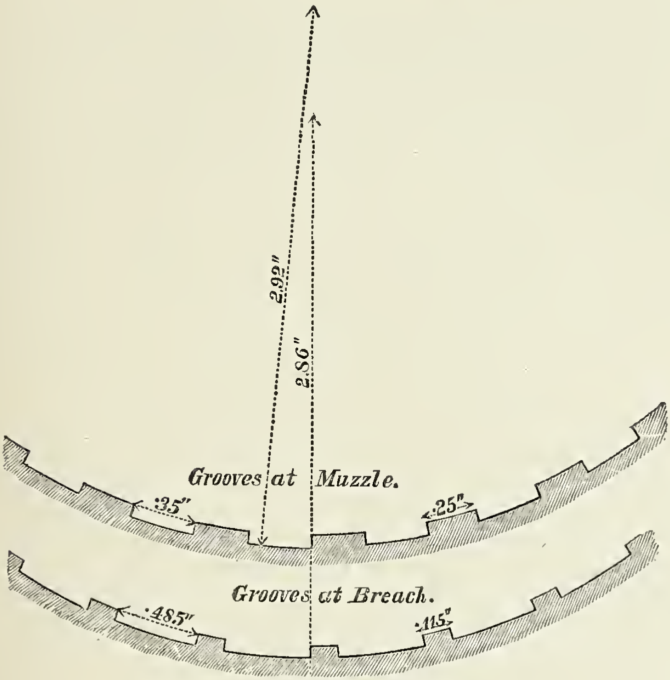


FIG. 166.

form, and the stability of the axis of rotation on leaving the bore is better assured; from which result great regularity and precision of fire. There is little or no difficulty as to erosion of the metal caused by the gas forcing its way between the projectile and the bore.

The lead jacket of the forced projectile does not prevent the employment of heavy charges. Forced projectiles do not wedge in the bore. The regularity of the movement of these projectiles does not wear or injure the bore. The soft-metal coating prevents damage to the lands.

The bursting of a projectile covered with soft metal has comparatively no baneful effect on the gun.

770. BREECH-LOADING.—Intimately connected with the subject of the different systems of rifling is that of the ad-

vantages and disadvantages of *breech-loading* for cannon. There are strong arguments both for and against the use of the breech-loaders—some nations using them altogether and others not at all.

771. *Advantages.*—A principal advantage claimed for breech-loading guns is rapidity of fire, but the result does not seem to have been attained in the large guns.

The gun can be loaded when run out, without exposing the men, and worked in a smaller space by limiting the recoil. Any ignited substance left in the bore can be seen and removed; and there is no danger of the projectile not being home.

The breech-loading gun may be made longer, occasionally, which is a great advantage where there is difficulty in burning the powder; moreover, a large powder-chamber may be employed for the better burning of the charge.

The advantages of the Fourth Class of Rifling (Art. 769) may be claimed in favor of breech-loading.

772. *Disadvantages.*—The breech-loading cannon is heavier and more expensive than one loading at the muzzle.

There are more parts to be damaged. In heavy guns, far from there being any increased facility in loading, considerable force has to be used and applied in a very careful way to the breech-closing apparatus, or the gun may be rendered temporarily unserviceable. Escape of gas, fouling or corrosion of the closing surfaces, and injury to the delicate Broadwell-ring or gas-check, are among the contingencies that may arise in service.

Much additional labor and outlay are required to construct and fit up interchangeable hollow screws or sliding stoppers; to fit and renew gas-checks; to apply opening and closing apparatus, which cannot be very simple, but which must be very strong and durable; to fabricate, keep clean, and maintain all these parts on such a plan that two or three men can manipulate them with ease and certainty, and without unusual risk of disaster from excitement or carelessness; and of such size and strength that the heaviest projectiles can be fired, with large charges of powder.

773. *Conclusions.*—The adoption of a system of working and loading guns by hydraulic power (Art. 886) must have an important bearing upon the question of the comparative merits of breech and muzzle loaders. One of the chief advantages claimed for breech-loaders is that any length of bore can be adopted without increasing the difficulty of loading, and that, therefore, a higher duty can be obtained from the

powder. It has also been urged that a gun of larger size can be worked in a given turret as a breech-loader. Successful mechanical methods for loading at the muzzle would seem to negative these advantages.

The suppression of windage and the power of placing the vent in the breech-block are important advantages claimed for breech-loaders. It has now become very important to suppress windage, which tends much more rapidly to score and cut up the bore in very heavy guns, fired with large charges of slow burning powder, than in small guns fired with light, quick-burning charges. The vent is also a serious trouble in very heavy guns, from its rapid erosion by the same cause. But it is claimed that the windage can be effectually suppressed in many muzzle-loading systems of rifling and projectiles, and an arrangement has been devised for stopping altogether the passage of gas through the vent, thus removing the difficulty of its erosion.*

In view of these facts, the relative merits of the two systems must remain undetermined for the present.

* In some experiments made in England by Capt. Noble upon the force of fired gunpowder, he succeeded in effectually closing the vent, as follows: The stoppage of the vent was effected by an apparatus consisting of a steel plug screwed into the body of the gun, immediately over the copper vent. This remained a fixture, but was capable of easy removal in case it should be desirable to fire by the ordinary process. The interior of the plug was bored out and screwed, so that another plug could be fitted inside of it. The inner plug had half the thread cut away as in the screw of the French breech-loading gun, so that it went in at once and by a quarter of a turn was rendered fast. Inside of the inner plug a little plunger worked in a cylindrical chamber, into which a primer representing the common friction-tube was dropped. In the centre of the plunger, there was a pin to fire the primer by detonation, and surrounding it a steel gas-check, which, when the powder was exploded, expanded so as to stop the escape of gas. The charge was fired by striking the external head of the plunger. The recoil of the plunger was stopped by a shoulder.

CHAPTER VI.

PROJECTILES.

Section I.—General Description.

774. Classification.—Projectiles may be classified—according to their form, as *spherical* and *elongated;* according to their structure and mode of operation, as *solid*, *hollow*, and *case shot.*

775. SPHERICAL PROJECTILES.—Spherical projectiles are commonly used in smooth-bore-guns, and for this purpose possess certain advantages over those of an elongated form. 1st, they present a uniform surface to the resistance of the air as they turn over in their flight; 2d, for a given weight they offer the least extent of surface to the resistance of the air; 3d, the centres of figure and inertia coincide; 4th, they touch the surface of the bore at only one point; they are therefore less liable to wedge in the bore and endanger the safety of the piece. 5th, their rebound on land and water being certain and regular they are well suited to ricochet-firing.

776. ELONGATED PROJECTILES.—The great improvements which have been made of late, in the accuracy and range of cannon, consist simply in the use of the elongated instead of the spherical form of projectile.

To attain accuracy of flight and increase of range with an elongated projectile, it is necessary that it should move through the air in the direction of its length. Experience seems to show that the only sure method of affecting this is to give it a rapid rotary motion around its long axis by the grooves of the rifles.

777. Length.—This necessarily varies in the different descriptions of projectiles for the same gun, inasmuch as it is to some extent subordinate to the consideration of bringing them all, with certain exceptions, to the same weight; but experiments go to prove that a length of two calibres at least is necessary for very accurate firing, and it is desirable for good "vis viva," or destructive effect on impact at any but very short ranges, to have the weight great in proportion to the calibre, or, in fact, to the surface of resistance, and of course this is favored by an increased length of projectile. As a rule, the best length for

accurate firing with any ordinary twist, has been found to be from two to three calibres.

778. Form of Head.—The form of head is governed by two considerations, *flight* and *penetration*. The latter gives different forms in different instances. (Art. 851.) The question of flight affects all equally, and on this many experiments have been made, which have resulted in the general adoption of what is termed an *ogivàl* head, or figure generated by the revolution of an ogival, or pointed arch, about its axis.

It has been found that the total pressure on a nine-inch spherical projectile, moving with a velocity of 1150 feet per second, is about 555 lbs. ANBM representing the spherical nine-inch projectile (Fig. 167), and the total pressure on a hemispherical-headed, elongated projectile of the same diameter represented by ACD BM, and moving with the same velocity, is 487 lbs.—thus showing a difference of 68lbs. total pressure.*

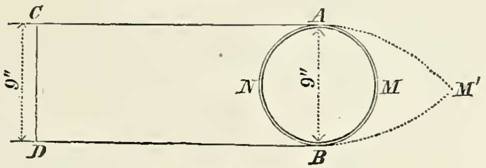


Fig. 167.

Now supposing the elongated projectile to move steadily, point first, the pressure on the respective heads, AMB, must be the same; therefore the difference of the total pressure, viz., 68lbs., must be due to the difference of *minus pressure* on the bases ANB, ACDB respectively, thus showing that the form of base of a projectile, materially influences the total pressure which it meets with, when moving through the air at a high velocity.

The total pressure on an ordinary ogival-headed projectile of nine-inch diameter, represented by ACDBM′, is only 389lbs., thus showing the great difference of pressure, viz., 166lbs., on an elongated ogival-headed projectile and a spherical projectile of the same diameter when moving at the same velocity through the air. Another great advantage which the elongated projectile possesses over the spherical, is that, for the same calibre, the momentum of the former is much greater, varying, of course, in proportion to their respective weights, which would be nearly three to one, depending on the length of the elongated projectile.

779. The construction of ogival heads of radii of 1, $1\frac{1}{4}$ and $1\frac{1}{2}$ diameter respectively, may be seen in Figs. 168, 169, and 170—

* Bashforth.

C and C′ being the centres and R the length of the radii in

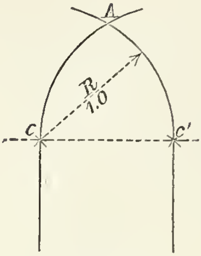


Fig. 168.

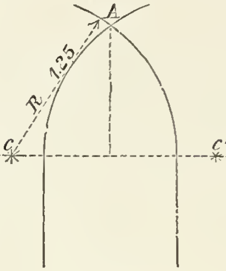


Fig. 169.

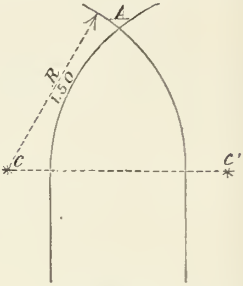


Fig. 170.

each case. It will be seen in the case of $1\frac{1}{4}$ diameter's radius that the head is exactly 1 calibre long.

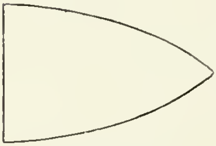


Fig. 171.

780. Newton gives the form of body (Fig. 171) which would, in passing through a fluid. experience the least resistance. This form, it is seen, is very similar to the ogival.

781. Piobert says that the figure (172) will experience the least resistance from the air. Its length is five times its greatest diameter, and its largest section is placed $\frac{2}{5}$ of the length from the hind part.

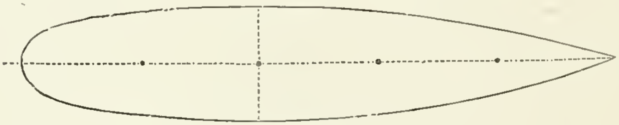


Fig. 172.

The shape of some of the Whitworth projectiles approach more nearly to this form than those of any elongated projectiles hitherto used. (Art. .)

782. Studded Projectiles.—These are fitted for rifling of the second class. (Art. 760.) The studs are usually of bronze, the proportions of the alloy being from seven to ten parts of copper to one of tin, which is sufficiently soft to enable the stud to be attached to the projectile by pressing it into under-cut holes in the latter, causing the end, which is cupped or hollowed out, to expand and rivet itself firmly in; it is swedged cold into the holes. (Fig. 173.)

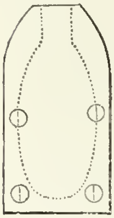


Fig. 173.

In studding a projectile, two rings of circular holes are usually cast in the walls, the number of holes in each ring corresponding to the number of grooves in the gun. The weakening of the walls by so many holes, and the concentration of the effort of rotation at these points, seriously affects the endurance of the projectile.

783. The system of studding to accommodate the increasing spiral, can be readily understood by Fig. 174, and the following explanation. EE′, DD′ represent the groove at seat of projectile; AA′, BB′ represent the groove at the muzzle.

O and O′ are the studs.

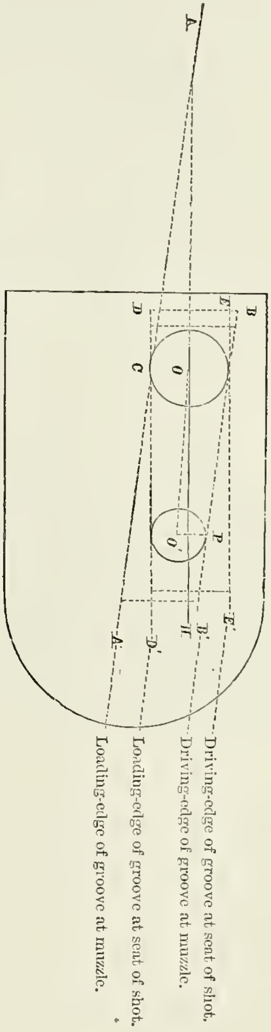


FIG. 174. Palliser's Differential Studding.

The object sought is to combine a double bearing with an accelerated spiral. The difficulty lies in the fact, that since the angle at which the grooves are inclined is continually increasing, the gun would be trying to turn the fore part of a rigid projectile faster than the hinder part, which would be impossible.

To overcome this difficulty, the rear stud is made larger than the front one. Thus, at starting, the three rear studs do all the work of turning the projectile, since EE′ is the driving-edge of the groove when it commences to move. This work is inconsiderable, as the angle of the twist at first is zero. But as the projectile travels along the bore, the friction will wear down the rear studs, and the assistance of those in front will be gradually called into play.

The rear studs are made large enough to fill the grooves; the size and position of the front stud is thus determined. Draw AA′ tangent to the larger stud at C, and making an angle A′AH = final angle of rifling. From O, the centre of the rear stud draw OO′, making O′OH = $\frac{1}{2}$ A′AH. It will readily be seen that a circle described with any point O′ as a centre along the line OO′, and the perpendicular O′P let fall upon BB′ as a radius, will touch DD′, and that the projectile will freely enter the gun, and that the bearing-edges of the stud will all press equally on the driving-edges of the grooves as the projectile approaches the muzzle.

The front stud touches the driving-edge on entering the bore, and the loading-edge when well home; and the reverse action occurring in firing, the share it takes in the work of rotation is very small, for until the driving-edge meets it, the whole pressure is on the rear studs. Its chief use appears to be to steady the projectile.

784. These projectiles must be handled and stored with great care to prevent the studs being bruised and injured so as to jam in the bore, or fail to grip on the grooves in firing.

They are liable to break up in the bore if fired a second time, and the studs are liable to sheer and thus prevent the centring of the projectile.

785. Expanding Projectiles.—These are used with rifling of the Third Class. (Art. 764.)

All the projectiles used in the navy for rifled ordnance are of the Expanding Class; being forced to take the grooves by the action of the charge of powder, and require no other precaution in loading than spherical shell. It is essential, however, that the base-ring of every rifle projectile. especially the Parrott, shall be greased before entering it into the gun, to prevent the formation of a hard deposit in the grooves.

Parrott Projectile.—Parrott's projectile is composed of a cast-iron body and brass ring cast into a rabbet formed around its base.

The ring is from 1 in. to $1\frac{1}{2}$ in. in width, and about 1 in. in maximum depth. The gas presses against the bottom of the ring and underneath it, so as to expand it into the grooves of the gun. (Fig. 175.)

To prevent the ring from turning in the rabbet, the latter is recessed at several points of its circumference, like the teeth of gearing.

The diameter of the rabbet is greatest at the extreme rear of the shot, so that the brass ring cannot fly off without breaking. The entire projectile is slightly smaller than the bore, so as to be easily rammed home.

Very few of the rings have been broken in practice; they should be separated from the iron base of the projectile at three or four parts of the circumference, in case any fail to expand and take the grooves.

This should be done very lightly with a cold-chisel, so as not to interfere with loading. It is only necessary to sever the

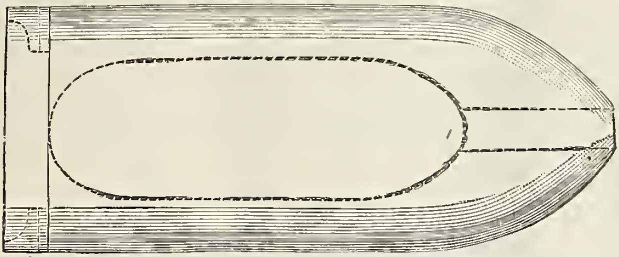


FIG 175.—Parrott 100-pounder shell.

contact of the two metals. The use of a little grease or other lubricating material around the ring of the projectile, before firing, is advantageous.

786. *Dahlgren Projectile.*—Dahlgren's rifle projectile consists of a cast-iron cylindro-conical projectile with a leaden cup attached to its base; offsets from the cup entering into recesses in the iron securely attach the cup to the projectile. (Fig. 176.) There are projections cast on the cylindrical portion which are but slightly raised from the surface of the shot; and in the groove around the cup is placed a mixture of tallow and lamp-black, which lubricates the bore after each discharge.

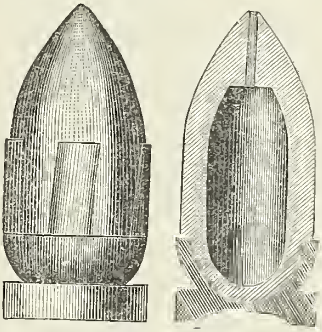


FIG 176.

787. *The Shenkle Projectile.*—Shenkle's projectile is composed of a cast-iron body, having its greatest diameter a little more than $\frac{1}{3}$ of its length from the forward end, from which point, to the rear end, it presents the form of a truncated cone, with straight projections cast upon it. (Fig. 178.)

Around the rear portion is placed a ring of *papier-maché* (Fig. 179), the interior of which is made conical and grooved to fit the projections on the casting; so that there shall be no lateral slipping; the exterior is cylindrical and slightly smaller than the bore, so as to run home easily. The powder-gas drives the *papier-maché* ring forward upon the case, whence it is jammed into the grooves of the gun, and made so compact as to rotate the projectiles without stripping. On issuing from

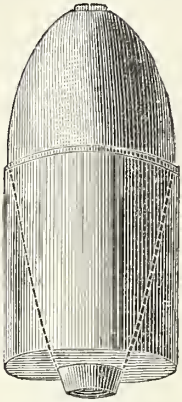


Fig. 177.

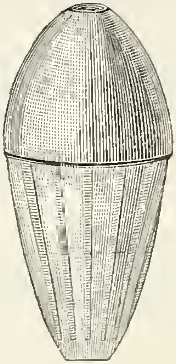


Fig. 178.

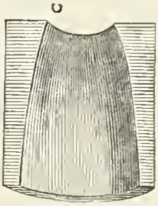


Fig. 179.

the bore the ring is blown to pieces, leaving the projectile unencumbered in its flight.

A great difficulty has been found in practice in always getting a proper quality of material for the sabôt ring.

These projectiles have gone out of use, as the papier-maché case was found to swell and expand upon being exposed to dampness and moisture.

788. *Hotchkiss Projectile.*—The Hotchkiss projectile is composed of three parts. It consists of a cast-iron body with a cylindrical base of diminished diameter, over which a cast-iron cap is fitted. These parts are slightly less in diameter than the bore of the gun. The groove between the body and the cap contains an expanding ring of lead; offsets from the lead entering into recesses in both the iron parts, and holding all secure. (Fig. 181.)

The first power of the powder, before the inertia of the whole projectile is overcome, is devoted to driving the cap farther upon the body, thus squeezing out the intermediate lead into the grooves of the gun, and at the same time holding the lead, as in a vice, so that it cannot revolve on the projectile. When discharged, the base-piece is driven forward upon the front piece to an extent which is definitely limited by its contact with the extreme rear, and by this movement expands the soft-metal ring to an amount just sufficient to fill the gun and take the grooves.

789. Lead-coated Projectiles.—These are used with rifling of the fourth class. (Art. 767.)

To attach the lead-coat the surface of the iron is well cleaned,

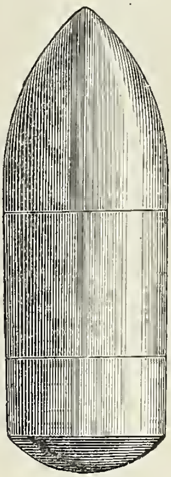


Fig 180.

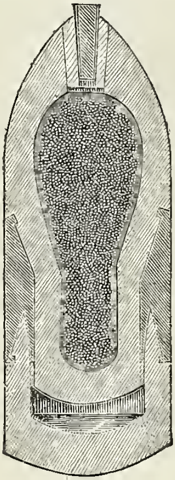


Fig. 181.

and covered with a zinc solder, when the lead is cast directly on that. The zinc amalgamates sufficiently with the iron and lead to give a very complete attachment. In order to get a clean metallic surface to which the zinc may adhere, the projectile is dipped into a sal-ammoniac solution; the next operation consists in dipping the projectile into molten zinc.

The lead-coat occasionally becomes detached in spots, where the lead has risen up into blisters from the formation of gas underneath it, occasioned by voltaic action between the different metals. Such blisters are generally very small, and may be pricked and then hammered down, without affecting the fitness of the projectile for service. If left to develop themselves they have been known to attain a large size. In the German service, the lead-coat is covered with a mixture of beeswax and benzine applied warm, and rubbed smooth with flannel rags. This does away with any necessity for lubricating the bore. (Fig. 182.)

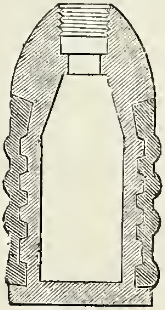


Fig. 182.

790. The lead-coating is preserved from injury by two grommets which are nearly cut in two to facilitate

removal, and the projectiles are stored in racks fitted in the shell-room.

Sometimes the body of the projectile is not strictly cylindrical, but rather smaller at the base, the lead-coating bringing the finished body into a cylinder. This form is considered good for penetration, but any lead-coating must considerably retard the projectile in endeavoring to force its way through armor.

This lead-covering causes a great waste of power, as it is the iron part alone, of the shell, that can do work against the iron plates, and consequently a considerable force is expended in projecting a part of the projectile which is useless for the work which has to be performed.

791. SOLID PROJECTILES.—Solid projectiles when used in heavy guns are known as *solid-shot*, *round-shot*, or *shot.* They are employed to destroy, fracture, or penetrate an object by the mere force of impact, and are used when great range, accuracy, and penetration are required. Solid shot are classified according to their weight.

792. HOLLOW PROJECTILES.—Under the head of Hollow Projectiles are included shells for guns, howitzers, and mortars. These are usually made of cast-iron, and are classified according to the diameter of the bore of the piece.

793. SHELL.—A shell is a hollow projectile filled with gunpowder, which is ignited by a fuze at the required moment, the bursting of the shell causing destruction by its explosive force and by the fragments, and, if the object be combustible, by setting it on fire.

The thickness of metal must be such that the shell may contain as large a bursting-charge as possible, but that it be strong enough to withstand the shock of the discharge within the bore of the gun.

The thickness of metal in a spherical shell is about one-sixth of the diameter, and the weight of the shell is about three-fourths that of the solid-shot of the same calibre.

CRANE'S IX-IN. SHELL consists of a shell within a shell. The advantage claimed is that upon bursting it separates into double the number of pieces.

It is made by first casting an VIII-in. shell with a IX-in. core; this casting (when sufficiently set, and before cold) is used as the core for a IX-in. shell.

PEVEY'S SHELL is made similar to the Crane's, excepting that there is a space of about seven-tenths (7-10ths) of an inch between the two shells, which is filled with small-sized iron balls.

The shell of a rifle-gun, being elongated, is, by giving it a greater length than the shot, brought up to the same weight as the latter.

794. Mortar-shells are fired from Mortars at high angles, being intended to fall upon and set fire to buildings, vessels, or other combustible constructions; to destroy earth-works, or by their great penetration before bursting to explode magazines protected from other projectiles.

They are fitted with two *lugs* placed one on each side of the fuze-hole, which serve for attaching a pair of *shell-hooks.*

The fuze-holes of mortar-shells are larger in diameter than those of other common shells, and they are not countersunk or bouched with composition.

795. CASE–SHOT.—Case-shot are a collection of small projectiles enclosed in a case or envelope.

The envelope is intended to be broken in the piece by the shock of the discharge, or at any point of its flight by a charge of powder enclosed within it; in either case the contained projectiles continue to move on after the rupture, but scatter out into the form of a cone; so as to cover a large surface and attain a great number of objects.

The three principal kinds of case-shot in use are *grape*, *canister*, and *shrapnel.*

They are adapted to all guns, and receive their names from the pieces in which they are used.

796. Shrapnel.—Shrapnel are thin-sided shell, in which are placed, besides the bursting-charge of powder, a number of small balls embedded in sulphur. They are cast in the same manner as ordinary shell, excepting that their sides are made thinner to allow for a greater number of balls. The charge of powder is quite small, being only sufficient to rupture the case and liberate the balls.

The thickness of the metal should be such that it will resist the explosion of the charge within the bore of the gun, but open readily with a small bursting-charge. The bursting-charge should be merely sufficient to open the shell without affecting the flight of the bullets.

A spherical shell of this class has a less thickness of metal than a common shell, viz., about one-tenth of its diameter, and its weight when empty is about half that of a solid shot of similar diameter. (Fig. 183.)

797. *Filling.*—To fill a shrapnel a funnel is screwed into the fuze-hole, and the case filled with the requisite number of balls. A round, hollow steel mandrel, made slightly tapering

towards the lower end, which is rounded off, and having a score cut on either side throughout its length to admit of a free passage for the melted sulphur to the interior of the shrapnel, is driven and worked through the fuze-hole to the bottom of the case. The projectile is then thoroughly warmed, generally in warm water, to prevent the cold metal from solidifying the sulphur before it has filled all the interstices.

It is then filled with melted sulphur, and as soon as the sulphur is set the mandrel is withdrawn; this is accomplished by first heating it from the interior by the insertion of a hot rod, when it is readily removed. The funnel is also removed, and the magazine formed by the mandrel is cleaned and the fuze-hole carefully tapped out.

In this magazine is deposited the charge of powder, where it is protected against all injury from the movement of the balls. By this arrangement the quantity of powder required to open the shrapnel is very small, and the bullets are prevented from striking by their inertia against the sides of the case and cracking it when the piece is fired.

Lead being much more dense than iron, the shrapnel is, when loaded, nearly as heavy as a solid shot of the same calibre

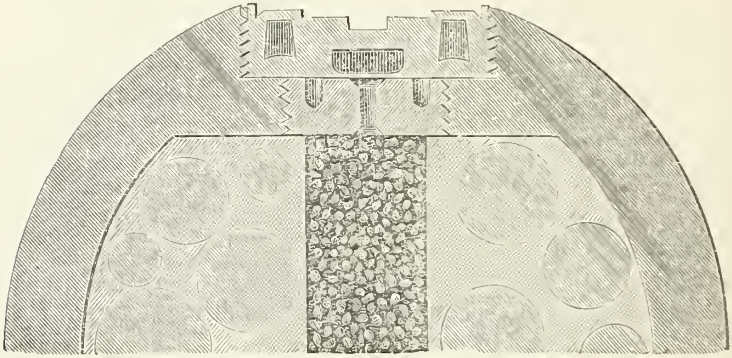


Fig. 183.—Section of 12-pdr. shrapnel, with Bormann fuze and filling of sulphur.

for the lighter guns. A shell of this class is, in fact, simply a canister-shot adapted to long range. The rupture may be made to take place at any point of its flight, and in this respect it is superior to canister and grape shot, which begin to separate the moment they leave the piece.

Table of contents and weights of spherical shrapnel for navy guns.

Calibre.	Weight of empty shell.	Contents.				Weight complete.
		No. of balls.	Size of balls.	Lbs. of sulphur.	Bursting-charge.	
XV-inch....	178 lbs.	1,000 iron.	1 inch.	30.	10 oz.	358 lbs.
XI-inch.....	76 "	625 iron.	0.85 "	10.	6 "	141 "
X-inch......	57 "	435 iron.	0.85 "	8.5	4 "	101 "
IX-inch.....	38 "	350 iron.	0.85 "	7.	3 "	75 "
VIII-inch....	29 "	220 iron.	0.85 "	5.	2.5 "	52 "
32-pdr......	15 "	235 lead.	0.65 "	2.25	1.25 "	32 "
24-pdr	11 "	175 lead.	0.65 "	1.5	450 grs.	24 "
12-pdr......	6.5 "	80 lead.	0.65 "	0.75	350 grs.	12 "

798. Rifle-shrapnel.—In the Boxer shrapnel for the rifled-ordnance of the English service the essential features of a shrapnel-shell are embodied.

This shell (Fig. 184) has a cylindrical iron body, with a chamber at the bottom, and four longitudinal grooves inside to facilitate breaking up; it is cast without a head. A tin case for the bursting-charge fits into the chamber, *on the shoulder* of which rests a wrought-iron disk. The shell is lined with paper, and filled with balls embedded in rosin. A wrought-iron tube passes down the middle of the shell and through a hole in the centre of the iron disk, to lead the flame from the fuze to the bursting-charge. A disk is placed over the top of the bullets.

The wooden head is ogival in form, and made of elm covered with thin wrought-iron, which is riveted to the shell. This head contains a socket and bouching for the fuze.

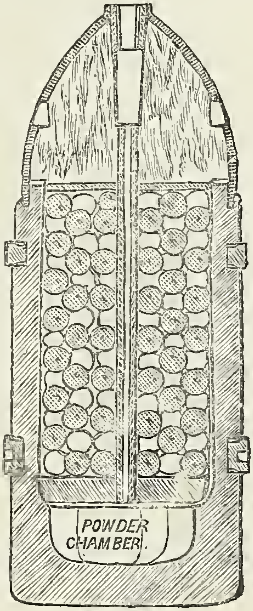


Fig. 184.

799. Grape-shot.—A grape-shot is composed of a number of small shot arranged around a spindle on an iron disk. Formerly the shot were

enclosed in a canvas-bag, which was drawn together between the balls, or "quilted" by a strong line; but the present method is more simple and durable. It consists of nine shot of a size appropriate to the calibre used, which are held together by two rings and a plate at each end of the stand connected by a rod. (Fig. 185.)

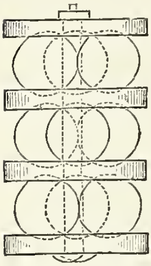


Fig. 185.

The diameter of balls for grape-shot varies with the calibre, being in all cases larger than those used for canister.

Grape-shot are now nearly obsolete, it being considered that canister-shot are sufficient for short ranges; and the canister-shot possesses the advantage of striking a great many more points at one discharge than grape. There is an advantage, too, in not having so many different kinds of ammunition.

It is the intention to abolish grape as soon as the stock on hand is exhausted.

800. Canister-shot.—A canister-shot is a metallic cylinder about one calibre in length, filled with balls and closed at both ends with wooden or metal disks. They are supplied for all guns.

For 8-inch canister, and all those of less calibre, the envelope is made of tin, while canister for the larger calibres have an envelope of iron.

The bottom of XV-inch canister is made of two thicknesses of 1-inch hard wood, crossing each other, and put together with wrought-iron nails clinched. A spindle, with a wrought-iron handle passing through the centre of the canister, is riveted on the bottom through a square plate. All other canister have bottom-heads of one thickness of hard wood. Top-heads are all made of white-pine.

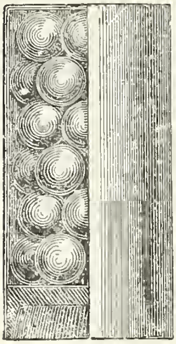


Fig. 186.

The case is notched, turned over the heads, and tacked down.

The balls for all canister are 1.3 inch diameter, and the number used varies with the calibre. To give more solidity to the mass, and prevent the balls from crowding upon each other when the piece is fired, the interstices are closely packed with sawdust.

801. Rifle-canister.—These are very similar in general appearance to those used in smooth-bore cannon. (Fig. 186.)

The case is of sheet-iron, or tin, with fringed ends which are turned over and soldered or riveted to iron or zinc disks.

The balls are of iron or zinc packed in rosin or coal-dust, sometimes in disks of wood. (Fig. 187.)

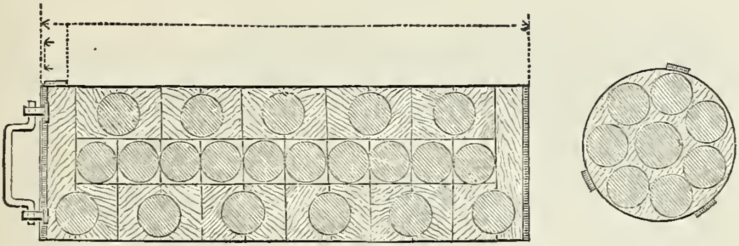


FIG. 187.

They are fitted with solder studs or rings of lead on the outside to take the rifling (Fig. 187), or with an expanding cup (Fig. 186).

HAND-GRENADES consist of small cylindrical shaped shell, with conical ends, fitted with a plunger at the striking-end, and a directing-feather at the other. The plunger fits loosely into the cavity in the forward part of the shell, and is made to project two or three inches beyond its face, being retained in place by a slight spring; it has attached to its outer end a circular piece of sheet-iron several inches in diameter. At the bottom of the cavity in which the plunger is placed a nipple is fixed, communicating with the bursting-charge, on which is placed an ordinary percussion-cap, which is exploded when the plunger is driven in violently, thereby igniting the charge.

There are three sizes of grenades, one (1), three (3), and five (5) pounds, and are intended to be thrown by hand, and may be very effectively used in repelling attacks by boats or by persons well sheltered against others completely exposed.

802. FABRICATION OF PROJECTILES.—They are usually made of gray or mottled cast-iron of good quality. Shells should be made of the best quality of iron, and with particular care, in order that they may not break in the gun.

803. PATTERN.—The pattern of a spherical projectile is composed of two hollow cast-iron hemispheres, which unite in such a manner as to form a perfect sphere; on the interior of each hemisphere is fastened a handle to enable the operator to draw it from the sand when the half-mold is completed. The *flasks* which contain the mold are made of iron, in two equal parts, united by means of hooks at their larger bases. The other ends are fitted with movable covers. (Fig. 188.)

804. Molding.—This operation is performed by placing the flat side of one of the hemispheres on the molding-board and

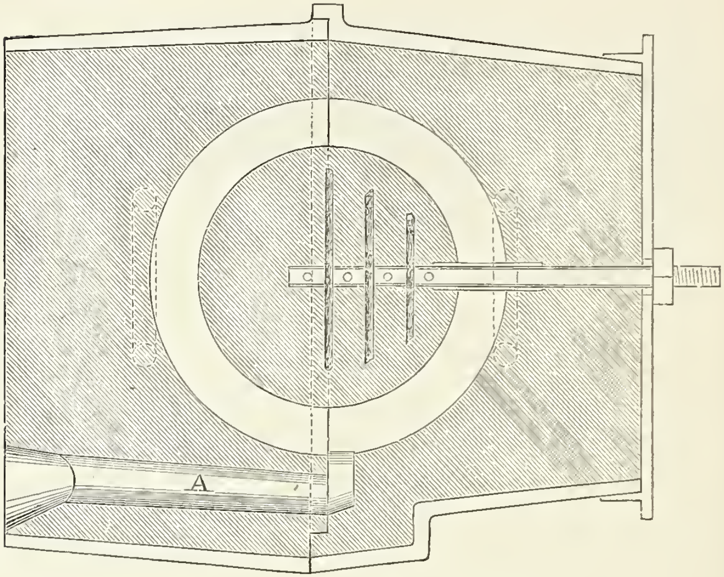


Fig. 188.

covering it with a flask. Sand is then poured into the flask, filling up the entire space between it and the hemisphere, and well rammed. The cover is then attached, and the flask turned over, the hemisphere is withdrawn, and the entire surface of the sand painted with coke-wash and dried.

The remaining half of the mold is formed in the same way, except that a channel for the introduction of the melted iron is made by inserting a round stick in the sand before it is rammed and withdrawing it afterwards, A, Fig. 188.

805. Hollow Projectiles.—Thus far the operations of molding and casting solid and hollow projectiles are the same. The cavity of a hollow projectile is formed by inserting a *core* of sand. This is a sphere of the proper size, made by compressing the molding-composition on a half-inch hollow iron spindle by means of two hemispherical cups. (Fig. 189.)

The requisite compression being given by screws. The core is by means of a gauge placed exactly in the centre of the mold and supported in that position by the stem which forms the fuze-hole. The stem is perforated with small holes to allow of the escape of steam and gas generated by the heat of the melted

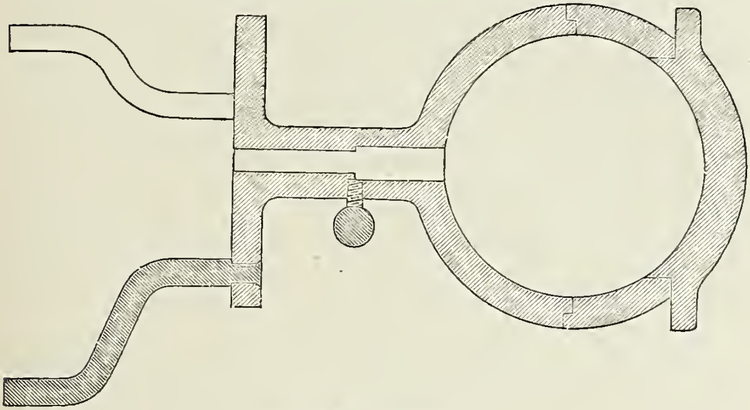


Fig. 189.—Core-box.

metal, that part of it which comes in contact with the melted iron, and forms the fuze-hole is coated with sand.

In pouring the melted iron into the mold with the ladle care should be taken to prevent scoria and dirt from entering with it, and for this purpose the surface should be skimmed with a wooden stick.

After the iron has become sufficiently hardened the flasks are opened and the sand knocked from the casting. Then the core is broken up and removed, and the interior surface cleaned by a scraper.

The greatest care is to be taken to remove every particle of sand or fragment of iron from the interior.

The sinking-head or projecting portion at the gate, and around the base where the two halves join, are taken off with a file or chisel if necessary.

A number of the balls are now placed in a large revolving iron cylinder, which by friction polishes and makes the surface more uniform.

806. Bouching.—The fuze-holes of all shell are bouched with gun-metal to receive the Navy-fuze-stock. In fitting the shell to receive the bouching, the bore should be tapped with a full thread, and the proper shoulder left at the bottom to prevent the bouching from being driven in by the shock of firing and causing premature explosion.

The object of the bouching is to prevent rust, and to have the same kind of metal in contact with the fuze-stock, so that there will be less danger in extracting or exchanging a fuze.

The fuze-holes of heavy rifle-shell are necessarily cast larger than the diameter of the regular fuze-stock, which can, however, be used with the aid of an *adapting-ring* of gun-metal, which is screwed in to reduce the diameter of the hole to the proper dimensions.

The fifteen-inch spherical shell are cast with three fuze-holes equally distant from each other, and situated in the angles of a triangle 4 inches apart.

807. CHILLED PROJECTILES.—Chilled-iron projectiles have been profitably employed to pierce armor-plates, on account of their intense hardness.

808. PALLISER PROJECTILES.—The English projectiles recommended by Major Palliser may be described as an example of chilled projectile.

The form of these are cylindro-conoidal, the head being ogival, struck with a radius of $1\frac{1}{2}$ diameters. The total length varies between 2 and $2\frac{1}{2}$ calibres. The bottom is flat, and in the centre of the bottom is a filling-hole for shells, closed with a composition screw-plug. (Fig. 190.)

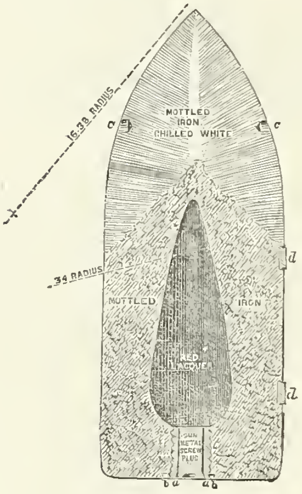


FIG. 190.

All Palliser shells are lacquered internally to give them a smooth, clean lining, which prevents the iron from either oxydizing at the expense of the powder, or firing it from friction by rapid rotation during flight. As the lacquer does not always hold well to the metal, serge-bags are introduced to contain the bursting-charge as an additional prevention against premature explosion. These bags are made bottle-shaped, and are introduced through the filling-hole.

Palliser shot are cored. The hollow up the centre enables them to cool more uniformly, and renders them less liable to split. It also slightly improves its proportions and its regularity of flight. The bottom is closed with a plug.

809. *How made.*—These projectiles are made of carefully selected iron, which, if run in sand-molds, would solidify as mottled, iron.

The projectiles are cast point down, for the sake of density and soundness in the head. The mold is formed of a metal-chill at the bottom extending up past the junction of head and body; the remainder of the mold is formed of sand, as also is the case for the formation of the interior. The chilling action therefore extends a little past the head of the projectile, which thus has a mottled body and a white head.

The Grüson projectiles are cast with a dead-head on the base, which is afterwards cut off, the object being to obtain a solid bottom to stand well under the shock of the discharge. The chilling is effected by the metal molds, in virtue of their great conducting-power, their thickness greatly affecting the extent of their action. The head thus chilled white, possesses generally the quality of white-iron, intense hardness, crushing-strength, considerable brittleness, and increased density.

The tip or point of a chilled projectile, is occasionally broken off by the impact of a shell or shot rolled or struck obliquely against it; for the point which may penetrate directly through many inches of armor without injury, may be fractured by a very slight transverse blow.

810. Steel Projectiles have proved more efficient than those of any other metal, but their expense has heretofore been too great to warrant their general use. For rifle projectiles they are made from solid ingots of steel turned to form, and bored out for shells. They are hardened by heating and cooling quickly, the head being to a certain extent chilled. The manufacture is expensive and tedious, and the tempering is a matter of difficulty, the shells being liable to crack. In order to overcome this difficulty hollow shot have been devised, the hole through the centre allowing the sudden shrinkage to take place without the injurious effects above alluded to.

811. *Whitworth's Steel Shell* are made from ingots of steel cast in the form of hoops, and drawn down to the necessary size under the hydraulic press. The ends are closed with screw plugs. They are therefore less costly than might be supposed.

812. INSPECTION.—Object of Inspection.—The principal points to be observed in inspecting projectiles are, to see that they are of proper size in all their parts, that they are made of suitable metal, and that they have no defects, concealed or otherwise, which will endanger their use or impair the accuracy of their fire.

As it would be impracticable to make all projectiles of exact dimensions, certain variations are allowed in fabrication, which are specified in the "Ordnance Instructions."

813. Inspection of Solid Projectiles.—The projectile is

inspected while unlacquered, perfectly clean, and before becoming rusty, so that the eye can detect any flaws or imperfections in the metal.

Each projectile is placed upon a table and examined to see that its surface is smooth, and that the metal is sound and free from seams, flaws, and blisters. If clusters of cavities or small holes appear on the surface, strike the point of the hammer into them, and ascertain their depth with the searcher. If the depth of the cavity exceeds 0.2 inch, the projectile is rejected; it is also rejected if any attempt has been made to conceal defects by plugging or filling holes in any mode whatever.

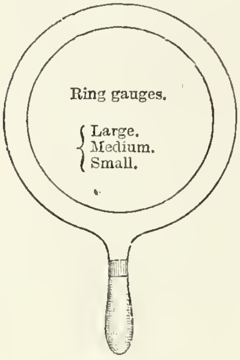


Fig. 191.

The projectile must pass in every direction through the large gauge (Fig. 191), and not at all through the small one; the *calipers* and *scale* will determine exactly the difference of diameters of the same projectile. The *ring* and *cylinder gauges* are examined before each inspection, and when found to have enlarged 0.01 of an inch, are laid aside and marked as unserviceable.

The projectiles are next passed through the *cylinder-gauge*, placed at an inclination of about two inches between the ends, and supported in such a manner as to be easily turned from time to time, to prevent its being worn in furrows. Projectiles which slide or stick in the cylinder are rejected.

The next proof is to drop a few taken indiscriminately from the lot under inspection from a height of twenty feet on a solid platform of iron, or roll them down an inclined plane of the same height against a mass of iron, after which they are again examined for defects of metal.

The average weight of solid projectiles is determined by weighing at least three parcels, of from 20 to 50 each, taken indiscriminately from the lot.

As many of the lightest are weighed separately as the Inspecting Officer deems necessary, and all found to fall below the least weight allowed by the *Ordnance Instructions* are rejected.

814. Inspection of Hollow Projectiles.—The surface of the shell and its exterior dimensions, form, weight, and strength, are examined and tested as in the case of solid projectiles, and subject to all the conditions there specified.

The shell is next struck with a hammer (Fig. 192), to judge by the ring or sound whether it is free from cracks; and the exterior and interior diameters of the fuze-hole (which should be accurately reamed) are verified, and the soundness of the metal about the inside of the fuze-hole ascertained.

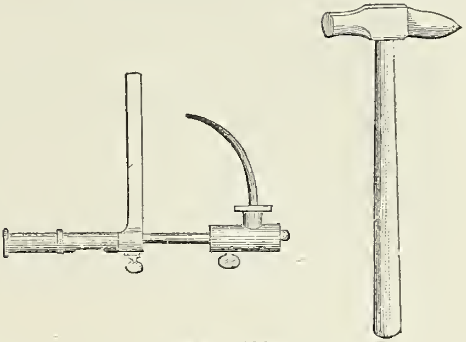
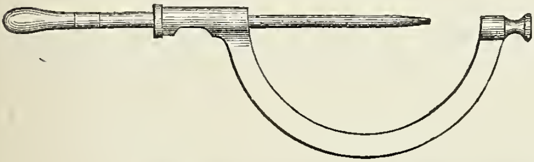
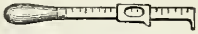


Fig. 192.

To determine the thickness of the metal, three points, at least, on the great circle at right angles to the axis of the fuze-hole are measured (Fig. 192.); also one at the fuze-hole (Fig. 193), and one at bottom. No shell is received which deviates more than one-tenth of an inch from the proper thickness in any part.

The shell is next placed in a tub of water, which should be





Gauge for thickness at fuze hole.

Fig. 193.—Gauge for thickness opposite fuze hole.

deep enough to completely cover it. A pair of hand-bellows and a wooden plug are inserted into the fuze-hole, the plug to fit the fuze-hole and the nozzle air-tight. Air is then forced by the bellows into the shell. If there are any air-holes in it, air-bubbles will rise on the surface of the water, and the shell is rejected.

This occasionally occurs from the escape of air from porous spots which do not extend to the interior of the shells. In this case the action of the bellows produces no increase of bubbles, which cease rising as soon as the spots or cavities are filled with water. Porous spots are also detected by their absorbing water, and drying slowly when exposed to the air, and likewise cause the rejection of the shell.

The Inspecting Officers stamp the shell at one inch from the fuze-hole with their intials, also those of the foundry at which they are cast.

The Inspector or one of his assistants must be present when shot or shell are inspected; and the stamps and marks are always retained in the possession of the Inspector.

Rejected shells are mutilated by chipping a piece out of the fuze-holes.

815. INSPECTION OF GRAPE AND CANISTER.—The dimensions are verified by means of a large and small gauge.

Table of Gauges for Smooth-bore Projectiles.

SHOT.

Dimensions, Weight.	XV.	XIII.	XI.	X.	IX.	8.	32.
Mean Diameter (in.)......	14.80	12.80	10.80	9.80	8.80	7.85	6.25
Mean Weight (lbs.)........	440.	276.	166.	124.	90.	65.	32.5

SHELL.

Dimensions, Weight.	XV.	XIII.	XI.	X.	IX.	8.	32.	24.	12.
Mean Diameter (in.).............	14.80	12.80	10.85	9.85	8.85	7.85	6.25	5.67	4.52
Thickness (in.)..................	2.85	2.57	2.	1.80	1.60	1.50	1.25	.90	.70
Diameter of fuze-hole......... ...	.65	.65	.65	.65	.65	.65	.65	..	..
Mean weight, empty (lbs.)........	330.	208.	127.	95.	68.50	50.	25.	17.	8.4
Weight of filled and saboted (lbs.)	352.	216.5	135.5	101.50	73.50	52.75	26.5	..	..

GRAPE.

Dimensions, Weight.	XV.	XI.	X.	IX.	8.	32.
Weight of Stand (lbs.)................................	..	34.75	26.10	20.4	15.7	8.75
Weight of Balls (lbs.)................................	..	89.10	71.70	52.20	37.12	24.80
Number of Balls..	..	15.	15.	18.	18.	12.
Diameter of Balls (in.)................................	..	3.55	3.34	2.80	2.50	2.50
Weight complete (lbs.)................................	..	125.08	98.62	74.10	53.25	33.50

SHARPNEL.

Dimensions, Weight.		XV.	XI.	X.	IX.	8.	32.	24.	12.
Mean of empty case.	Gauge (in.)	14.80	10.85	9.85	8.85	7.85	6.25	5.67	4.52
	Thickness (in.)	1.25	1.	.87	.75	.69	.60	.55	.45
	Weight (lbs.)	178.	76.	57.	38.	29.	15.	11.	6.5
Balls	Number	1000.	625.	435.	350.	220.	235.lead	175.lead	80.lead
	Diameter (in.)	1.	.85	.85	.85	.85	.65	.65	.65
	Weight (lbs.)	140.	51.	33.5	27.	17.	14.	10.5	4.75
Sulphur (lbs.)		30.	10.	8.5	7.	5.	2.25	1.5	.75
Bursting-charge (oz.)		10.	6.	4.	3.	2.5	1.25	450. grs.	350. grs.
Weight complete, saboted (lbs.)		358.	141.	101.	75.	.52	32.	24.	12.

CANISTER.

Dimensions, Weight.		XV.	XI.	X.	IX.	8.	32.	24.	12.
Windage (in.)		.25	.25	.25	.25	.25	.25	.15	.15
Height, finished (in.)		14.	12.	10.5	9.5	8.75	7.75	6.	5.
Thickness of Head.	Top (in.)	1.	5-8	5-8	5-8	.75	.50	.35	.3
	Middle (in.)	1.	5-8	..	..	..	..	..	..
	Bottom (in.)	2.	1.	1.	1.	.75	.50	1.90	1.90
Balls	Number	600.	315.	290.	230.	162.	100.	29.	39.
	Diameter (in.)	1.30	1.30	1.30	1.30	1.30	1.30	1.30	1.
	Weight (lbs.)	150.	85.	70.	65.	45.	28.	12.5	5.85
Weight finished (lbs.)		207.	120.	98.	70.	50.	30.	14.55	7.75

816. PRESERVATION OF PROJECTILES.—They are cleaned from rust and covered with a thin lacquer, when they are first received and when they are stored.

The following colors are established when put on board ship: all shot, black; shell, red; and sharpnel, white. The length of fuze is stencilled on the shell.

Covers of boxes containing projectiles are painted the same color as their contents, and the length of the fuze of a loaded projectile is stencilled in black on the box. Empty shell, whether in store or in transportation, are most carefully protected from dampness. They have the fuze-bouching coated with composition, and the fuze-hole is stopped by a plug of very soft wood which is well coated with a mixture of oil and tallow and screwed in. The ends of the plugs are not sawed off even with the shell, but left square and project sufficiently to allow them to be unscrewed by means of a wrench; and when these plugs are removed for the purpose of fitting the shells for service, they are not thrown away, but preserved for future use.

817. Stowage.—They are piled with the fuze-holes down, and free from contact; under cover, when practicable, but with free ventilation. Projectiles in boxes must be stowed in tiers with thin battens of wood between the tiers, so that there may be free circulation of air.

Platforms of masonry, or of condemned projectiles, are prepared to pile them on. Square piles are to be preferred where there is room.

Projectiles, after having been piled, are so far examined each year, as to ascertain if they require to be cleaned, re-lacquered, and repiled to secure their proper preservation.

For the proper stowage and preservation of projectiles on board ship, shell-rooms are provided, the same care and attention being given to their construction, location, and means of lighting and flooding as in magazines. The loaded shell, being either in boxes or bags, are stowed in the shell-room in tiers or ranges, held in place by wooden battens if necessary; and when there are various kinds, they are to be stowed on separate tiers, with pieces of plank between them, in such manner that each kind can be readily obtained. It is seldom that the shell-room will contain the full allowance boxed; the remainder will be put on board empty.

Empty shell are to be stowed on board ship by themselves, in a dry place, unsaboted, in bulk. A sabot, straps, tacks, and lashing is furnished for each empty shell; after target practice the number of loaded shells is to be made complete.

818. Lacquering.—Whenever projectiles are to receive lacquer, care is taken that the quantity applied does not increase the diameter more than is indispensably necessary, and in no case above established high gauge. Old lacquer and rust are removed by scraping, as far as can be conveniently done, before a new coating is applied.

Neither hammering nor beating is resorted to for this purpose.

After numerous experiments upon different lacquers employed for the preservation of projectiles from rust, the French have abandoned all of them.

The projectiles are simply piled, under sheds when practicable, or in the open air, and, when put on board of ship, cleaned of rust and rubbed over with whale-oil: the same means adopted every three months of the cruise.

819. The Condition of Loaded Shell, and especially of their fuzes, is frequently examined into, taking out a fuze occasionally so as to detect any injury which may arise from moisture, and such as may be found damaged are replaced by spare fuzes.

Projectiles returned from cruising ships are emptied, cleaned, and plugged.

In emptying shell they are handled carefully and placed on a bench with a hole in it to receive and support the inverted shell. A wooden vessel placed below receives the powder.

The powder which has been removed from shells is only used for filling shell, as it always contains a small quantity of grit, which renders it unfit for general service.

All powder taken from shell is sifted, and all dust and particles of dirt removed, as far as possible, before putting it into barrels.

Should the powder have become caked, so as not to be easily removed by washing out the shell, a handful of small iron shot put in the shell facilitates this operation.

820. Removing Fuzes.—Whenever it is expedient or necessary to examine the fuzes and loading of shell which have been already prepared, great care is observed in removing the fuze, and it is never done in the shell-room.

The fuze-stock may generally be safely unscrewed with the fuze-wrench, taking care, in the first place, to strike the side of the shell gently with a wooden mallet, to detach the powder from the fuze, to work very slowly, and not to endeavor to overcome any unusual resistance. No attempt should be made to open a shell, for the purpose of unloading it or destroying its charge, in any other way than by unscrewing the fuze-stock.

In doing this, if the stock do not yield at once to an ordinary effort with the wrench, then the shell should be marked and immediately set aside, to be thrown overboard.

821. *To find the number of balls in a pile*, multiply the sum of the three parallel edges by one-third of the number of balls in a triangular face.

In a square-pile, one of the parallel edges contains but one ball; in a triangular pile, two of the edges have but one ball in each.

The number of balls in a triangular face is $x\left(\frac{x+1}{2}\right)$; x being the number in the bottom row.

The sum of the three parallel edges in a triangular pile is $x + 2$; in a square pile, $2x + 1$; in an oblong pile, $3X + 2x - 2$; X being the length of the top row, and x the width of the bottom tier; or $3m - x + 1$; m being the length, x the width of the bottom tier.

If a pile consist of two piles joined at a right-angle, calculate the contents of one as a common oblong pile, and of the other as a pile of which the three parallel edges are equal.

*Section II.—Deviations.**

822. General Considerations.—The term *deviation* must be understood to mean not only the deflections, right or left, of the line of fire, but also the differences between the ranges of similar projectiles fired under like condition from the same guns.

Very great irregularities occur in the paths of spherical projectiles. If a number of projectiles be fired from the same gun, with equal charges and elevations, and with gunpowder of the same quality, the gun-carriage resting upon a platform, and the piece being pointed with the greatest care before each round, very few of the projectiles will range to the same distance; and, moreover, the greater part will be found to deflect considerably, unless the range be very short, to the right or left of the line in which the gun is pointed.

With elongated projectiles the fire is far more accurate, but still the ranges and deflections are subject to variations of greater or less amount.

The causes of the deviations of projectiles, whether fired from smooth-bore or rifle guns, and independent of inaccuracy in pointing, and variable position of the gun-carriage, are *wind*, *variable projectile force*, and *rotation of the earth*.

823. Effect of Wind.—Should the wind be blowing in gusts and be changeable in direction, it is difficult to allow for it in pointing the gun; but with a steady breeze, in a pretty constant direction, a few rounds will generally be sufficient to show the allowance necessary. The velocity of the wind is very low compared with that of the projectiles, but it remains usually nearly the same throughout its flight, whereas the velocity of the projectile decreases rapidly; it therefore frequently happens that the wind appears to have greater effect towards the end of the range, and it may be often noticed in

* Owen.

practice, that projectiles deviate in a rapidly increasing curved line.

The wind, if strong, will greatly affect the ranges of projectiles; decreasing or increasing the range according as it may be blowing with or against the projectile.

The lower the velocity of a projectile, the greater will be its deflection caused by the wind, as, for instance, upon mortar-shells, on which, having low velocities and long times of flight, the wind exercises a very disturbing influence. The greater the density of the projectile, the less will its motion, during flight, be affected by the wind; and thus shells are more influenced by wind than shot.

The wind exercises a very great deflecting influence upon an elongated projectile during its flight, rendering it difficult to obtain accuracy of fire at long ranges, even from rifled guns, excepting in very calm weather.

If the centre of gravity be placed very near the centre of the long axis, the force of the wind will be pretty evenly distributed over the whole length of the projectile. Should, however, the centre of gravity be placed far in advance of or behind the centre of figure, the force of the wind will press unequally upon the shot, and uncertain deflections will most probably occur.

824. Variable Projectile-force.—It is impossible with our present facilities to manufactnre large quantities of powder of a perfectly uniform quality; but supposing it could be accomplished, the force from a given charge would be liable to variation according to the state of the atmosphere, and the condition of the powder as affected by the time it has been in store; it will also be frequently found in practice that the charges have not been weighed out with perfect accuracy, nor the gun loaded so that the projectile is always in the same position with reference to the charge. The consequence is, that very few projectiles fired from the same gun with what are called equal charges, leave the bore with exactly the same initial velocity.

825. Rotation of the Earth.—The deviation of a projectile caused by the rotation of the earth is a complicated problem. The principle that this rotation will impress upon the projectile a tendency, upon leaving the bore, to move with the same velocity in the same direction as the point upon the surface from which the gun is fired, is readily comprehended, but not its application to some particular cases.* The devia-

* For a general discussion of this subject, see an Article by Prof. Wm. Ferrel in *The Mathematical Monthly* for August, 1860.

tion due to this cause is too slight to be regarded in practice.

826. FAULTY DISPOSITION OF THE LINE OF SIGHT.—The line of sight may be improperly placed and situated out of the vertical plane, either in consequence of the construction of the gun or its carriage, or by the effect of the inclination of the plane upon which it is placed. In these two cases the line of fire maintaining a fixed and determined position, in respect to the axis of the gun and the vertical plane of fire, the deviations are constant for equal distances and equal inclinations, and it becomes easy to correct them after a few trials.

827. INFLUENCE OF THE STATE OF THE AIR.—The barometic state of the atmosphere may also produce an effect upon the ranges; for the greater the density and elasticity of the displaced fluid, the greater will be the retardation of the projectile.

The phenomenon of refraction also slightly modifies the range, but these last causes are scarcely appreciable in practice.

828. DEVIATION OF SPHERICAL PROJECTILES.—The principal causes of the deviations of projectiles fired from smooth-bore guns, are

1st. Windage.

2d. The imperfect form and roughness of the surface of the projectile.

3d. Eccentricity of projectiles arising from their not being homogeneous.

829. WINDAGE.—Windage causes irregularity in the flight of a projectile, from the fact of the elastic gas acting in the first instance on the upper portion of the projectile and driving it against the bottom of the bore.

The projectile reacts at the same time that it is impelled forward by the charge, and strikes the upper surface of the bore some distance in advance, and so on, by a succession of re-

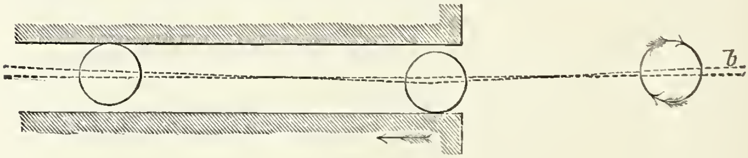


FIG. 194.

bounds until it leaves the bore in an accidental direction and with a rotatory motion, depending chiefly upon the position of the last impact against the bore. (Fig. 194.)

Thus, should the last impact of a concentric projectile, when fired from a gun, be on the right-hand side of the bore, as represented in the figure, it will have a tendency to deflect to the left in the direction *b*, while at the same time a rotation will be given to it in the direction indicated by the arrows, or to the right. The effect of this rotation being to cause the projectile itself to deviate to the right during its flight, so that the deflection will not be to the left, but to the right, unless the range is very short.

If the projectile leave the gun, rotating on a vertical axis, with its forward part moving from left to right—supposing the observer to be behind the piece—there will be a diminished pressure on the right side and an increased one on the left side, which will therefore cause it to deviate to the right.

If a projectile strike the bottom of the bore, the rotation of the fore-part would be from up downwards, and instead of deflecting to the right, the range would be decreased.

Suppose the projectile to rotate in an opposite direction, the results would be reversed. Should it, on leaving, strike any intermediate part of the bore, a compound effect would be produced, according to the position of the point of impact.

It appears from these explanations, that a projectile leaving the gun, rotating on any axis, except one parallel to that of the bore, will deviate according to the direction of the rotation.

830. Eccentricity.—Should the centre of gravity of a projectile not coincide with the centre of figure, it is termed *eccentric*, and is found to deviate according to the position of the centre of gravity when the ball is placed in the bore of the gun; should the line joining the centre of gravity and the centre of figure of a projectile be not parallel to the axis of the bore, the charge of powder will act on a larger surface on one side of the centre of gravity than on the other, so that there will be a rotation from the lightest towards the heaviest side.

If Fig. 195 represent an eccentric shot, the centre of gravity, G, of which is below the centre of figure F, the powder, acting on a larger surface above than below G, will give it a rotation as indicated by the arrow, and from what has been previously said, the deviation will be to the side on which the centre of gravity lies; this is the case in practice, for it has been ascertained by experiment that if a projectile be placed in a gun so that its centre of gravity is to the right of the vertical plane passing through the axis of the bore, it will deviate towards the right, and *vice-versa;* also if the centre of gravity be upwards, the range will be increased; and if downward, diminished.

It is found in practice that projectiles deviate in a curved line, either to the right or to the left, the curve rapidly increasing towards the end of the range. This probably occurs

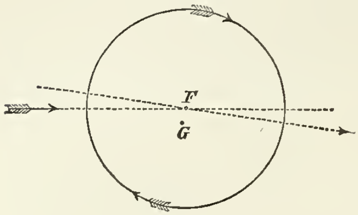


Fig. 195.

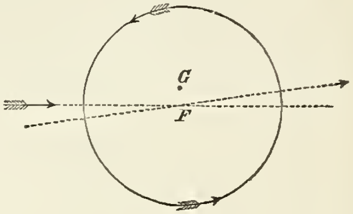


Fig. 196.

from the velocity of rotation decreasing but slightly compared to the velocity of translation; or if a strong wind is blowing steadily across the range during the whole time of its flight, this deflecting cause being constant, while the velocity of the projectile diminishes, the curve will manifestly increase with the range; the trajectory is, therefore, a *curve of double curvature*, its projection on either a horizontal or vertical plane being a curved line.

831. *Conclusion.*—From the foregoing considerations it follows, that the smoother the surface of the projectiles and the less their windage and eccentricity, other things being equal, the greater will be their accuracy. Experiments show that the preponderating side should be put next the charge, and the line joining the centre of gravity and the centre of figure should be parallel to the axis of the bore.

The position of the preponderating side is found by floating the projectile in a bath of mercury, and the degree of promptness with which an eccentric shot, floated as above, assumes the position due to its preponderance, is regarded as the measure of that preponderance.

832. DEVIATION OF ELONGATED PROJECTILES.—If the projectile come out of the gun perfectly centred, that is, rotating round its longest axis, and having that axis coincident with the line of flight, there will be no tendency, either of the axis of rotation, or of the projectile itself, to deflect, so long as the motion is in a straight line, because the resistance of the air will act uniformly all around. As soon, however, as the trajectory has begun to curve downwards under the influence of gravity, the resistance of the air acts more on the under side than on the upper, and effects will be pro-

duced depending on the resultant direction of the resistance of the air in relation to the centre of gravity.

833. Practically, the path of the projectile is found to result in a deviation, increasing uniformly with the distance from the gun, and depending, as to its direction, on the direction of the deflecting-force at the moment of its first application.

If the deflecting-force act on the projectile in a vertical direction upwards, the horizontal projection of the line of flight will be a line deviating to the right or left, of the plane of fire, according as the twist is right or left handed. If the deflecting-force act in the opposite direction, the projectile will be deflected to the left or right, according as the twist is right or left; and whatever be the direction of the deflecting-force, the deviation will be a uniformly increasing one at right angles to it.

834. These effects may be illustrated experimentally by means of a gyroscope provided with a small elongated projectile instead of the disk used for ordinary experiments. (Fig 197.)

The projectile must be made with the greatest care, so that its centre of gravity coincides exactly with that of the two rings within which it is placed; the rings are so arranged that one can turn round a vertical axis, and the other round a horizontal axis, the projectile being therefore free to turn in any direction. A cylindrical portion of metal extends beyond the base of the projectile, in prolongation of its longer axis, round which the string is wound to give the required rotatory motion.

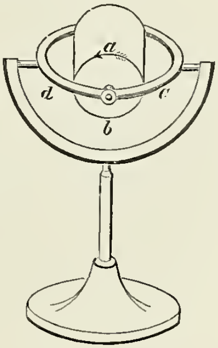


FIG. 197.

As the projectile in the gyroscope has no motion of translation, a strong current of air must be directed upon it, so as to represent the resistance of the atmosphere to a projectile moving with a high velocity. The diameter of the nozzle of the blower should be equal to, or rather larger than, that of the projectile, and the centre of the blast should be directed below the point of the projectile in the position indicated by R in Fig. 145.

835. If Fig. 145 represent the elongated projectile of the gyroscope, it will be found that a pressure, R, exerted anywhere between *a* and *b* will produce a similar effect to an

upward pressure exerted at the point E. Supposing, however, the projectile to be rotating rapidly in the direction indicated by the arrow in Fig. 197, and the pointed end is facing the spectator: then, if a pressure be exerted at *b*, corresponding to E in Fig. 145, the point of the projectile will not rise (at least perceptibly), but will move laterally in the direction *c*, that is, to the right, with reference to an observer behind the gyroscope; if a pressure be exerted at *d* (Fig. 197), the point will fall; if at *a*, the point will move laterally in the direction *d*, or to the left, with reference to an observer behind the gyroscope; lastly, if a pressure acts upon the rotating body at *c*, the point will rise. Now should a pressure be exerted in any intermediate part of the circle *abcd*, as, for instance, between *b* and *d*, then the motion of the point of the projectile will be compounded of the motions caused by respective pressures at *b* and *d*, that is to say, the point will move laterally to the right (with reference to an observer behind the gyroscope), and droop at the same time.

836. If a strong blast of air be directed on the fore part of the rotating projectile, the centre of the current being a little below the point, but in the same vertical plane with it, as shown by the dotted lines in Fig. 145, so as to represent the resistance of the air to a projectile moving with a high velocity, the pointed end will first move slowly to the right (towards *c*, Fig. 197), effects being afterwards successively produced by the blast similar to those which would be caused by a pressure acting gradually round the circle *acbd* (Fig. 197), as already described.

If pressure be exerted *behind* the centre of gravity instead of *in front*, or on the fore part of a projectile rotating with a *left-handed rotation*, the above effects will be reversed.

837. The line of flight is therefore not absolutely a straight line, but becomes a curve of double curvature; and if projected on a vertical plane at right angles to the plane of fire, would consist of a series of cycloidal curves, were the time of flight sufficiently great, increasing the distance of the projectile from the plane of fire by the length of one of them at each revolution. The length of these curves depends upon the amount of the deflecting-force, and their number is equal to the number of revolutions made by the projectile in its flight.

838. When an elongated projectile is fired from a rifle-gun, it leaves the bore rotating rapidly round its longer axis; and if the initial velocity were very low, the projectile experiencing but

slight resistance from the atmosphere, the larger axis would remain (as in vacuo) during the whole time of flight parallel or nearly so to its primary direction, as shown in Fig. 198.

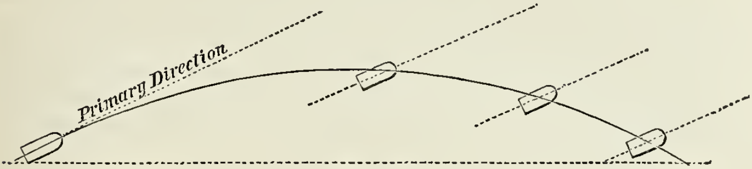


FIG. 198.

In explaining the effect produced by the resistance of the air upon an elongated projectile moving with a high velocity, the projectile will be supposed to have what is termed a right-handed rotation: that is, the upper part turns from left to right, with reference to an observer placed behind the gun; for the direction of the grooves of rifled pieces are almost invariably so as to give such rotation.

After the projectile has left the bore, the resultant of the resistance of the air will, unless the centre of gravity be very far forward, act upon a point in front of the centre of gravity and below the longer axis, at all angles of elevation given in practical gunnery. The effect produced by this pressure will depend chiefly upon the form of the head of the projectile; therefore, let us first consider the effect upon a conoidal head.

839. *Deviation of the Conoidal-headed projectile.*

The pressure R (Fig. 145), exerted anywhere between a and b, will have a tendency to raise the point a or to produce a similar effect to an upward pressure exerted at the point E. This will result in giving the point a a lateral movement to the right. (Art 833.) As this lateral movement of the point proceeds so will the resultant act more and more to the left of the vertical plane, passing through the longer axis of the projectile. And as the deviation continues at right angles to the direction of the deflecting-force, the point will soon begin to droop.

The point of the projectile first moves to the right, then downwards, still keeping to the right, then to the left, and so on, describing a portion of the circle, the continuance of the motion depending upon the time of flight and velocity maintained. As the velocity becomes low, the circular motion of the point will gradually cease; but in practice, during the few seconds of flight which generally elapse, as the velocity is pretty high throughout, there is probably sufficient time and pressure not only to turn the point to the right, but to bring it down on to the trajectory, or even below it.

840. Of course the longer axis of an elongated projectile does not remain, during flight, continually a tangent to the trajectory, unless the centre of gravity, as in an arrow or rocket, is very near the face end; yet, practically, on account of the drooping of the point, the longer axis may throughout a considerable portion of the time of flight approximate very nearly to a tangent to the trajectory, as in Fig. 199.

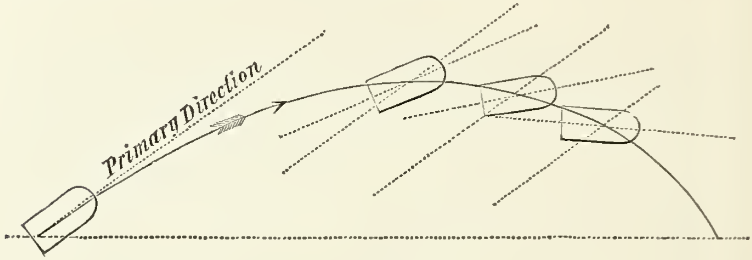


FIG. 199.

The effects on targets furnish most satisfactory evidence of this; it is almost invariably found that the holes made in targets are circular, even when elongated projectiles descend at considerable angles.

The most probable explanation of this fact must evidently be, that the point of the projectile has drooped during flight, so that, on striking the longer axis is nearly perpendicular to the plane of the target. (Fig. 199.)

This drooping of the point is of importance, for did the axis remain parallel during flight to its primary direction, the projectile would most probably, when fired at any but a very low angle, on striking an object of hard material and solid structure turn up against it lengthways, and therefore produce but trifling effect. This has not, however, been found to take place in practice, but on the contrary the penetration of elongated projectiles at considerable ranges, are always remarkably great. There is little fear of the projectile turning up against an object unless the velocity of translation and rotation be very low, and the angle of fire very high.

841. *Deviation of the Flat-headed Projectile.*—A pressure exerted upon the head and below the larger axis, as (R Fig. 146), will have a tendency to cause the head to droop; or will produce

an effect similar to a downward pressure, acting at C; just the opposite of what is observed with a conoidal-pointed projectile.

Therefore (Art. 833), the projectile will be deflected to the left or right, according as the twist is right or left handed.

It is found in practice that conoidal-headed projectiles fired from rifled guns giving a right-handed rotation, always deviate to the right; and in the few cases tried with guns giving a left-handed rotation, the deviation is to the left; with flat-headed projectiles, these deviations are reversed.

842. *Drift.*—This peculiar deviation is called *drift*, and is generally constant for the same ranges—so that it can be allowed for in pointing the gun, by using a horizontal slide graduated and attached to the tangent scale, or by inclining the tangent scale to the left.

Section III.—Effects.

843. General Consideration.—A knowledge of the destructive effects of projectiles is of very great importance. In general, these effects depend upon a variety of circumstances, such as the velocity of the projectile at the moment of impact, its weight, form, diameter, the material of which it is made, the nature of the object struck, and the relative position of this latter with regard to the trajectory of the projectile.

When a projectile strikes an object, its energy is expended, not only in penetrating, fracturing, or producing vibration in the material of the object, but, when the latter offers great resistance, in breaking up or changing the form of the projectile.

844. Impact of Projectiles.—In order to arrive at a clear understanding of what takes place when the motion of a projectile is arrested by any resisting medium, it is necessary to recall some of the elementary principles upon which these phenomena depend.*

The manner in which a projectile acquires its velocity, is a good illustration of the manner in which its motion is destroyed.

If the mean pressure, P, of the gas be multiplied by the space, S, passed over by the projectile while acquiring its velocity, the result will be the measure of the work done by the charge of powder; and it will also be equal to the work of stopping the same projectile, no matter how or by what means it may be brought to rest.

* King.

The same result is generally arrived at by measuring the velocity imparted to the projectile under the circumstances mentioned, and multiplying the square of the velocity by one-half of the mass of the projectile; or, since the mass is equal to the weight divided by the force of gravity, the expression for the work stored in the projectile, and which must be expended in bringing it to rest, $= \frac{W.v^2}{2\,g}$, where W = weight of the projectile in pounds, v = velocity of the projectile in feet, and g = the force of gravity in feet, or the velocity which a body will acquire by its own weight in one second of time.

This expression involves indirectly the same quantities as that first mentioned; namely, the mean pressure of the gas and the distance passed over by the projectile; assuming this measure for the work stored in the projectile, it remains to consider how this work is expended.

845. The following are the different effects produced by the impact of a projectile upon any solid body; some of these being so connected as to render their relative importance extremely doubtful.

Compression.—The first effort of impact is to compress or drive back those portions of both projectiles and target first coming in contact upon those immediately behind them; the amount of this compression depending upon the material and velocity of impact, as well as upon the form of the projectile.

Elongation.—The greater part of the work of the projectile in penetrating wrought-iron and similar materials is expended in overcoming the tenacity of the material, or in elongating the fibre. This is evident when we consider that punching or shearing consists not so much in cutting the fibre, as in bending it, and afterwards pulling it in two lengthwise.

Shearing.—This, as just stated, consists chiefly in the two strains already mentioned.

Bending.—This also implies tension and compression; the back of the target being elongated, and the front compressed.

Pulverizing—a portion of the material. This takes place only in case of hard materials, as stone or cast-iron, and it then absorbs a very great amount of work. Like bending and shearing, it involves compression and elongation, the material being compressed until it yields laterally to a tensile strain.

Motion.—While the work is being expended, a certain amount of time is allowed for the force of the projectile to impart motion to the target, especially that portion immediately in front of the projectile.

Friction.—The friction is very great, especially in the case of the more pointed form of projectile, and varies inversely with the velocity of the projectile.

Heat.—This is due to friction, both external and internal, that is, of the projectile and fragments against the target, and against each other during the distortion of the material, from compression, bending, etc.

The suddenness with which this heat is generated is almost unequalled by any known source of heat. It is well known that the heat developed in the interior of loaded shells, on striking violently a thick iron plate, is sufficient to ignite the powder, and this fact has been utilized in dispensing with fuzes for exploding armor-punching shells.

The effect of a projectile on striking a mass or target of any form or material, may be divided into two general portions, one being entirely local, while the other is distributed over more or less surface according to circumstances.

The former is the *penetration*, and the latter may be called the *concussion*.

846. PENETRATION.—General Theory.—The most common substances encountered by projectiles are arranged in the following series, in the order of their resistances to penetration:—*air, water, sand, wood, lead, copper, wrought-iron, soft steel, cast-iron, chilled iron, hardened steel,* etc. All other substances may be arranged between these, or in continuation of the series.

Air opposes the motion of a projectile by its inertia, elastic force, and the pressure due to its weight. The projectile compresses the air in its front and disperses it laterally, while the rear of the projectile is relieved by its motion of the normal pressure of the air. A small amount of resistance is also met with in the shape of friction.

Water.—In the case of water these resistances are increased by the greater density and weight of this substance, and there is also a slight additional resistance due to the cohesion among the particles.

Sand, being a solid, or at least made up of solid elements, presents the additional resistance of "crushing-strength." It cannot be penetrated at a high velocity without crushing some of the grains, and the higher the velocity the greater the amount of work expended in this manner. This resistance to crushing implies a continuation of the elastic force beyond the elastic limits, and involves indirectly tensile strength, since a solid in being crushed must enlarge laterally and finally yield to a strain of tension.

Wood.—In penetrating wood, *lead*, or any of the other materials, "tensile strength" forms the chief element of the resistance, while inertia and friction become of minor importance.

847. *Elasticity.*—The office of elasticity in all these cases is to transmit the effect of the projectile from those particles first acted upon to those more remote, and thus calling into play their inertia or tensile strength, as the case may be; and were it not for this property, the statical resistance of a plate of any material to perforation would be entirely independent of the thickness of the plate; a thick plate would offer no greater resistance than a thin one, since each layer or unit of thickness would be perforated without receiving any assistance from its neighbors.

The *work* of penetration would then vary directly with the distance penetrated, or the thickness of the plate; elasticity, however, has its maximum point of usefulness in resisting penetration, and beyond this it becomes a great disadvantage. While increasing the number of fibres or elementary portions of the material broken at once, thereby increasing the statical resistance, it diminishes the time during which this resistance opposes the motion of the projectile in like ratio; and the amount of motion destroyed or generated increases with the time as well as with the force or resistance. For this reason hardened steel and chilled iron are less efficient in stopping projectiles than soft iron, although they offer a much greater statical resistance to penetration.

There are many reasons for believing that a general formula for the penetration of projectiles in all materials may be deduced, when experiments have been sufficiently extended, in which the constants will simply require changing to suit any particular case under consideration.

848. PENETRATION OF SPHERICAL PROJECTILES.—The area presented by a ball may be taken as equal to that of its great circle; if, then, R = the mean resistance per square inch offered by the object throughout the penetration, and r = the radius of the shot,

$R \pi r^2$ = resistance to be overcome by shot—the formula for *accumulated work* being:

$$P.S = \frac{wv^2}{2g},$$
$$P = R \pi r^2;$$

and putting p for S, the space penetrated

$$R \pi r^2 p = \frac{wv^2}{2g},$$

$$p = \frac{wv^2}{R \pi r^2 2g}.$$

Let $d =$ weight of a cubic inch of the material of the shot;

then $$w = \tfrac{4}{3} \pi r^3 d,$$

and $$p = \tfrac{4}{3} \frac{r \pi^3 dv}{R \pi r^2 2g} = \frac{2rdv^2}{3 Rg}.$$

This formula, although answering for low velocities, gives too great penetration for high velocities; it is, however, sufficiently accurate for the deduction of the simple laws stated below.

R, which will vary with the nature of the material fired at, whether wood or masonry, or other substances, must be found by experiment.

When the resisting material is the same,

$$P \text{ varies as } r d v^2,$$

or the penetration is proportioned to the diameter and density of the shot, and to the square of its velocity on impact—so that the larger the diameter of the ball, and the greater its density, the deeper will be the penetration; especially as the final velocity for the same *initial velocity* will be higher.

When projectiles of the same density are fired into the same material,

$$P \text{ varies as r } v^2,$$

or with the diameter of the shot and the square of its velocity on impact.

849. Penetration of Elongated Projectiles.—The penetration of an elongated projectile is greater than that of a spherical projectile of equal weight, when both are fired with the *same* initial velocity; for the former presents a less *area* to the resistance of the object; it can have a pointed head, and it will have a greater final velocity, being less retarded during flight.

In general, however, an elongated projectile is fired with a lower initial velocity than a spherical projectile of equal weight from a smooth-bore gun; and, therefore, at a short distance, the latter will most probably produce more effect as regards penetration than the former; but as the range is increased, so will the penetrating power of the elongated projectile be greater compared with that of the spherical, for the former will maintain a high velocity much longer than the latter.

850. *Formula for Perforation of Iron Plates.*—One of

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the first questions to present itself in connection with armor-plating is the relation between the thickness of the plate and the diameter, weight, and velocity of the projectile required to perforate it; or, having given the diameter, weight, and velocity of a projectile, required the thickness of a single wrought-iron plate which it will just perforate.

Several formulæ have been proposed for this purpose, but the great difficulty has been the want of experimental results sufficiently accurate and comprehensive to verify the principles upon which they are based; and to give the correct values for the constants or co-efficients which enter them. Captain Noble, R. A.,* gives the following formula for the penetration of wrought-iron plates by steel shot, the impact being direct:

$$\frac{Wv^2}{2g} = 2\pi Rkb^2, \text{ where}$$

W = weight of shot in pounds,
v = velocity on impact, in feet,
g = the force of gravity,
$2R$ = diameter of shot in feet,
b = thickness of unbacked plate in feet,
k = a coefficient depending on the nature of the wrought-iron in the plate, and the nature and form of head of the shot.

Solving the above equation for b, gives:

$$b = v\sqrt{\frac{W}{4\pi Rgk}};$$

and for k,

$$k = \frac{Wv^2}{4\pi Rgb^2}.$$

In order to determine k the following series of equations can be formed:

$$4\pi R_1 gb^2k - W_1v_1^2 = o.$$
$$4\pi R_2 gb^2k - W_2v_2^2 = o.$$
$$4\pi R_3 gb^2k - W_3v_3^2 = o.$$
etc., etc., etc.

The variable quantities in these equations are R, b, w, and v;

* "Report on various experiments carried out under the direction of the Ordnance Select Committee, relative to the penetration of iron-armor plates by steel shot." By Capt. W. H. Noble, R. A. London: 1866.

π being the usual representative of the ratio of diameter to circumference of the circle, and g representing the force of gravity in dynamical terms.

Having determined the value of k, the "work" necessary to penetrate any unbacked plate of given thickness may be calculated.

This formula is only claimed to give a near approximation, as the case is one which does not admit of absolute accuracy, involving, as it does, many sources of error and uncertainty, which it is impossible to eliminate without an almost interminable series of experiments.

851. FORM OF HEAD.—That the penetration of an elongated projectile is influenced by the form of its head has been shown by experiment, many different forms of head having been tried. The flat head has been strongly advocated, because it is asserted to be a better form for punching than any of the pointed heads, and because it is also asserted that it will bite into an iron plate at such an oblique angle as would cause a pointed head to merely glance. But the truth of these assertions has not been generally admitted. The flat-headed projectile is objectionable both as regards accuracy and velocity, and it has also a tendency to upset or bulge at the head on impact, and this result is very marked.

The pointed projectile is superior in accuracy and range, and does not upset on impact to anything like the same extent.

It is asserted that it cuts through an iron plate to a better advantage, or rather tears through bending back the plate.

852. OBLIQUE IMPACT.—Another point in connection with the penetration of elongated projectiles is the effect of different forms of head upon the rotation of the projectile when the impact is oblique.

If the axis of the projectile is tangent to the trajectory on impact, and at the same time normal to the target, there will be no tendency to rotate about any axis parallel with the plane of the target. In Fig. 200, if we suppose a projectile to arrive at A, under these conditions it will undoubtedly penetrate the plate directly. But let one arrive at D or E, and there will be a tendency to rotate, and this tendency will depend upon the form of the projectile as well as upon the angle between the trajectory and its axis.

Now it is asserted, on the one hand, that the advantage in the latter case will be in favor of the flat-headed projectile, since the moment of the rotating force will be the variable resistance of the plate multiplied by the lever arm Dd, for the pointed projectile, and the same multiplied by a much shorter lever arm, Ee, in case of the flat-headed projectile, and this may be negative; or in other words, there may be a tendency to rotate

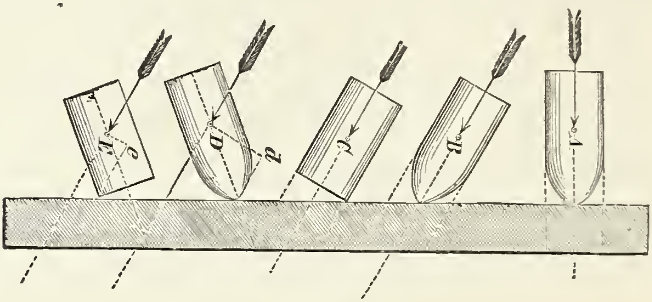


FIG. 200.

towards the normal, which would be a decided advantage. This would take place when the line of the trajectory passed within the base of the shot.

In the third case, represented at B and C, a projectile is moving with its axis tangent to the trajectory, but oblique to the target; here there is also a tendency for the flat-headed projectile to rotate toward the normal, but it is questionable whether such rotation would be advantageous. The pointed projectile would have a less tendency to such rotation.

On the other hand the respective motions of a flat and pointed headed projectile on oblique impact are explained as follows: It is asserted that the flat-headed projectile on striking (Fig. 201), cuts out a portion of the face of the plate, which it carries along in front, thus increasing the thickness to be penetrated, and, remaining nearly parallel to its original direction, it has to pass through the plate obliquely.

While if the projectile has a pointed head (Fig. 202), the point enters at first more deeply into the plate than the flat head, and the centre of gravity moving forward, the projectile turns around more readily than with the latter, so that its axis becomes perpendicular, or nearly so, to the face of the plate, having then only the least thickness to penetrate.

It is difficult to obtain for comparison the results of practice with the flat and pointed headed projectiles of the same material fired at targets inclined to the line of the range; the former having been so little used, as its form is so objectionable, both as regards accuracy and velocity.

On the whole it may be said that in the case when the projectile ought to be capable of piercing the plate or target, there is little difference between the effect of a flat head and a hemispherical head; but when the target is beyond the power

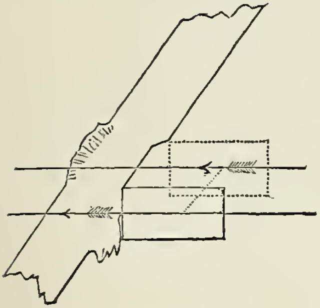


FIG. 201.

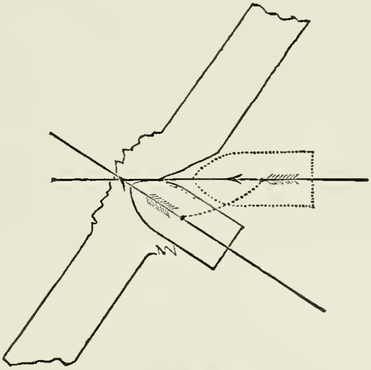


FIG. 202.

of the projectile, the hemispherical head makes the deepest indent.

853. CONCUSSION.—The impact of a projectile, in addition to indenting or penetrating a target, produces more or less bending, tearing, and other damage at a distance from the point of impact; which effects may be classed under the term "Concussion."

The effect of concussion is transmitted from the point of impact in all directions, in the same manner as sound-waves and increases with the elasticity of the material. Whatever tends to diminish the elasticity of the structure, as dividing it into many pieces, or using soft ductile material to receive the projectile, will diminish the effect of concussion. This effect is expended in two ways:

First, in giving motion to the structure or in developing inertia; and, *second*, in overcoming the tenacity of the material, either in bending or tearing those portions first acted upon from those more remote.

Both of these components, increase with the whole amount of work expended by the projectile, other conditions being equal.

The first component, being motion converted into motion, is nearly independent of the amount of penetration; it would be absolutely independent but for the fact that where the penetration is very slight the projectile or pieces of it may be thrown to the rear by the elasticity of the target, and this effect, re-acting upon the target, would be in addition to that due to the stopping of the projectile. Taking an extreme case, suppose the target and projectile to be perfectly elastic, and to resist all penetration: the projectile would be thrown to the rear with nearly the velocity with which it struck, and the velocity imparted to the target would be double what it would have been had the target and projectile been perfectly inelastic.

The second component will increase as the amount of penetration diminishes, since the less the penetration, the greater must be the force exerted by the structure to absorb a given amount of work from the projectile. But the amount of penetration for the same form of projectile, and with other conditions equal, diminishes nearly as the diameter of the projectile increases; and since the work stored in a projectile varies directly with its weight, or the cube of the diameter, we may conclude that *that portion of the effect of concussion expended in overcoming the cohesion of the material varies directly with the fourth power of the diameter of the projectile;* on this supposition this effect, for the X, XV, and XX inch spherical shot, would be as 1, 5 and 16, respectively, while the relative penetration of these projectiles would be only about as 1, $1\frac{1}{2}$, and 2.

The same effect may also be shown to vary directly with the velocity of impact. For a given amount of work expended by the projectile, it is evident that the lower the velocity, or the longer the time allowed for the force or resistance of the target to work, and the concussion to be transmitted to distant points, the greater will be the effect in bending the target, breaking bolts, and otherwise shattering the structure; but the whole work arises with the square of the velocity, and this, divided by the velocity, leaves the first power of the velocity as before stated.

The form of projectile is supposed to be the same in all cases.

The effect of changing the form would depend upon the change in penetration, those forms which give the greatest penetration giving the least effect of concussion.

854. ARMOR-PIERCING PROJECTILES.*—Projectiles intended for practice at objects composed of wood, masonry, or earth, are made of cast-iron, but since the introduction of iron for the defence of ships and fortifications, a material possessing greater hardness than ordinary cast-iron is required to overcome the resistance opposed by thick wrought-iron plates. Both elon-

* Mallet.

gated and spherical projectiles for use against armor should be of the hardest and toughest material possible.

The power of a projectile to stand up to its work and deliver its full blow on the target depends on the *shape* as much as on the *quality* of the metal of which it is composed.

855. SHAPE.—*Spherical Projectiles.*—The resistance of the plate, neglecting friction, acts as a normal to each point of the surface of contact of the projectile; thus, in Fig. 203 it will be seen that the portion of a spherical projectile included between A and B, which we may term the zone of compression, is subject to a crushing pressure towards the centre, O, but it may be said to be under no tensile strain. While the posterior portion of the projectile is suddenly checked by it in the form of a wedge, when a portion of the work stored up in it—(the amount depending on the tensile strength of the material of the projectile)—is impressed on the target through the front portion, A O B, while the remainder is carried off unprofitably in the fragments into which the posterior portion breaks.

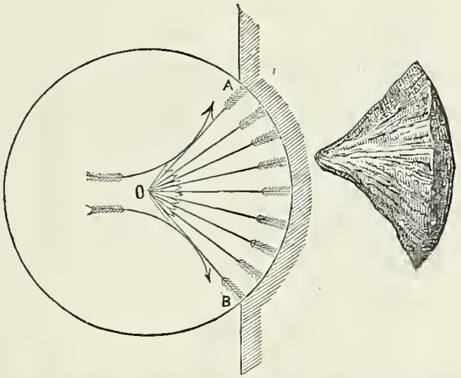


FIG. 203.—Anterior Fragment of round shot after impact against armor coinciding nearly with zone of compression.

On examining the projectile after impact, a part very nearly corresponding to A O B in form, will be found intact (Fig. 203), with the fractured surface scored and polished, while the remainder will be dispersed in small fragments.

We know that any casting fractures most easily in the direction of a normal to its surface, the crystals settling themselves so as to form lines on this direction.

Theoretically, the portion represented by Fig. 203 ought to be smaller as the penetration is less—except in the case of the entire blow being too small to overcome the tensile strength of the metal in the manner described:—when the projectile would only split irregularly or in an extreme case remain entire.

In all instances, obviously a great amount of the work stored up in the projectile is wasted; not that actually employed in breaking it, for such work is clearly the result of the reaction from the target; but whatever power remains stored up in the fragments, after they sever themselves from the mass of the projectile.

Since it is impossible to predict what part of a spherical projectile fired from a smooth-bore gun will come in contact with the target on impact, it is necessary that the material should be such as will offer the greatest union of hardness, crushing-strength, and tenacity; therefore steel has been resorted to in some instances, and may be regarded as the culminating point of development of the smooth-bore projectiles.

856. *Elongated Projectiles.*—The flat-ended form possesses a peculiar advantage as regards the projectile, and another as concerns the plate.

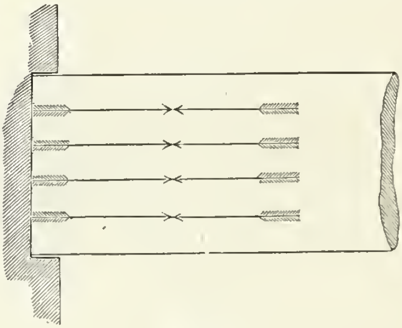


Fig. 204.

As to the projectiles, it may be seen (Fig. 204) that in direct impact the whole of the resistance of the target acts in lines parallel to the projectile's axis, which direction is the most favorable to the projectile retaining its mass and delivering its full blow on the target, and again, if the target is to be punched by actual shearing, the flat-head is the form best adapted to effect it.

The flat-head would probably be best in the case of direct firing against plates composed of hard iron, for it is easy to conceive of a hard material offering very great resistance to the forcing open of a pointed head, which might be punched by the clean shearing of a flat-headed projectile.

857. The power given by rotation, of keeping the same portion of a projectile presented to the front, is of peculiar value in punching armor-plates; it enables the head of a projectile to be made of any desired form, while the power of reducing the calibre of a projectile in proportion to its weight, which is perhaps the principal advantage obtained by rifling, is also most important here, the depth of penetration being in inverse proportion to the circumference.

858. In shells, however, this stability of the axis of rotation

tells more fully, for it enables every part of the projectile to be made of such proportions as will give the maximum power at the moment of impact. The walls of an elongated shell being chiefly subjected to a longitudinal strain, an interior hollow may be made without entailing the great weakness existing in spherical shells as compared with solid shot. Hence it follows that while smooth-bore shells have seldom or never been fired at armor, rifled shells have proved very successful.

859. There are two causes which contribute to give shells peculiar power against iron plates.

The first is that it is not necessary to weaken the head of a shell by making a fuze-hole in it; because no fuze is required, the heat generated on the impact of a projectile against the armor being sufficient to fire the bursting-charge. To such an extent is light as well as heat generated, that on firing at a target after dark, a pale flash is seen to follow the impact.

The *second* cause that operates to favor the action of shells, is the fact that when the shell has penetrated to a depth of even a few inches before rupture occurs, the sides are supported by the armor around them, and the explosion, being confined at the sides, acts to the front with greatly increased force.

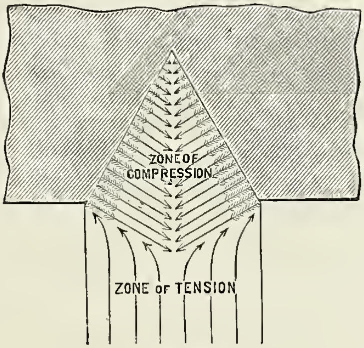


FIG. 205.

860. In a conical head (Fig. 205), the normal pressures throughout form a zone of compression acting as a wedge towards the body of the projectile, whose angle is the supplement of that of the cone of the head. This is better than that formed in the spherical head, because the angle is less acute, and because the apex of the wedge, instead of being a fixed point throughout (the centre of the sphere), moves along the axis of the projectile as it enters deeper and deeper into the target.

In the ogival head (Figs. 206 and 207), it will easily be seen how much superior is the action. In this the wedge is at the commencement slightly acute, but then the resistance acts on a small surface and is comparatively small, and the angle increases, till, at the junction of head and body, it becomes 180°, or a straight line (Fig. 207), so that we then have the body of the projectile in much the same condition as the flat-headed bolt driving before it an ogival wedge, which opens the armor by wedging rather than by clipping or punching.

861. It is possible, no doubt, to conceive of a material that

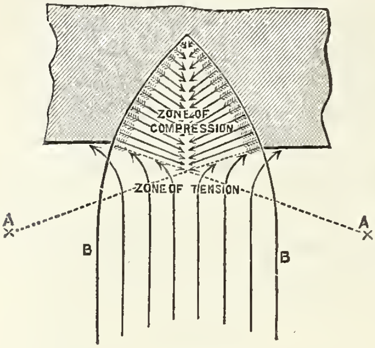


Fig. 206.

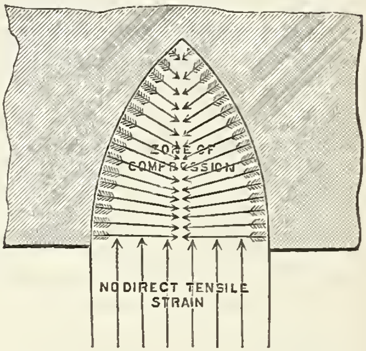


Fig. 207.

might be sheared by the flat projectile more easily than opened by the ogival; but it would be to contradict the results of experience to say that plate-iron was such a substance; and as the softer and more plastic natures of plate-iron have been found to hold their bolts the best, and stand the longest, and so have been universally adopted, the ogival has become obviously the correct form of head.

862. The Effect of Hardening Projectiles is probably much greater than is generally supposed; that is, the amount of work gained is much greater than the increase of strength of the projectile.

It is well known that a very small force may under certain circumstances determine the performance or non-performance of a very large amount of work. In like manner a very slight addition to the rigidity of a projectile, by hardening or otherwise, may determine whether a very large amount of work shall be wasted upon the projectile or expended upon the plate.

863. Another means of increasing the work done upon the armor-plate in comparison with that done upon the projectile is by increasing the velocity of the latter. That is, a projectile moving at a low velocity may be smashed up or flattened against the plate, while the same projectile fired at a higher velocity may go through the same plate almost uninjured. On this principle a lead shot may be fired through an iron plate, or a tallow candle through a pine board.

864. For the larger calibre of rifled guns, but one style of armor-punching projectile is usually supplied; this being a shell with thick walls, which may be fired empty as a shot, or with the bursting-charge to give the explosive action of a shell. It is found to penetrate best when fired as a shot; the action of the bursting-charge, generally taking place before the projectile reaches its full depth, interferes with penetration when the armor is very strong; but when the front-plates are not very thick, the backing may be shattered to a greater extent from the explosion of a bursting-charge.

865. ADVANTAGES OF STEEL OVER CHILLED PROJECTILES.—Late trials have shown a superiority of steel projectiles over those made of chilled cast-iron, and although the former are somewhat more expensive than the latter, on the principle that the best is at the same time the cheapest, it would be misplaced economy to leave any means unavailed of to increase the penetrating power of projectiles.

The quality of chilled projectiles, from the nature of their manufacture (Art. 809), is necessarily unreliable; whereas this is not the case with hammered cast-steel, or at least not to the same extent by far, even when large masses are produced, and the difficulty of manufacture increases with the calibre.

The most essential difference in the behavior of steel and chilled projectiles on striking the target, consists in the reaction on the projectile showing itself in the latter by breaking up, while the former are only set up. As the breaking up of the chilled shells may take place before the bursting-charge comes into operation, whereby the rending effect is considerably prejudiced, this material appears far less adapted for shells than steel.

The superiority of steel in this respect is still further increased by the fact that the steel shell can have thinner walls, consequently a larger chamber, and can thus hold a larger bursting-charge than the chilled metal.

866. EXPERIMENTS AGAINST ARMOR.—The experiments made of late years, although numerous and costly, have not been carried out in such a manner as to afford the necessary data for establishing the laws of penetration. In these experiments numerous circumstances have been approximated to, or assumed, and there have been generally many points of absolute difference between the experimental structures and those to be built for service.

By far the larger number of all the experiments of which we have record, were made upon targets small in area, although representing the entire thickness of parts to be used in practice; these small targets being held and braced up in various ways, generally different from the manner in which the same targets would be supported were they to form integral parts of a permanent structure. Nor have the tests applied to these targets been as a rule correct imitations of what they would probably receive in service; having been fired at deliberately with the guns and projectiles of the same country, as the targets.

867. Armor-Plates and Backing.—The following deductions have been made from trials with armor-plates extending over several years.

The best material to resist projectiles is soft, tough wrought-iron; and to attain these qualities it should be pure, free from sulphur, phosphorus, and carbon. Steely-iron, commonly known as homogeneous iron, puddled steel, etc., when in large masses is easily cracked by projectiles, and is not, therefore, suitable for armor-plates. Soft-steel may be used for armor-plates; but when cost is taken into consideration, it is doubtful if it possesses any advantages over wrought-iron.

Rolled iron does not offer quite so much resistance as hammered iron, yet if the size of the plate admit of it, it is to be preferred on the score of economy. Plates should be as large as possible to reduce the number of joints which are lines of weakness.

A solid plate offers for the same thickness a greater resistance to a projectile than a laminated one, or one made up of several thinner plates; but when the surface is rounded in shape, and of small extent, as in the Monitor turrets, the latter may be used to great advantage, as great thickness may thereby be easily obtained.

It is difficult in practice to obtain very large and thick masses in great numbers of uniformly good quality and at a moderate cost.

With targets made up of several plates, the chief difficulty has been to contrive bolts of suitable form, and to dispose them so that the strength of the target is not quickly impaired by the *shearing* of the bolts from the vibrations of the separate plates, or by their fracture on being struck by projectiles.

868. *Wood-backing* alone, unless combined with rigid horizontal angle iron stringers, affords but little support to the plate; that is to say, a projectile which is capable of penetrating a plate unbacked, will also be capable of doing so if it be backed with wood alone. Wood-backing is, however, of great value because it distributes the blow; it deadens the vibrations and saves the fastenings; also it stops the splinters.

The best form of backing appears to be that in which wood is combined with strong horizontal angle-iron attached to the inner skin, and extending to the armor-plates; this, by giving rigidity, very considerably assists the plate to resist penetration.

An inner skin of iron is of the greatest possible advantage; it renders the backing more compact, and prevents the passage of many splinters.

Oak and teak are the most suitable timbers for backing-plates, and are used as such on vessels. A yielding backing is found to occasion less strain on the fastenings than a very hard one.

Where projectiles are made of the same material, and are similar in shape, their penetration into unbacked plates is nearly in proportion to their *living force, or their weight multiplied by the squares of the velocity of impact.*

869. The resistance which an unbacked plate offers to penetration is nearly in proportion to the *square of its thickness*, provided this thickness be confined within ordinary limits. In the case of oblique plates the penetration diminishes nearly with the *sine of the angle of incidence.*

870. The most suitable material for shells to be used against iron plates is tempered steel. These projectiles should be made of cylindrical shape, with thick sides and bottom to direct the explosive effect of the charge forward after penetration is effected.

The most suitable material for solid shot is hard, tough cast-iron.

Palliser's chilled shot are made of this material, and so are the shot made for our service.

871. It follows from the preceding, that the most suitable covering or shield for cannon is a conical-shaped turret made of wrought-iron plates, as large as it is practicable to make them, backed with oak or teak.

To protect the men from the fragments of projectiles which may penetrate completely through this covering, there should be an "inner skin" of thick boiler-plate placed behind the wood.

872. With our XV-inch cast-iron projectiles, made of the best charcoal-iron, poured and worked in a peculiar manner so as to obtain hard and solid masses, the penetration is quite as great and uniform as that obtained with *steel* shot of equal weights propelled by similar charges, the only difference being that the iron breaks after passing through, while the steel is only compressed or flattened, a result rather in favor of the iron

shot, if entrance is made between-decks, where men are exposed to its fragments.

873. Effects on Wood.—The effect of a projectile fired against wood varies with the nature of the wood and the direction of the penetration. If the projectile strike perpendicular to the fibres, and the fibres be tough and elastic, as in the case of oak, a portion of them are crushed, and others are bent under the pressure of the projectile, but regain their form as soon as it has passed by them.

It is found that a hole formed in oak by a ball of four inches in diameter closes up again, so as to leave an opening scarcely large enough to measure the depth of the penetration.

The size of the hole and the shattering effect increases rapidly for the large calibres. A nine-inch projectile has been found to leave a hole that does not close up, and to tear away large fragments from the back portion of an oak target representing the side of a ship-of-war, the effect of which on a vessel would have been to injure the crew stationed around; or, if the hole had been situated at or below the water-line, to have endangered the vessel. If penetration take place in the direction of the fibres, the piece is almost always split, even by the smallest shot, and splinters are thrown to a considerable distance.

In consequence of the softness of white-pine, nearly all the fibres struck are broken, and the orifice is nearly the size of the projectile; for the same reason the effects of the projectile do not extend much beyond the orifice.

When a round-shot strikes against a surface of oak, as the side of a ship, it will not stick if the angle of incidence be less than 15°, and if it do not penetrate to a depth nearly equal to its diameter.

874. Effect on Earth.—Earth possesses advantages over all other materials as a covering against projectiles; it is cheap and easily obtained, it offers considerable resistance to penetration, and to a certain extent regains its position after displacement. It is found by experience that a projectile has very little effect on an earthen parapet unless it passes completely through it, and that injury done by day can be promptly repaired by night.

The powers of resistance of pure, compact quartz-sand to the penetration of projectiles has been found very much to exceed that of ordinary earth.

The size of the openings formed by the passage of a projectile into earth is about one-third larger than the projectile, increasing, however, toward the outer orifice.

Elongated projectiles are easily deflected from their course in earth. They are sometimes found lying in a position at right-angles to their course, and sometimes with the base to the front.

Unless a shell be very large in proportion to the mass of earth penetrated, its explosion will produce but little displacement.

875. Effect on Masonry.—The effect of a projectile against masonry is to form a truncated conical hole terminated by another of a cylindrical form. The material in front of and around the projectile is broken and shattered, and the end of the cylindrical hole even reduced to powder.

Pieces of the masonry are sometimes thrown 50 or 60 yards from the wall.

The elasticity developed by the shock reacts upon the projectile, sometimes throwing it back 150 yards.

The exterior opening varies from four to five times the diameter of the projectile, and the depth varies with the size and density of the projectile and its velocity.

Solid cast-iron shot break against granite, but not against freestone or brick. Spherical shells are broken into small fragments against each of these materials.

The most destructive projectile against masonry is the elongated percussion shell.

876. Punching and Racking.—It has been shown that the penetration of a projectile depends more upon velocity than weight, and that the elongated is a better form than the spherical for mere penetration or *punching*. It must, however, be remembered that very heavy shot, fired with velocities which might not enable them to penetrate or punch holes in iron armor, may still do great damage, especially if many are fired successively, by breaking bolts and shaking the whole fabric; also, that a spherical shot, having a larger diameter than an elongated projectile, may often do more damage in cracking or shattering a plate, than the latter in *punching* it, the *work* done by the ball being distributed over a larger area; the same argument will apply to the case of two elongated projectiles, having different diameters, striking a target with the same force, as measured by wv^2. Hence there are two general methods of attempting the destruction of iron-clad vessels, termed respectively *racking* and *punching*. We have preferred the racking system.

877. *The Racking System* requires heavy projectiles of large diameters, fired with low velocities, to destroy and shake off the armor by repeated shocks without penetration, and thus to expose the vessel to the effects of ordinary projectiles.

878. *The Punching System* requires elongated projectiles of moderate weight, fired with high velocities, so as to perforate the armor, and, if near the water-line, to sink the vessel, or at any part to injure men or machinery, or explode the magazine within the vessel.

879. *The Two Systems Combined.*—The two forces may prepare the way for each other, so as to produce a more formidable result than when they are independently exercised.

The defect of the light-shot system when the range is very long or the armor very thick, and of the heavy-shot system when the range is even very short and the armor is laminated or so constructed as to suffer little from racking and shaking, is the waste of power in producing local effect, that is fruitless because it is incomplete.

By combining the two systems, the light fast shot may weaken the armor by the loss of substance and continuity, until the heavy shot can carry in a large section of it bodily; and at the same time the general straining and cracking of plates produced by the heavy shot will make punching all the easier.

880. Force of Impact.—In order to estimate the probable effect of a projectile upon an object, it is necessary to calculate the *total energy* in the projectile at the moment of impact.

The "*vis viva*," or *total energy* of a body in motion, is the whole mechanical effect or work which it will produce on being brought to a state of rest, without regard to the time occupied; and it varies as the weight of the body multiplied by the square of its velocity. This work, accumulated in the moving body, is represented by the weight which it is capable of raising one foot high, and is equal to the weight in pounds of the moving body multiplied by the square of its velocity in feet, and divided by twice the accelerating force of gravity.

$$\text{Or, Total Energy} = \frac{wv^2}{2g},$$

where w = weight of projectile,
v = final velocity,
g = force of gravity. (32.2 ft.)

Example.—Thus, if a projectile of 165 lbs. weight be moving with a velocity of 1470 feet per second, the work accumulated in it, or the power it will actually exert on impact, is

$$\frac{165 \times (1470)^2}{64.4} = 2472 \text{ foot-tons.}$$

881. THE PUNCHING EFFECTS OF PROJECTILES are usually compared by calculating what is termed the *energy per inch of circumference* in foot-tons, which is found by dividing the *total energy* by the number of inches in the circumference of the projectile.

$$\text{Energy per inch of circum.} = \frac{wv^2}{2g \times 2\pi R},$$

where R = radius of projectile.

It will be readily seen that more force is required to drive a large projectile through a plate than a small one.

Therefore, if the object is to know the depth to which projectiles will penetrate, size must enter as an element in the question. It has been found that an approximate standard of comparison is furnished by dividing the total energy stored up in a projectile by its circumference.

The reason of this is plain. Suppose the projectile to act literally as a punch, and to clip a round disk out of the plate of sufficient size to allow it to enter; it is clear, in such a case, that the work performed is simply that of shearing the plate round the edge of the projectile. Thus the energy of the projectile will be met by the resistance required to shear the target in this manner, in a line which coincides with the exact circumference of the projectile. No doubt this supposition is not correct, as any one knows who has seen plate-firing. It is, however, sufficiently near the truth to furnish a standard of comparison between projectiles of various calibres.

CHAPTER VII.

GUN-CARRIAGES.*

Section I.—United States Naval-gun-carriages.

882. General Considerations.—The first of all considerations as to the mounting of the battery, is that it should admit of the utmost possible rapidity of fire, united with accuracy of aim. It is important to secure the greatest possible efficiency of the weapon under the conditions in which it is required to be employed.

The duty of providing the most perfect means of working guns seems to be second only in importance to that of adopting the best material, form, and construction for the gun itself. Of two similar guns, that which can fire the greatest number of rounds in a given time is certainly most effective, and rapidity of fire depends much more on the gun-carriage and conveniences for loading, than upon any peculiarity attaching only to the gun.

883. Owing to the increase in the size and power of ordnance since the introduction of armor, gun-carriages have gradually become elaborate machines; and mechanical science, in the hands of naval experts, has produced carriages and slides which enable the heaviest guns to be easily, accurately, and safely worked on the broadsides of ships. The great superiority of wrought-iron to timber as a material for gun-carriages is now universally acknowledged.

884. Although the mechanism has been greatly improved, the physical force of the gun's crew is still the source of the power by which the gun is worked. As long as this is the case a practical limit to the weight of gun that can be efficiently worked is imposed, and it would seem that this limit has been already reached. As still larger guns are in prospect, the necessity naturally presents itself for substituting an inanimate and unlimited power—like that of steam acting directly or through the medium of water under pressure.

885. The heat and elasticity of steam, and the difficulty of conveying it from place to place, render it unsuitable for direct application to the working of guns; but in the *hydraulic system*, so successfully developed for commercial purposes, steam is

* Compiled by Lieut. Commander G. W. Coffin, U. S. Navy.

made available as a central source of power, by employing a steam-engine to pump water into pipes, which transmit it at high pressure to the various points of application of the force where it acts in hydraulic pressure to produce the different movements required. It is this system which has been applied to the loading and working of heavy guns.

886. The application of this system to naval gunnery was put in successful practice in some of our iron-clads during the late war.

Loading from below deck by depressing the muzzle (Art. 1028) was devised by Mr. Stevens and practised on board one of our vessels.

Taking up the recoil on a steam or air cylinder (Art. 1026), and running out and in by steam as recommended by Captain Eads, was also successfully practised.

Muzzle-pivoting the guns so as to obtain 25 deg. elevation and lateral train in a fixed turret with a port no larger than the muzzle was practised on some of our monitors with entire success.

887. Requirements of Mechanical Carriages.—These are: powerful moving-machinery so contrived as to be unaffected by the concussion of firing; self-acting controlling gear, almost independent of human carelessness; the gradual absorption of, rather than ridgid resistance to, shocks; the dispersion of concussions over large surfaces; independence of distortion of, or other injuries to, the ship's side; smoothness and ease of motion in every direction, and safety under all conditions of the sea.

888. Disappearing Systems.—Guns mounted on the disappearing principle, are arranged to drop when fired into a position in which they can be loaded under cover, and from which they are only raised when required again to deliver their fire. (Art. 1022.)

It is yet undecided how far this principle is generally applicable in substitution of turrets for the protection of guns at sea. One great difficulty would seem to be that of effectually closing the opening, by which the gun must pass up and down, through the deck so as to prevent the entry of water, and it is difficult to conceive how rapidity or accuracy of fire can be attained in this way.

889. In this system the gun must not only be loaded while lowered and under cover, but it is usually fitted to be trained and aimed while there, by indirect methods, such as by telescopic apparatus adapted to the gun's axis, and so arranged that it can enable an observer to look over and above the cover. It is not probable that any such indirect instrumental apparatus

can be constructed which, when adapted to a heavy rifled gun shall admit of the accuracy of fire of the piece being adequately met by a corresponding exactness of aim.

The disappearing principle was first recommended by Captain J. B. Eads, and was adopted for trial in several of our western iron-clads.

890. THE MARSILLY BROADSIDE CARRIAGE (WOOD).

Nomenclature.

A.—Brackets.	M.—Trucks.
B.—Rear Transom.	N.—Cap Squares.
C.—Breast Piece.	9.—Side Tackle-bolt.
D.—Sweep Piece.	10.—Train " "
I.—Saucer.	11.—Transporting Tackle-bolt.
F.—Front Transom	K.—Roller Handspike.
L.—Boss of Roller Handspike.	P.—Washer and pin.

Dimensions.

Height of Trunnions	34	inches.
Extreme length of Carriage	68	"
Width of Front	39.5	"
Width of Rear	44	"
Thickness of Wood	7.5	"

891. *The Brackets*, A, are made of heavy white oak, jogged and dowelled together as in Figure 208, and firmly secured to each other by the bolts 1, 2, 3, 4, 5—1 and 2 cap-square bolts; 3, 4, and 5, bracket bolts. The rear portion of the brackets are extended downward to the deck, the upper descending by a curve and two steps; the latter being faced by strips of metal, to take the chafe of the handspikes when used on them. The brackets are joined by the *Front* (F) *and Rear Transoms* (B), which are jogged into them, the front transom having two bolts (7 and 8), and the rear, one (6); the Front Transom, F, is scored out to permit vertical motion of the chase of the gun in the carriage.

892. *The Breast Piece*, C, is firmly bolted to the front transom and works against the Sweep Piece, D, fitted to ship and unship from the ship's side by composition pins and sockets.

893. *The Socket Plate* consists of a metal plate, with indentations or sockets for the boss, L, of the Roller Handspike, K, to take in. It is placed under and at the rear edge of the Transom B.

894. *The Roller Handspike*, K, consists of a bronze head

and socket with a hickory handle; in the head are placed two *lignum-vitæ* rollers, four inches in diameter, working on a line through the sides of the head. A boss, L, is cast at the junc-

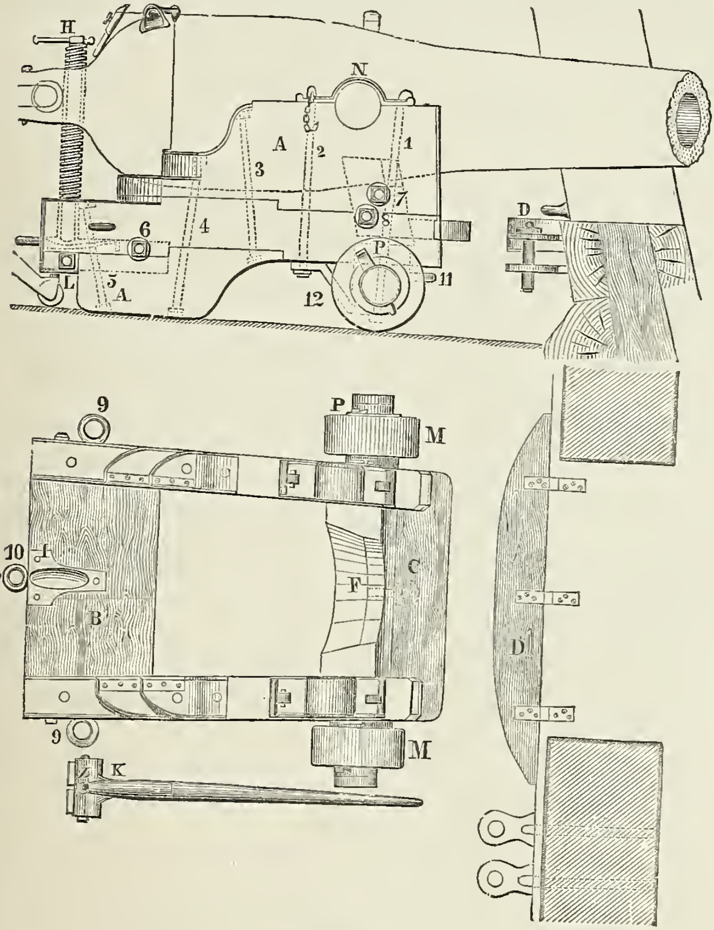


Fig. 208.

tion of the head and socket, making an angle of 70° with the socket. In the socket is placed the hickory handle.

When in use, the lift of the carriage is greatest with the boss, L, vertical, as it is then raised $\frac{1}{2}$ inch above the deck. In service the best result is obtained with the handle at the hip; care must be used to maintain the axis of the roller perpendicular to the motion of the carriage, otherwise the weight cants the head, causing the rollers to deface the deck.

895. *The Truck Axle* is let into the Brackets, A, and secured to them by the cap-square bolts, 1, and the brace, 12, through which the other cap-square bolt passes and is set up by a nut.

896. *The Trucks*, M, are of *lignum-vitæ*, one calibre in thickness, and retained on the axle by a washer and flange-pin, P.

897. *The Saucer*, I, is of composition, and secured to the Rear Transom, B. From its shape it permits a horizontal movement of the lower end of the screw, due to its deviation from the perpendicular, in elevation or depression.

898. *Resistance to Recoil.*—As the recoil of the gun is to the rear and downward, considerable resistance is offered by the friction excited between the carriage brackets and deck; the recoil is thus checked in proportion to the friction exerted.

899. *Manœuvring the Carriage.*—To run the carriage in and out, or transport it about the deck, the Roller Handspike, K (Fig. 208), is shipped under the rear transom, B, and the gun readily moved on its trucks and the roller handspike.

900. *Elevation Obtainable.*—Broadside carriages are so constructed as to give 11° elevation and 7° depression to the gun, and for four different heights of the lower port-sill above the deck, viz., 24, 20, 18, and 16 inches, according to the requirements of their position.

901. *Preservation.*—New carriages should be kept well painted, and the trucks, axle-trees, and trunnion-holes oiled. Staining or keeping them bright is strictly prohibited.

902. *Gun Tackles* are to be of well-stretched manilla, cut of sufficient length to allow of full recoil, and with end enough to hitch around the straps of their inner blocks.

903. *Metallic Gun Tackle Blocks* are supplied to all Marsilly and heavy pivot carriages; these have ribs on the hooks, which keep the blocks fair with the falls, and prevent their fouling on recoil.

Breechings are of the best three-strand, shroud-laid, and soft, hemp rope, 9 and 10 inch for the larger guns, from 6 to 9 for the smaller; they should be long enough, when fitted, to allow the muzzle of the gun to come one foot inside of the port. Breechings are never to be covered, blackened, or in any way rendered less pliable than when first fitted.

904. Wrought-iron Carriage for VIII-Inch Gun.

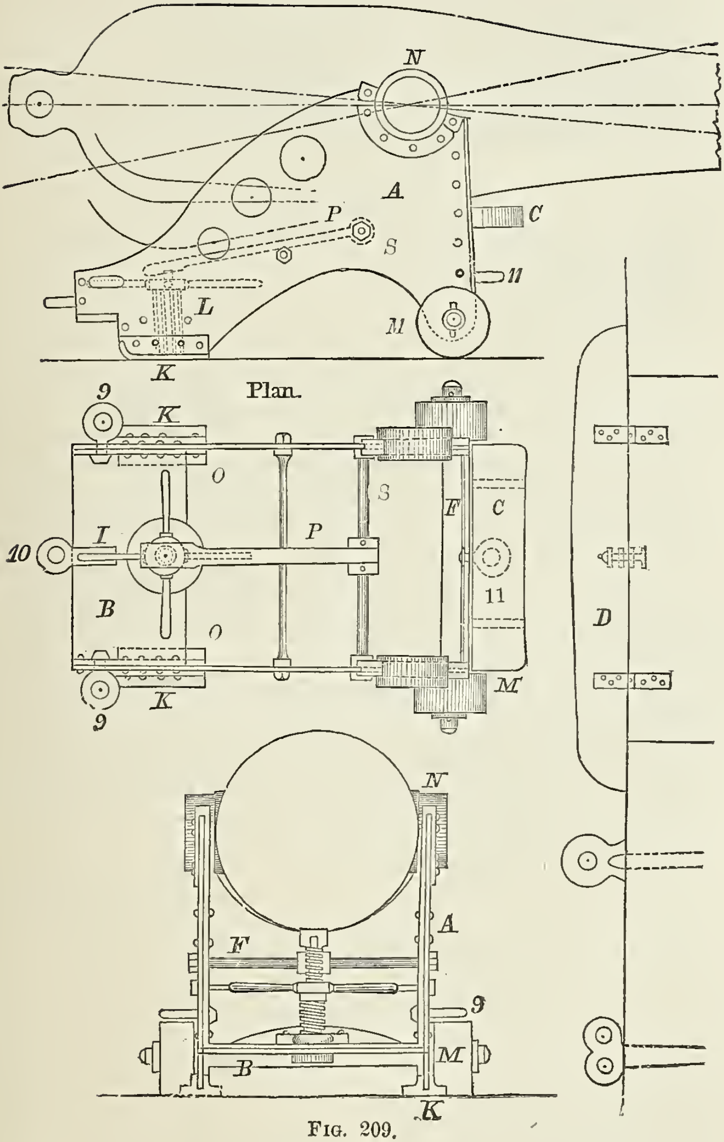


Fig. 209.

Nomenclature.

A.—Brackets.
B.—Rear Transom.
C.—Breast Piece.
D.—Sweep Piece.
F.—Front Transom.
K.—Composition Shoes.
L.—Elevating Screw.
M.—Trucks.
N.—Cap Squares.
O.—Angle Iron.
9.—Side Tackle-bolt.
10.—Train " "
11.—Transporting-bolt.

Principal Dimensions.

Height of Trunnion	36	inches.
Extreme Length of Carriage	56	"
Width of Carriage	27	"
Thickness of Iron	$\frac{3}{4}$	"
Weight of Carriage	981	lbs.

905. *The Brackets*, A, are made of $\frac{3}{4}$ inch wrought-iron ; on their rear lower portion are placed composition shoes, K, which rest upon the deck.

906. *The Transoms*, BF, of the iron carriage, are of wrought-iron plate, and occupy the same position as in the wooden carriage ; the front transom, F, and rear, B, are riveted to the brackets by angle-iron, O.

907. *The Truck Axle* passes through the forward lower ends of the brackets, shown in the figure by the dotted line; on these axles composition trucks, M, one calibre in thickness, are placed.

908. *Elevating Gear.*—At the height of the Breast Piece, D, and just in rear of the Trunnion Holes, are rods connecting the brackets; on these are pivoted a bar, P, whose rear end rests on the head of the male and female screw, L, which works in the bed-plate of the carriage to such an extent that when the gun has extreme elevation, the screw is considerably below the Bed-plate, B, yet does not touch the deck.

909. *Side* (9), *Train-tackle* (10), *and Transporting Bolts* (11) are of composition, and occupy the same position as in the wood carriage.

910. *The Breast Piece*, C, is of wood and arranged to be at the height of, and work on, the Sweep Piece, D.

The Socket Plate is very similar to that on the wood carriage, occupying the same position.

911. *Cap Squares*, N, are of composition, and secured to the brackets by screw nuts.

912. *The Recoil* is checked by the friction exerted between the deck and the composition shoes, K, whose rear edges are curved upward to prevent injury to the deck on recoil.

913. *Wrought-iron* is employed in the manufacture of gun-carriages for the reason that it does not splinter like cast-iron on the impact of shot. Because of their less weight, less space occupied, and non-liability to injury in service, these carriages promise to entirely supersede the wood carriages.

914. When Parrott guns are mounted in broadside, a Marsilly carriage is employed, differing from the ordinary carriages in that the brackets are extended farther to the rear to accommodate the additional length of gun.

915. PIVOT CARRIAGES.—*Object.*—Guns which are expected to be fired at greater elevations than the ordinary port will admit of, are mounted upon pivot-carriages, which give an elevation of 20° to the gun, and a much larger arc of train than the broadside carriage, the bulwarks of the ship being arranged to let down in order to accomplish it.

On Spar Decks the slide may usually be pivoted amidships, and on both bows when placed forward; if aft, astern and on both quarters; and there being fewer obstructions aft, the gun in some cases has a full sweep from one beam to the other.

On Gun Decks the arc of train is somewhat limited, yet considerably greater than with the broadside carriage; the ship's side is arranged to let down like the bulwarks on spar-decks, the fighting pivot being at the ship's side.

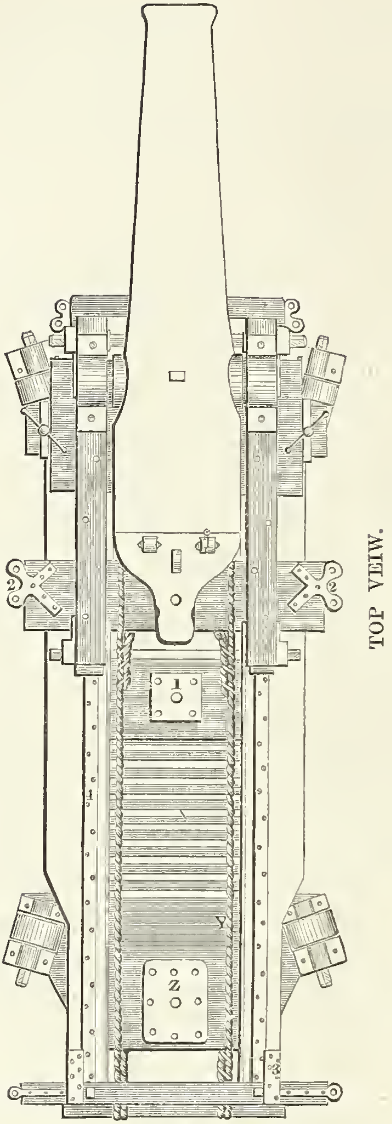
916. THE XI-INCH PIVOT CARRIAGE (WOOD) is composed of two principal parts, the slide and the carriage proper (Fig 210), the former being secured at one of its ends by a pivot bolt, P. Fig. 212 is traversed by tackles, to bring the guns to bear upon the object, or to change position in firing.

917. *The Carriage* differs from the Broadside in the suppression of trucks, and the substitution, therefor, of three transoms B (Fig. 214), front, middle, and rear; the lower sides of which rest upon the slide, and by their friction modify the recoil.

918. *The Brackets*, A, are in two parts, gogged and dowelled together, and they and the transoms, B, are firmly secured to each other by the bolts, O.

919. *The Transoms*, B, extend beyond the brackets and slide-rails, C, the forward being for the compressors, f, and the rear for the double eye bolted to it, to which the blocks of the in and out tackles hook; a third called the Breast Transom J is bolted between the front ends of the brackets, and is scored out as in the Broadside carriage.

920. *The Journal Plates* (g) attached to the brackets, carry rollers on an eccentric axle, extending across, between, and beyond the brackets; levers are supplied to be shipped on



WOODEN PARTS.

N. Battens and Slats.

Y. Preventer Breechings

METAL PARTS.

Z. Upper Pivot-plate.

1. Middle Roller-plate.

2. Eyes for Tackles.

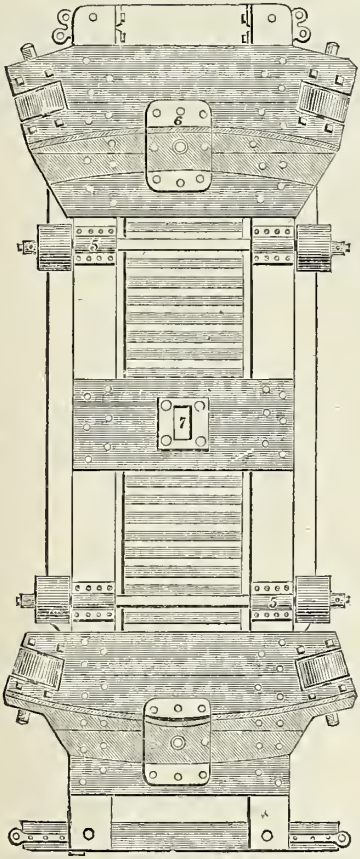
3. Hurter Straps.

4. Rail-plates.

FIG. 210.—Plan of XI-Inch Gun-carriage and Slide.

the end of the axles, throwing the eccentrics in and out of action.

BOTTOM VIEW.



METAL PARTS.

5. Transporting journals.

6. Pivot-plates & guide-flanges.

7 Middle roller

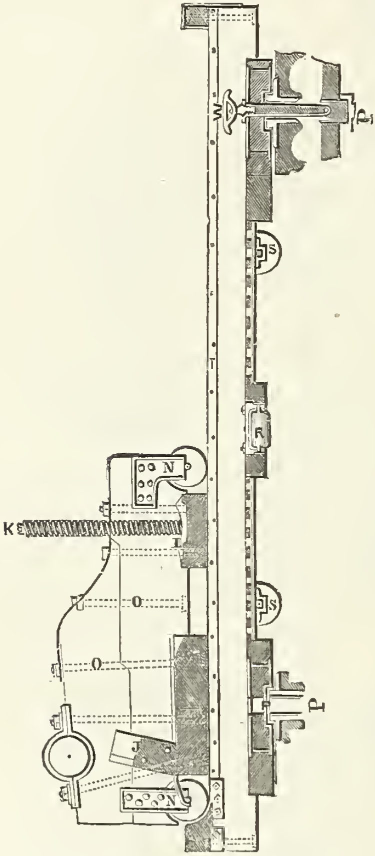
Fig. 211—Plan of Slide for XI-Inch Gun-carriage.

Note.—*All metal parts are composition, except the axles, levers, elevating screw and bracket-bolts.*

921. *The Compressor*, f (Fig. 214), is placed upon the projecting portion of the Front Transom B, and is worked by means of a screw and handles, binding the transom and compressor-batten D, closely together, by which the recoil is restrained, and kept within the limits of the slide. On the rear transom is placed a metal

saucer, L, on which the lower end of the Elevating Screw, K, rests, the upper portion working in the cascabel of the gun.

922. *The Slide* consists of two wooden rails, C, jogged into transoms, front, middle, and rear (E, Fig. 214), and connected beneath by slots, and at their ends by cross-pieces called *Hurters*. (F, Fig. 214.)



CARRIAGE.

WOODEN PARTS.

J. Breast Transom scored for elevation, as is also the middle transom.

METAL PARTS.

K. Elevating Screw.

L. Saucers.

N. Inside journal-plate.

O. Bracket-bolts.

SLIDE.

METAL PARTS.

P. Bossed Sockets, Plates, & Pivot Bolts.

R. Middle Training Truck, with Journals.

S. Transporting Trucks, Axles, & Journals.

T. Guide Plates inside of rails.

FIG. 212.—Sectional View of XI-Inch Gun-carriage and Slide.

The transoms, E, three in number, project beyond the slide-rails, and have attached to them rollers, G, on eccentric axles;

the rear for training, and the front for shifting the slide, or traversing it. At the proper position in each of the transoms, front and rear, is placed a metal plate, with hole for the pivot-bolt (Fig. 211), 6.

923. *The Compressor Battens, D* (Fig. 214), are two strips of oak equal in length to the distance between pivots, which are attached to the slide-rails, C, on the outside; against these the under lip of the compressor, f, takes when set taut.

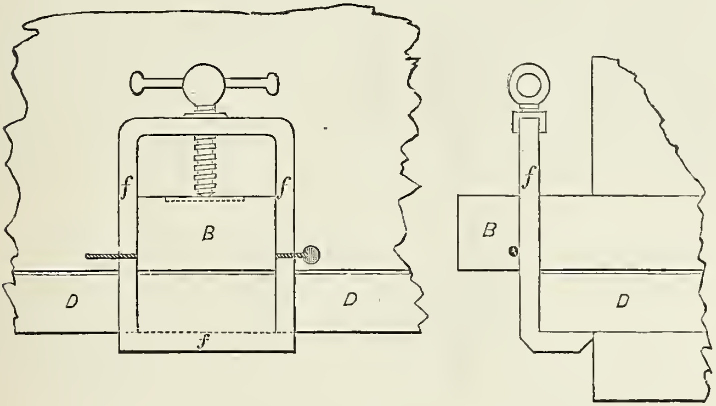


FIG. 213.—Pivot Compressor.

924. *The Hurters*, F, are the two cross-pieces bolted to the rails, and having their inner sides curved for the carriage-rollers to run against, should the carriage get beyond control, going out or in. To these and the slide are attached composition eyes for the blocks of the in-and-out training and traversing tackles.

925. *Metal Tracks* are laid upon the deck for the slide-rollers, G and H (Fig. 214), to run upon, being struck with a radius equal to the distance between their rollers and the opposite pivot. For each position of the slide, in traversing, bossed sockets, P (Fig 212), are inserted in the deck for the front and rear pivot-bolts.

926. *The Bossed Socket*, P (Fig. 212), consists of a raised rim of metal around the pivot-hole, a corresponding slot in the slide transom securing the coincidence of the hole in the slide with that in the socket, thus facilitating the entrance and removal of the pivot-bolt, W.

927. *The Eccentrics*, G and H (Fig. 214), when out of action

allow the slide-transoms, E, to rest upon the deck, and those of the carriage upon the slide. In order to train or shift the slide, the levers are shipped upon their axles, the rollers, G and H, put in action, thus lifting the slide from the deck, and leaving it free to be moved by its tackles. In the same way the carriage is lifted from the slide to run in or out.

928. *Recoil.*—Before firing, the compressor, f, is set taut by the screw, binding the carriage transom, B, and compressor-batten, D, together. When the gun is fired, the recoil is absorbed by the friction exerted between them.

929. *The Compressors*, f (Figs. 213 and 214), are not intended to entirely supersede the use of breechings, but rather as an auxiliary; the main reliance being placed on the Breeching, which should be shackled to the ship's side, and not to the slide, as in the latter position unnecessary strain is brought on the pivot-bolt.

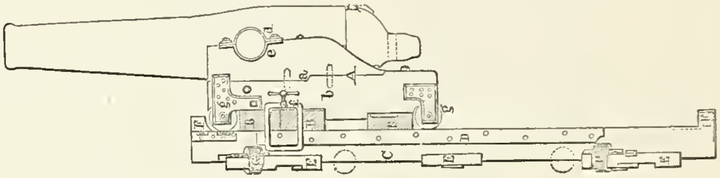


FIG. 214—Side Elevation of XI-Inch Gun-carriage and Slide.

CARRIAGE.

WOODEN PARTS.	METAL PARTS.
A. Brackets of two pieces, with jog, a, and dowels. b.	d. Cap Squares.
	e. Trunnion Plates.
B. Transoms, projecting beyond the rails, front, middle, and rear, jogged into brackets.	f. Compressor, with screw and lever.
	g. Rollers and Journal Plates.

SLIDE.

WOODEN PARTS.	METAL PARTS.
C. Rails.	G. Shifting Trucks.
D. Compressor Battens.	H. Training Trucks, both with journals, and eccentric axles.
E. Transoms; front and rear, each in two parts, middle in one part.	
F. Hurters, front and rear.	

Firing to Windward, the compressor, f, should be set just taut enough to check the recoil and ease the strain on the breeching.

Firing to Leeward, the gun on recoil has to run up an inclined plane; consequently the compression required is very slight.

With the Vessel on an Even Keel, it is usual to set the Compressor a certain number of turns, which is known to give the proper compression.

930. *Shipping the Levers.*—In order that this may be done expeditiously, both axle and lever are marked with a cold-chisel, and should always be hove up past the centre and rest against the wood of the slide or carriage.

931. *Transporting.*—For transporting the pivot-carriage and slide from one end of a vessel to the other, composition sockets, S, are attached to the under side of each slide-rail; through these pass square axles, carrying at their extremities metal rollers. The axle, being passed through the slide, is lifted on its rollers, the transporting trucks shipped, and the slide lowered; it now rests on the transporting trucks, S, and may be readily moved to any desired position. (5, Fig. 211.)

A Middle Roller, 7 (Fig. 211), has in some cases been provided for the slide of the XI-inch gun, which from its great length is liable to sag at the centre.

932. *Running out to Leeward* in a sea-way, even with precautions and a well drilled crew, there is liability of the gun breaking away and doing damage. To guard against this,

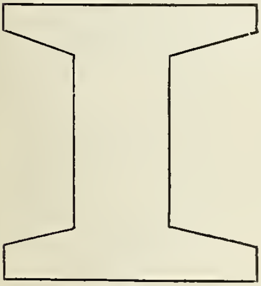


FIG. 215.

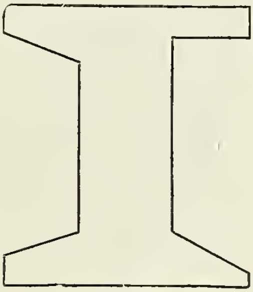


FIG. 216.

Preventer Breechings, Y, are fitted (Fig 210), of such a length as to be just taut when the gun is out, and allow the front carriage trucks to reach but not ascend the curve of the front hurter, F; for if the trucks should ascend this curve, the compressor-straps must surely give way to the power exerted to separate the carriage and slide by such a heavy weight moving with its velocity.

933. XI-inch Iron Pivot-Carriage.—

Nomenclature.

SLIDE.

A.—Slide rails.
B.—Transoms.
C.—Front and Rear Hurters.
D.—Pivot-holes.
E.—Transporting Trucks.
F.—Slide Rollers.
1, 2, 3.—Tie Bolts.
4.—Transporting Axle.

CARRIAGE.

G.—Brackets.
H.—Front Bed-plate.
I.—Rear Bed-plate.
K.—Eccentric Rollers.
L.—Front Rollers.
M.—Cap Square.
N.—Composition plates to increase friction.
O.—Angle iron connecting brackets, etc.
P.—Bolts for Preventer Breeching.
Q.—Compressor Plate.
R.—Bolts of In-and-Out Tackles.
S.—Vertical Transom.
P′. P′.—Journal Plates. V Compressor.

PRINCIPAL DIMENSIONS.

Extreme length	15 ft. 7 in.
Length between Pivots	11 ft. 10 in.
Width of Slide	3 ft. 6 in.
Width of Rails	0 ft. 5 in.
Radius of Training Track	10 ft. 10 in.
Radius of Traversing Track	12 ft. 6 in.

934. *The Slide*, A, consists of two rails of double T rolled

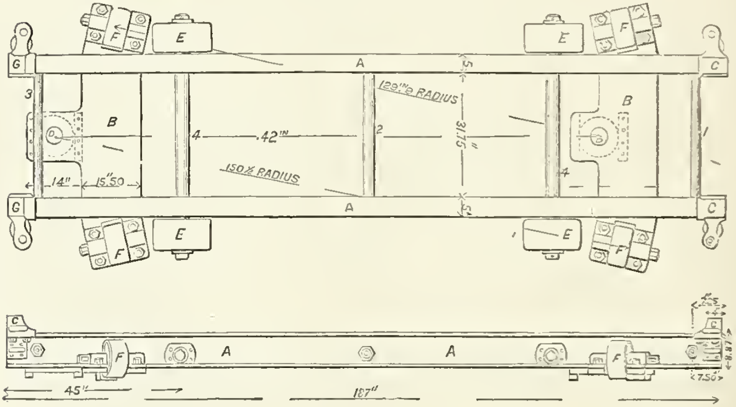


Fig. 217.

wrought-iron, 8.87 inches high by 5 inches wide, connected by the tie-bolts, 1, 2, 3.

935. *The Transoms*, B, are of $1\frac{1}{2}$-inch wrought-iron of the form shown in the figure, and riveted to the under side of the

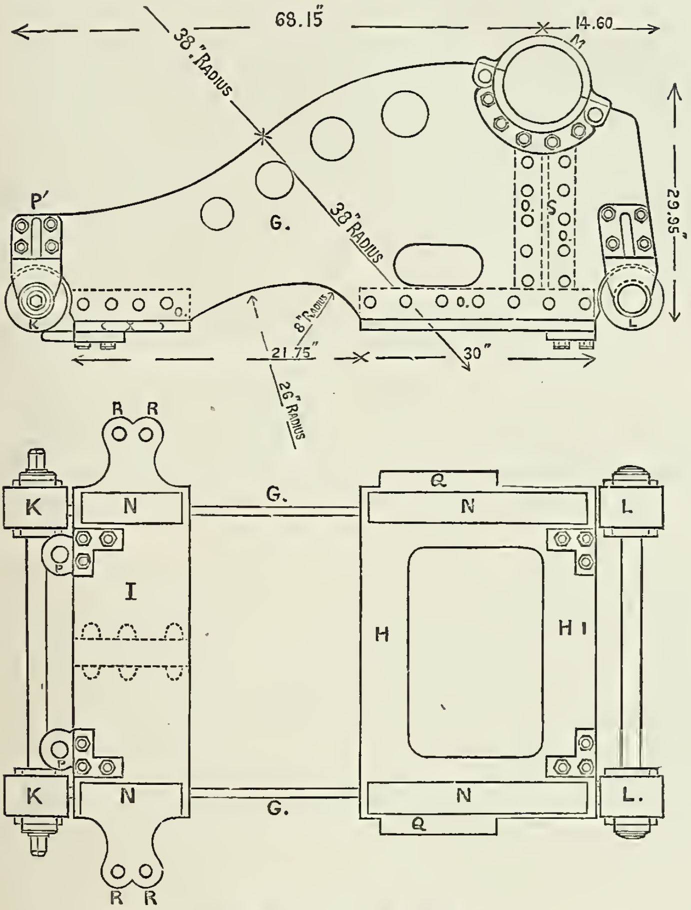


FIG. 218.—XI-inch Carriage.

rails, A; they project beyond and have fitted to them composition rollers, F, on eccentric axles, the latter being secured by plates and bolts; levers shipped on the projecting ends of the axles put the rollers in and out of action.

936. *The Hurters*, *C*, are the brass castings riveted to each end of the slide-rails for the carriage-trucks to run against. Each of these carries bolts for the blocks of the in-and-out tackles be-

neath them, and to the vertical part of the T rail, are attached brass plates with bolts for the blocks of the shifting and training tackles.

937. *Coincidence of the Pivot-holes*, D, is secured by plates screwed to the slide transoms, B, and distant from each other a little more than the diameter of the bossed socket, indicated in the figure by the dotted circle around the pivot-hole, D.

938. *Form of Rail.*—The wrought-iron rails, A, when first manufactured have the form shown in Fig. 215, but before being placed for the slide the under side of the upper outer portion of the T is removed, giving it the form of Fig. 216, in order that the compressor may have a flat surface to act on.

939. *Transporting.*—About ten inches in rear of the front and the same distance in front of the rear trucks are placed the sleeves for the transporting axle and trucks, E, the latter of such a diameter as to sustain the slide clear of the deck when let down from its eccentric rollers, F.

940. *The Carriage.*—All iron parts of the carriage are made of $1\frac{1}{8}$-inch wrought-iron, the journal-plates, rollers, cap-square, trunnion-rests, and preventer-breeching-bolts being of brass.

Immediately beneath the trunnion-hole is a vertical iron plate, S, extending down between the brackets to the bed-plate, H.

941. *The Brackets*, G, rest on the bed-plates, and they and the vertical transom, S, and bed-plates, H and I, are riveted together with the angle iron, O.

942. *The Bed-plates*, H and I, extend beyond the brackets, the rear, I, being shaped to a double eye, for the blocks of the in-and-out tackles, the front, H, contracting into a plate for the compressor-screw to work upon.

943. *The Journal Plates*, P′, for the eccentric axle and rollers are riveted to the rear end of the brackets, G, the axle extending across, between, and beyond the plates and carrying rollers, K, revolving in the plates. These axles are eccentric in order that, by the use of levers, the trucks may be placed in or out of action at pleasure. In the former case the carriage is raised and rests on its rollers, K; in the latter, it rests on the slide, A.

944. *Form of Eccentric Axle.*—An ordinary cylindrical axle has cast on it an eccentric (Fig. 219), that is, instead of the two cylinders being concentric, the axle passes on one side of the centre, X, of

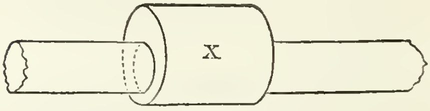


Fig. 219.

the larger circle. With the axle at its lowest position, the rollers are out of action; at its upper position, the carriage is raised by the action of the rollers, a height corresponding to the eccentricity of the axle.

The front trucks, L, are like those of an ordinary carriage, always resting on the slide and revolving on any movement of the carriage.

945. *The Compressor*, V (Fig. 220), consists of a composition casting, V, having a vent, V′, at the centre of the upper arm, through which works a screw bolt, W, with handles. It is placed on the compressor plate, O, its under lip, x, taking against the under side of the upper, T, of the rail. When the

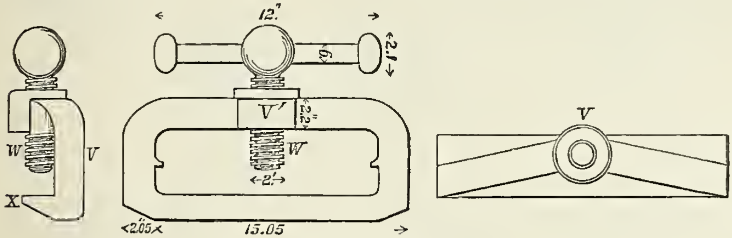


FIG. 220.—XI Compressor.

screw is turned, the rail is compressed between the compressor plate, O, and the lip of the compressor, x. The recoil is thus limited by the friction of the different parts.

946. *Recoil.*—As the bed-plates, H and I, and rail are each of iron, acting alone, sufficient friction would not be excited to keep the recoil within the desired limits. To correct this deficiency, after the brackets, G, have been riveted to the bed-plates, plates of composition, N, are screwed to that portion of the bed-plates in contact with the slide, thus increasing the friction to the required point. As the compressors are placed as near as possible to the brackets, the latter are cut out to allow space in turning the handles of the compressor.

947. *Necessity of Eccentric Rollers in the Slide.*—The slide-rollers, F, are all eccentric for the reason that when shifting the slide at sea, with much motion on the ship, it is absolutely necessary to have complete control of it; for should it once get away from the crew, it becomes a serious matter to again confine it.

When this is likely to occur, the levers are at once let down, throwing the rollers out of action and the slide upon the deck, when, from the great weight, the friction of the transoms on the deck will almost immediately stop it. This would be impossible were the slide always free to move on its rollers, and only confined by tackles.

948. 20-PDR. RIFLE PIVOT CARRIAGE.—

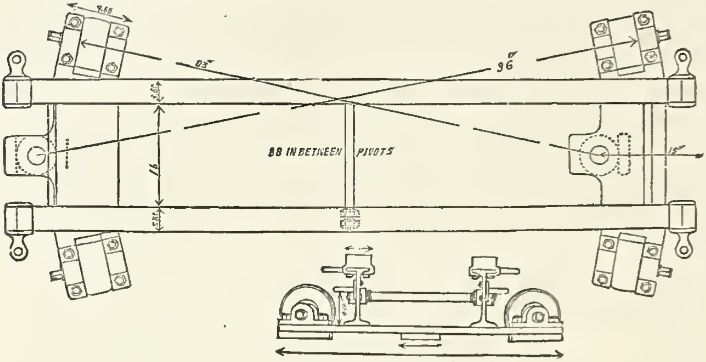


FIG. 221.

Principal Dimensions.

Extreme length	97 inches.
Length between Pivots	88 inches.
Width of Slide	23.6 inches.
Thickness of iron	¾ inch.
Radius of Training Track	83 inches.
Radius of Shifting Track	96 inches.
Extreme length of Carriage	48 inches.

Its construction is essentially the same as the XI-inch carriage, the only difference being that the bed-plates of the twenty-pounder are of bronze cast with two upright pieces, to which the iron brackets are riveted, while in the XI-inch, angle iron is used to connect their brackets and bed-plates. Only one tie bolt is used to connect the slide-rails at their centres. As the beds are of bronze the requisite amount of friction can always be obtained by the compressor. (Figs. 221 222.)

949. XV-INCH TURRET CARRIAGE.—

Nomenclature.

A.—Box Bracket.
B.—Bed Plate.
C.—In-and-out gear.
D.—Compressor.
E.—Cog-wheel.
F.—Guides.
G.—Carriage-braces.
H.— " Rollers.
I.—Iron rails.
K.—Balance-wheel.
L′.—Elevator-rest.
M.—Curved lever.
N.—Front Transom.
O.—Rear "
O′.—Sleeve.
O″.—Nut.
P.—Small Cog-wheel.
R.—Compressor Plates.

950. *The Slide* consists of two heavy iron rails, I, extending from one circumference of the Turret to the other, and

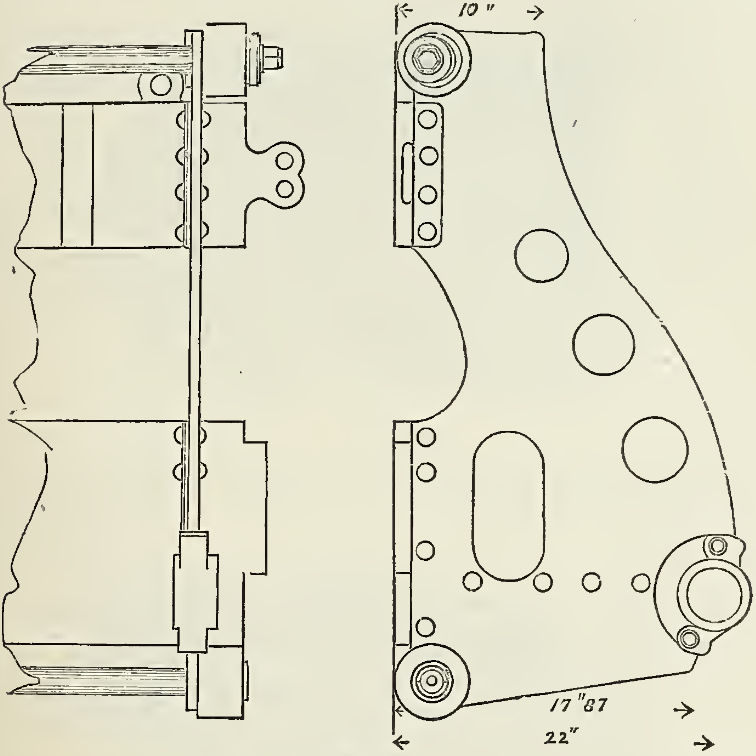


Fig. 222.

firmly secured to it; on these run the carriage rollers, H. Between the two iron rails, and parallel to them, are four wooden joists, L, called compressor-battens, each six inches square. (Fig. 225.)

951. *The Carriage* is of wrought-iron. The brackets, A, being of the box form, while the bed-plate, B, and front, N, and rear O, transoms, are of single plate-iron. All parts of the carriage being riveted together, and the brackets, A, supported by the two traces, G. At each under corner of the bed-plate, B, is placed an angular metal plate, F, called a guide, preventing lateral motion of the carriage on the rails.

952. *The In-and-Out Gear*, C, consists of an axle extend-

ing across the front end of the carriage, carrying rollers, H, placed in the brackets. Just inside the outer bracket, the axle

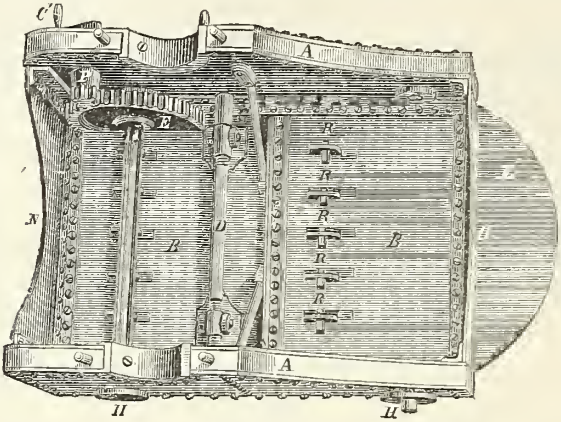


FIG. 223.

has on it a large cog-wheel, E, a shorter axle placed higher in the bracket, working the larger cog-wheel by means of the

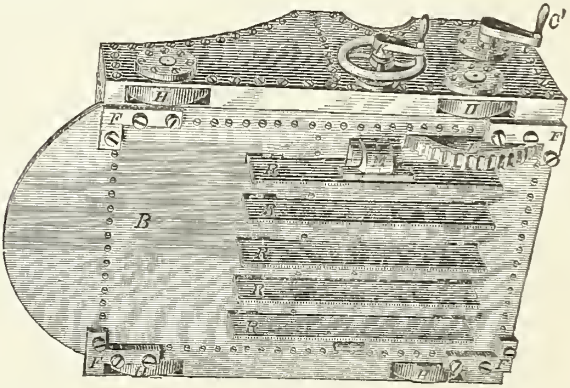


FIG. 224.

smaller cog, P, in its inner end. To the outer end is fixed a crank, C′, to be worked by hand.

953. *The Carriage Rollers*, H, are four in number: the forward two attached to the axle of the "In-and-Out Gear," and the rear to short axles in each bracket.

954. *The Compressor Gear*, D.—To the bottom of the carriage is piveted an iron plate (P. Fig. 225), whose ends project downward through the Bed-plate, B; on these are hung curved levers, M. To one is pivoted a sleeve, O′, and to the other a nut, O″. A rod passing through the bracket and the sleeve has on its end a thread, which works in the nut on the opposite lever; lateral motion of the sleeve on the rod being prevented by collars outside the bracket. The rod has attached to it a balance-wheel and crank, K.

955. *The Compressor Plates*, R, five in number, are of ½ inch iron (Fig. 224); their ends project through the Bed-plate and are keyed; their lower portions extending downward between the wooden joice or battens, L (Fig. 225), parallel with them and the iron rails.

956. *Action of the Compressor Gear.*—As the balance-

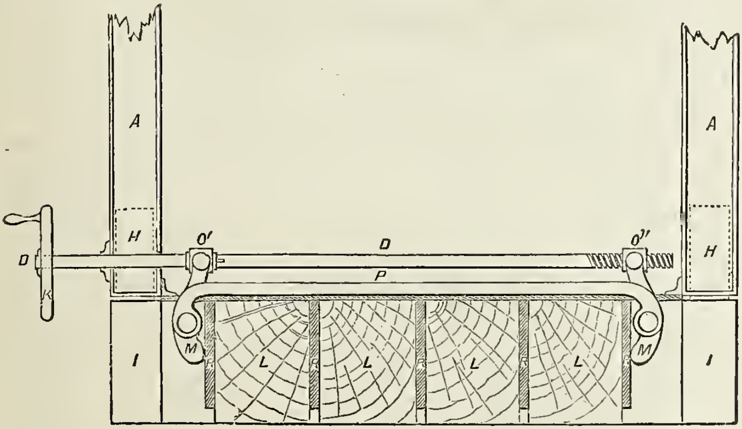


FIG. 225

wheel, K, is revolved it carries the rod with it, causing the upper ends of the curved levers, M, to separate, and the lower to approach; the latter press against the two outer compressor-battens, L, forcing them out of parallelism, and binding the iron plates, R, and battens, L, firmly together. When the gun is fired its recoil is absorbed by the friction of the several parts. Reversing the motion of the wheel separates the plates and battens, leaving the carriage free to move on its rollers.

957. *Elevator-Rest.*—The elevating screw usually rests on the projecting portion, L′, of the bed-plate. In some carriages a semicircular plate is riveted to the rear transom, having on

its circumference a vertical plate connected to a fore and aft plate, the two supporting an iron saucer, on which the lower end of the elevating-screw rests, the upper end passing through the cascabel of the gun.

958. *The Hurters* are flat plates of iron bolted to the rails, to prevent the carriage going beyond the proper point, out or in.

959. *Elevation.*—The port is cut from the circumference, of the turret, of such dimensions as to allow of 10° elevation and 5° depression, and permit only vertical motion of the muzzle of the gun in it.

960. *The Port Stopper*, S (Fig. 226).—When the gun recoils after firing, the open port, Z, is free to the entrance of an enemy's shot. To protect those in the turret while loading the gun, a heavy mass of iron, S (Fig. 226), curved to allow the gun to pass going in and out, is pivoted at the top and bottom of the Turret, and worked by a lever and tackle. As the gun recoils, the Port Stopper is swung around, covering the port, and swinging sufficiently near to the inner circumference of the Turret to prevent shot fired at an angle from entering the Turret between it and the port. The gun being loaded the port-stopper is swung around and the gun run out.

961. *Loading.*—The loading hatches, T, are placed abreast the rear of each carriage when in, the communication between the turret and below being open when the guns are pointed abeam. As the projectiles are very heavy and the space in the turret limited, mechanical appliances are made use of to carry the projectile to the muzzle of the gun. These consist of a long iron rod, U, pivoted above the loading-hatch, the movable end being fitted to slide on a guide at the top of the turret abreast the muzzle of the gun. The shell-tackle is hung on the rod by its strap, which carries a roller travelling on the rod. When the gun is to be loaded, the shell is whipped up to the requisite height, the whip hitched, and the projectile run to the muzzle of the gun on the rod. After each fire, the turret is revolved so as to bring the gun abeam and leave the loading-hatches open.

962. *The Rammer and Sponge.*—The port being closed by the port-stopper, S, an ordinary handle cannot be used, hence that in use consists of a number of sections which connect with each other by a spring catch. The rammer or sponge, being fixed to the first section, is entered and the next section put on; in this way the whole is made up and the gun sponged or the projectile pushed home. In removing the sponge or rammer, each section is taken off as its catch comes to the muzzle.

963. *Pointing.*—The guns being fixed in the turret, point-

ing is effected by revolving it until the guns bear upon the object, which is determined by the person at the sight-hole, Y.

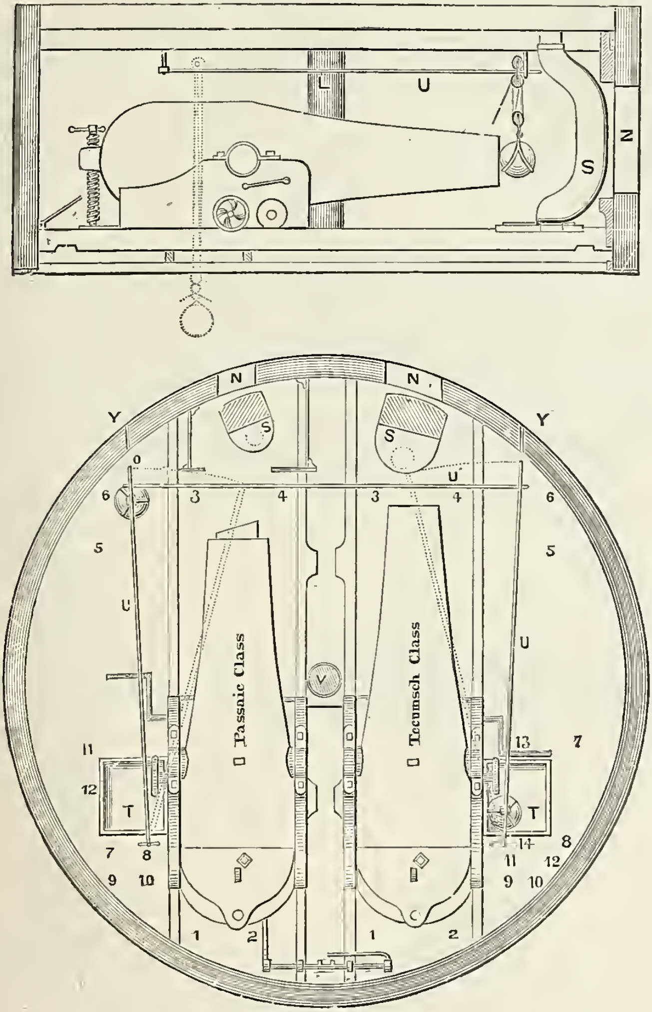


FIG. 226.

This consists of a circular opening of about two and a half or three inches diameter cut through the turret, parallel to the rails on which the carriage runs. In this opening is placed an instrument (Fig. 227), consisting of a hollow cylinder of brass,

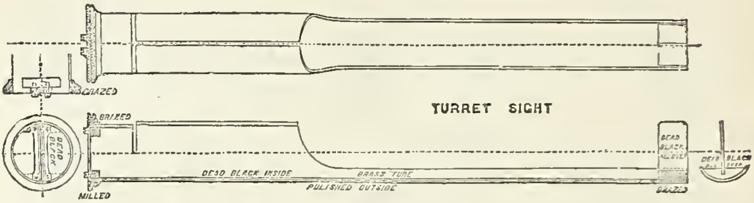


FIG. 227.

having a portion of its circumference at the outer end cut away, and a vertical piece soldered to it. The inner end of the cylinder is closed, and a vertical slit cut in it. The officer at the sight-hole, looking through the slit, brings the vertical piece on the object, when the engineer at the starting-bar ceases to revolve the turret.

964. *Sights.*—The gun besides being fitted with the ordinary sight has a trunnion-ledge and level (Fig. 228). This con-

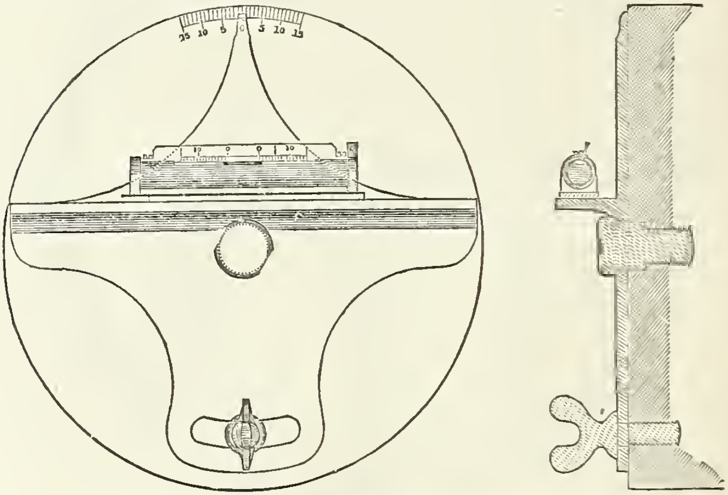


FIG. 228.—Trunnion-ledge and Level for XV-inch Gun.

sists of a brass plate pivoted to the centre of the trunnion, the upper portion ending in a pointer, the lower having a slot and thumb-screw working in it. A ledge projects from the plate, on which is placed a spirit-level. The upper face of the trunnion is graduated for a certain number of degrees of elevation and depression.

To elevate the gun, loose the thumb-screw and move the pointer to the number of degrees desired; tighten the screw and lower the breech until the bubble of the spirit-level marks zero. The gun then has the elevation indicated by the pointer; reversing the operation, depression is obtained.

965. *The Turret* when not in use rests upon the deck, a raised rim of metal protecting its lower edge from being jammed by shot. A shaft, L, passes down through the vessel to the kelson, with arrangements at its lower end for being raised by a wedge and ram. When this is done the turret is raised from the deck and rests on the shaft, and is revolved by steam gearing. The turret is composed of a number of one-inch wrought-iron plates, firmly bolted together, making a total thickness from eleven to thirteen inches. The people in the turret are protected from the fastening bolts, which are likely to fly out on the impact of heavy shot, by a casing of iron placed a few inches from the inner circumference of the turret.

966. Above the turret is placed an iron pilot-house, from which those controlling the movements of the vessel may see by the bevelled openings in its circumference. In some monitors the guns and their carriages have been arranged to work by steam, and the turret to be raised by an hydraulic-pump attached to the lower end of the shaft, instead of the wedge and rams. This would seem to be a decided improvement over the old method, or that generally in use.

967. MORTAR CARRIAGE (Fig. 229).

Nomenclature.

1.—Circle.	10.—Hurter.
2.—Bracket.	11.—Ratchet.
3.—Mortar.	12.—Clevis lug.
4.—Face.	13.—Stringers.
5.—Trunnion.	14.—Rear Transom.
6.—Carriage Steps.	15.—Heavy Cross-bolt.
7.—Eccentric Socket.	16.—Lever (eccentric).
8.—Carriage Roller.	17.—Circle-lever.
9.—Circle Eccentric.	18.—Guides.

Principal Dimensions.

Length of Carriage	9 ft.	4 inches.
Width of Carriage, Front	4 "	9 "
Width of Carriage, Rear	4 "	6 "
Height of Trunnion	3 "	2 "
Diameter of Circle	11 "	6 "

968. *The Carriage.*—In consequence of the high angles at which mortars are fired, their carriages differ from ordinary gun-

carriages in that they rest for their whole length on the circle or platform.

969. *The Brackets*, 2, are each made of two pieces of boiler-iron, separated from each other by flat bars of iron placed at suitable intervals, to stiffen the brackets in the direction in which the weight and recoil bear upon them. All parts are held together by screw-bolts. The brackets are united to each other by the steps, 6, axle-tree, 8, two iron stringers, 13, crossing

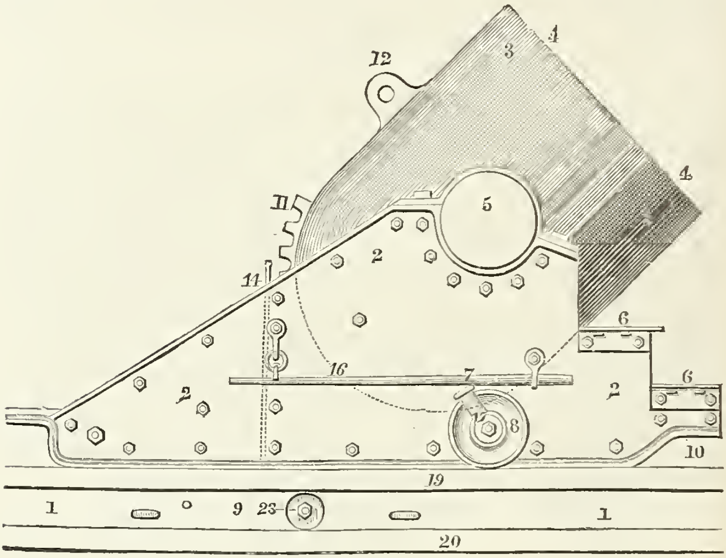


FIG. 229.

diagonally under the piece near the bottom of the brackets, a rear transom, 14, and a heavy cross-bolt, 15.

970. *The Transoms.*—The steps, 6, serve the purpose of front transoms, and are made by laying plates of boiler-iron horizontally; the lower being nearly twice the size of the upper, and bolted to the brackets. The upper is scored out in the rear to allow for the curved form of the piece. The rear transom, 14, is a plate of iron placed vertically between the brackets in rear of the piece, and is fitted with an elevating loop, which serves as a fulcrum for the elevating lever.

971. *Running In and Out.*—The motion of the carriage in running in or out is obtained by a pair of rollers, 8, on an eccentric axle, placed underneath and a little in front of the curve

of the trunnions. On the projecting end of the axle a lever, 16, ships, by which the rollers may be thrown in or out of action. The motion of translation of the carriage is given by handspikes placed in holes in the circumference of the trucks, 8; the latter being first thrown in action by the lever in the socket, 7. The movements of the carriage are directed by composition guides, 18, screwed to the circle and fitting over flanges at the bottom of the brackets. A heavy piece of oak, called the Hurter bolted to the circle, limits its outward movement, the brackets being curved to fit the slope of the hurter.

972. *The Mortar Circle*, (Fig. 230).—The naval mortar is

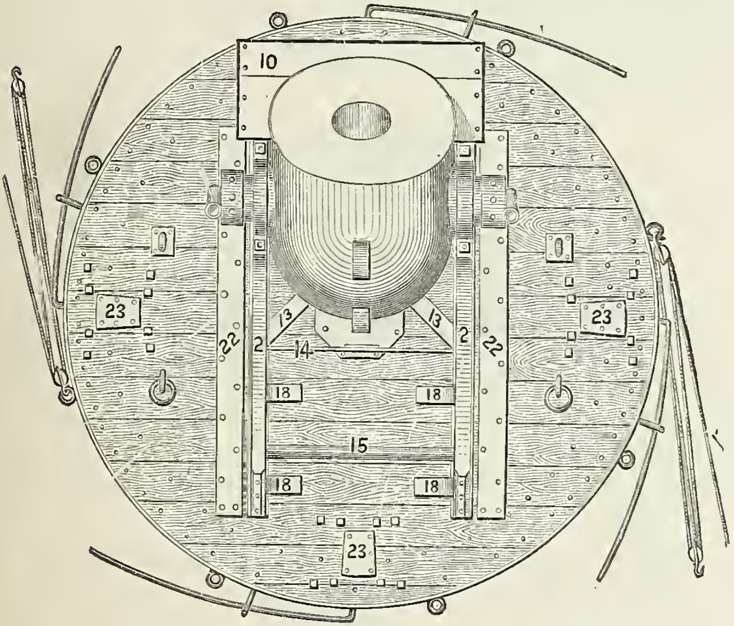


FIG. 230.

generally used on board schooners built for the purpose. It is carried amidships, and that part of the deck on which the circle rests is raised about three inches above the remainder. The circle is a circular platform made by two thicknesses of oak beams; the upper, called the deck planks, are laid at right angles to the direction of the recoil; the lower layer, called sleepers, being laid parallel to the axis of the piece. The two layers are bolted to each other horizontally and vertically, and strengthened circumferentially by two steel hoops, 19 and 20, one at the top and bottom. This disposition of the planks offers the greatest resistance to recoil. On its upper surface are bolted composition tracks, 22, for the carriage rollers. A heavy bolt through its centre, working in a frame-work beneath, keeps it in position.

973. *Eccentric Rollers* (23) are four in number, and placed at equal distances in the circumference of the circle. On the ends of the axles, curved levers (17) ship, by which the circle is raised on its rollers, and may be revolved about its central pivot by tackles hooked to eye-bolts in the circle and deck.

974. *The Deck* is strengthened underneath the circle by a column of heavy beams laid across each other, and extending from the kelson up to the under side of the deck.

975. HOWITZER BOAT-CARRIAGE. (Wood.)

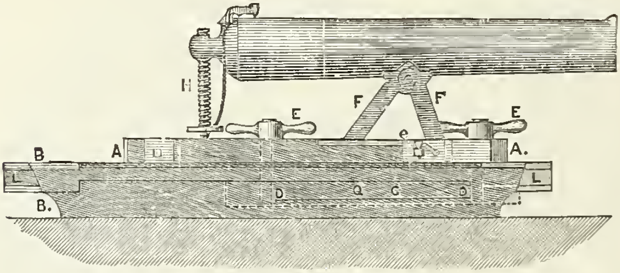


FIG. 231.

Nomenclature.

A.—Bed.
B.—Slide.
C.—Compressor Plate.
D.—Compressor Bolts.
E.—Compressor Handles.
F.—Lugs for Loop.
G.—Bed-plate.
H.—Elevating Screw.
K.—Athwart-ship Sweep
L.—Pivots.
M.—Pivot Plates.
N.—Fore and aft Sweep Piece.

976. *The Slide* consists of a wooden top-piece resting on two side pieces which are slightly inclined from the vertical and slope at each end towards the end of the top-piece, where metal plates are attached for the pivot-bolts, of the carriage. In the top-piece, and extending nearly its whole length, is a slot in which move the bolts, D, and wooden guide of the Bed-plate. The bolts, D, are square at their lower ends and pass through the bed-plates, up the slot, and through the bed, A. On their upper ends a thread is cut, and corresponding nuts

with handles, E, work on a composition plate let into the wood, flush with it. On this the nuts press when screwed down, compressing the slide, B, between the bed, A, and bed-plate, G, and controlling the recoil by the friction of the different parts.

977. *The Compressor* is composed of the several parts C, D, E, G, and A; that is, it consists of a combination of all, resulting in friction between certain parts and modification of the recoil. When the compressor handles are set as taut as the strength of an ordinary man will allow, it always suffices to keep the recoil within the limits of the stop in the slide. In order that the compressors shall invariably perform their function, the surface of the parts in contact must be plain but not smooth.

The Bolts, D, being passed through the bed-plate loosely, were the handles taken off, they would drop out; to prevent this, small buttons are placed on the under side of the bed-plate, G.

The Lugs, F, are cast of composition with a cavity to receive the loop of the gun, which rests in it, and is retained there by a bolt passing through the lug and loop; the latter being secured by a pin and washer.

978. *Elevation* is obtained by a screw, H, passing through the cascabel of the gun; its lower end has a knob working in a box fitted to the bed; a disk a few inches above the knob serves to turn the screw.

979. *The Boat-carriage* should be so placed in the bow of the boat as to carry the muzzle of the Howitzer just above and clear of the gunwale and stem of the boat. Two pieces of yellow pine, K, are laid athwart-ships so as to bear the carriage at that height, and on these it traverses when pivoted at the stem.

980. *Pivots.*—Six pivots, are pivoted to each boat; stem, each bow, stern, and each quarter. The two iron plates, M, of each pivot, being welded together and bolted to their positions, the distances between the stem pivot-plate, and that of either bow, must correspond to the distances between the pivot-holes in each end of the slide; they are thus at the points of an equilateral triangle, which enables a rapid and certain management of the gun in changing its position. (Fig. 232.)

981. *Pivoting.*—If the carriage be pivoted at the stem, it may be brought to either bow, by pivoting the rear end of the slide to one bow, removing the stem pivot, and training the forward end to the opposite bow; to change it from the bow to

the stem pivot, the process is reversed. To sustain the carriage when pivoted at the bow in sweeping, a piece of yellow pine scantling, N, is placed fore and aft amidships and mortised into the rear cross-pieces.

The stern of the boat is similarly arranged, but from the form of the boat at that part there is more space, and the gun can always be worked easier there than forward.

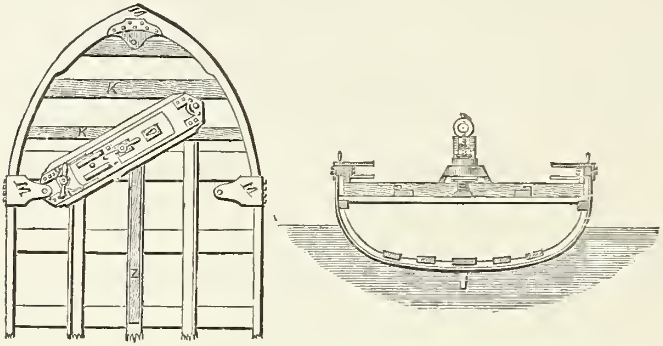


FIG. 232.

982. THE IRON BOAT-CARRIAGE.—(Fig. 233.)

Wrought-iron Boat-carriages are now being made and supplied to vessels in service, the dimensions being the same as those of the wooden carriage, in order that they may replace them and not entail any change in the present fittings of boats.

983. *Nomenclature.*

A.—Slide
B.—Bed.
C.—Bed-plate.
D.—Lugs for Loop.
E.—Elevator Box.
F.—Compressors.
G.—Rests of Slide.

Principal Dimensions.

Extreme length	68½	inches.
Length between Pivots	64.1	"
Length of Bed	37	"
Length of Bed-plate	26.3	"
Width of Bed	7.75	"
Extreme width of Slide	11.75	"
Height of Loop-bolt	13.05	"

984. *The Slide*, A, consists of a wrought-iron plate, riveted to two wrought-iron Z-shaped sides, the heads of the rivets

being taken off to present a plain surface to the bed, B. The upper plate of the slide contains a slot extending nearly its whole length. Between the ends of the slot and slide are holes for the front and rear pivot bolts.

985. *The Bed Plate.*—Between the side pieces, a composition bed-plate, C, travels forward and back; to this plate are attached bolts, having a thread cut on their upper ends; these pass through the slot in the slide and holes in the bed, and

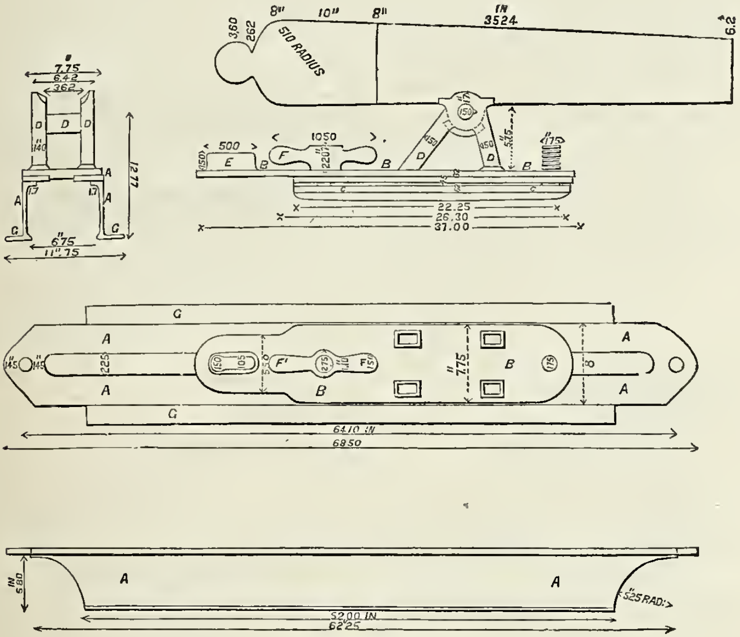


FIG. 233.

have working on them corresponding nuts with handles by which the necessary compression of the slide between the bed and bed-plate is produced, thus modifying the recoil.

986. *The Bed*, B, which rests on the slide, A, is a bronze casting, consisting of a plate having on its upper surface projecting pieces, D, called *the lugs*, which have a cavity in them for the loop of the gun; the elevator box, E, and holes for the compressor-screws.

987. *Recoil.*—As the slide is of wrought-iron, while the bed

and bed-plate are of bronze, advantage is taken of the friction exerted between the different metals to check recoil. This is accomplished more effectually by having the frictional surfaces of different kinds of metal, than when only one kind is employed.

988. *The Sides* curve upward at each end to allow space between the carriage and pivot-plate, and to facilitate its movements.

By reference to the rear elevation of the carriage (Fig 233), the manner of riveting the top plate to the Z-shaped sides will be readily understood, and that the slide rests on the lower portions of its sides, which, being 2½ inches wide, give abundant stability to the carriage in training.

Three tie-bolts, not shown in the figure, placed at the front, rear, and centre of the slide, connect the sides and prevent lateral motion. As these are placed low down, they do not interfere with the movements of the bed-plate, C.

These carriages are considerably lighter than the wooden carriages; and being of iron, are consequently less liable to injury from exposure in service.

989. THE HOWITZER FIELD-CARRIAGE. (Fig 234.)

Nomenclature.

B.—Trail.	E.—Trail-wheel.
C.—Trail-braces.	F.—Socket.
D.—Lugs.	G.—Elevator.
H.—Elevator-box.	K.—Ammunition boxes.

990. *The Carriage* is of wrought-iron, its weight being reduced to the least limit, about 500 lbs.; the axle, has cast at its centre lugs to receive the loop of the gun.

991. *The Trail*, B, is curved, being bolted to the axle, and supported on either side by the rod braces, C, which bolt to the trail and axle. At its rear end the trail expands, and is slotted for the trail-wheel, E. This is hung on a hollow axle, to which is attached on each side a guide that is hinged at the forward part of the seat; this allows the trail-wheel to be thrown back on the trail and put out of action. A pin chained to the trail passes through it and the hollow axle. With the wheel in the slot and confined by the pin, the trail of the carriage rests on it, as in Fig. 234. Beyond the slot is a socket for the trail handspike. The elevator-box is like that in the boat-carriage.

992. *The Field Carriage ashore.*—As it is designed to operate independently of a limber, light composition frames, having pins projecting upward, are attached to the trail and axle on

each side, on which the ammunition boxes rest. Their bottoms are fitted with metal sockets for the projecting pins of the frames. The carriage is drawn by means of a drag-rope hooked to a becket near the sockets; this rope has inserted at suitable intervals wooden handles for the crew to hold. At the hook are two shorter ropes, called guide ropes, by which the direction of the trail is governed when on the march. To the axle is hooked a short drag-rope, which is used as a check, or holding-back rope in steep descents.

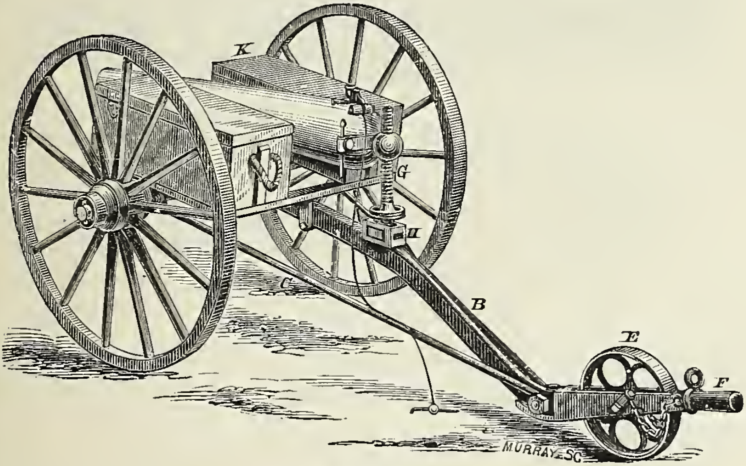


FIG. 234.

When in action, the trail-pin is removed, and the trail-wheel thrown back on the trail, allowing the trail to rest upon the ground, which serves to check the recoil.

993. *The Field Carriage in the Boat* is placed aft with its trail over the quarter (Fig. 235), so as not to impede the movements of the coxswain. For convenience in running it forward or aft, as when shifting the gun from the boat to the field-carriage, or the reverse, three wooden tracks or skids are laid fore and aft on the thwarts, and bolted. The centre being for the trail, the other two for the carriage-wheels.

994. *For Landing the Field Carriage,* short skids projecting ahead to the beach or landing are provided; these hook to the bows of the boat, and are braced at the shore end by a long iron rod and hook; on these the carriage-wheels run.

995. *Implements.*—With the field and boat carriage are supplied Rammer, Sponge, Ladle, Worm, and Handspike; two of

those mentioned being on the same handle, one at each end. The latter answering a double purpose, first as a trail hand-spike, and second as a shifting-spar; having fitted to its centre

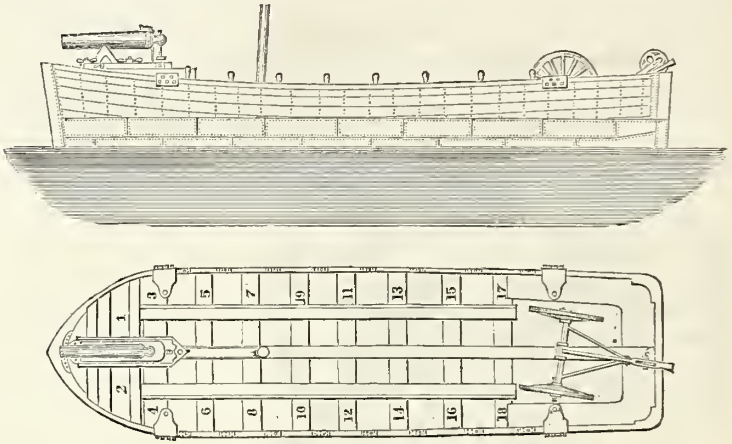


Fig. 235.—Frigate's Launch.

a metal hook used in the gromet around the neck of the cascabel in shifting, mounting, and dismounting the Howitzer.

Section II.—English Naval Gun-Carriages.

996. The Broadside Scott Carriage.

Nomenclature.

A.—Bracket.
B.—Bow Compressor.
C.—Elevating Gear.
c.—Releasing Lever of Elevating Gear.
D.—Chain Nipper of In-and-Out Gear.
E.—Carriage Wedges of Bow Compressor.
b.—Eccentric Lever and Gear.
F.F.—Coned and Grooved Rollers.
G.—Metal Hook for lip of Front Track.
H.H.H.′—Raised Metal Tracks.
K.—Cogged Training Track.
L.—Preventer Pivot Bar.
M.—Slide Wedges of Bow Compressor.
N.—In-and-out Gear.
O.—Endless Chain.
P.P.—Winches of Training Gear.
R—Shaft of Training Gear.
S.—Training Wheel.
S′.—Cog-track.
T.—Shaft Support.
W.—Training Brake.
X.—Hydraulic Jack.
Y.—Compressor Pawl.
Z.—Buffer Blocks.

997. *The Carriage* is of the box girder description, of mixed wrought and cast iron (wrought outside, and cast inside),

and, unlike the old pattern, is long and low, thus remedying the rearing back tendency of short and high carriages, and the consequent downward strain on the deck and slide, and giving a

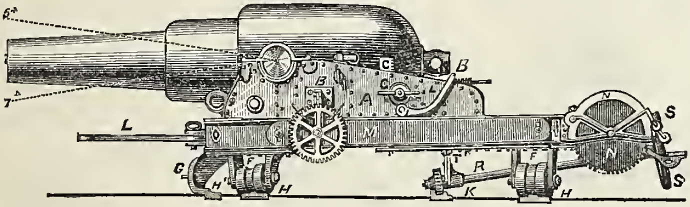


FIG. 236.

much greater surface to absorb the concussion or shock of recoil. As the carriage is made so much lower, the slide is correspondingly raised, thus maintaining the same height of the axis of the trunnion above the deck, and allowing room for the cogged gear beneath the slide.

998. *The Slide* is of girder wrought-iron, filled in on each side with teak (see Fig. 239), with no head-plate, thus allowing the gun to be run farther out and facilitating pointing. The upper surface of the slide is an inclined plane, having an angle of from 3° to 5° for ordinary broadside guns, which serves to check the recoil, and facilitates the running out of the gun.

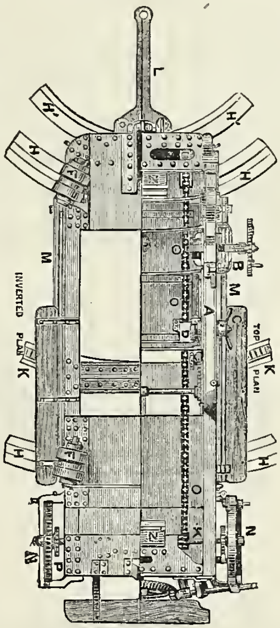


FIG. 237.

999. *The Deck* (Fig. 237) beneath the slide has bolted to it four (4) metal tracks, H, H, H′, and K; the first two, H, are usually solid, and have cast on their upper surface a rib to take the groove of the slide-rollers F. These tracks are raised at their extremities, to allow for the deck curvature, and thus prevent alteration of the sights in extreme training. The track, K, is cogged for the cog-training wheel, and may be of brass or iron, usually the former. The track H′ is of metal, having cast on its forward side a strong projecting lip, under which the metal hook, G, attached to the slide, takes.

1000. *The Pivot* (Fig. 238) is independent of the ship's side and any accident that might occur to it, as the recoil is received from the coned and grooved rollers, F, of the slide,

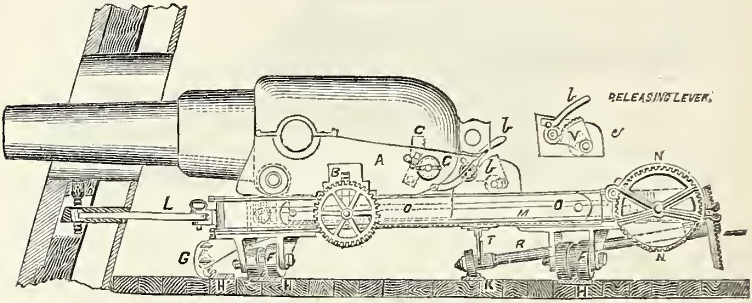


Fig. 238.

and the metal hook, G, by the three metal tracks, H. Were the shock received by a pivot at the side, a heavy shot impinging there might and probably would prevent the further service of the gun.

1001. *The Dimensions* of a 12-inch 25-ton Broadside Gun-carriage are as follows: Length of slide, 15 ft. 6 in.; width, 6 ft.; length of carriage, 8 ft. 9 in.; height of trunnion above the deck, 5 ft. $1\frac{1}{2}$ in., the relative length of slide and carriage permitting a recoil of 6 feet.

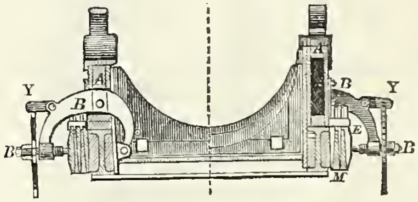


Fig. 239.—Section at Compressor.

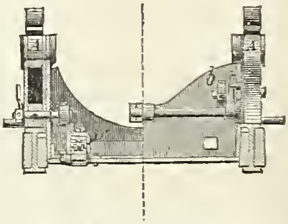


Fig. 240.—Rear view of Carriage.

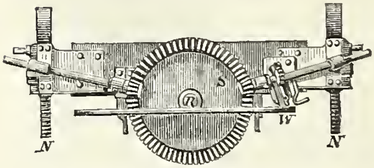


Fig. 241.—Rear view of Slide.

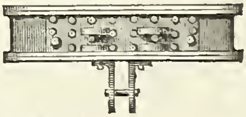


Fig. 242.—Front view of Slide.

For other guns the dimensions are similarly proportioned.

1002. *The Self-Acting Bow Compressor*, B, consists of strong metal bows hung by their centres through a hole in each side bracket. (See Fig. 246, B.) From the carriage short wedge-shaped plates, E, are suspended between hard wooden *baulks*, and wedge-shaped iron plates fixed to the girders of the slide M. A wheel with screw attached works through the outer end of the metal bow, setting the plates firmly together (Fig. 239). The circumference of the wheel is notched to receive a *pawl*, Y, attached to the bow at the height of the wheel. The weight of the gun, when let down from its eccentric rollers, drives the upper wedge, E, tight between the lower ones, M, and the downward concussion of firing tends to drive them still more together, while the action of lifting the gun-carriage on its eccentric rollers, to run it out, releases the wedges because of their shape.

1003. *The Elevating Gear*, C (Fig. 238), consists of a cogged arc attached to the side of the breech of the gun, acted on by a cog-wheel inside, and drum outside the bracket, and fixed to the same pinion. Through it, sockets are pierced in the periphery of the drum, into which pointed handspikes are placed in elevating or depressing the gun—a clamp outside the drum nipping it at the desired elevation; a holding-pin attached to the bracket assists the clamp.

1004. *The Eccentric Gear*, *b* (Fig. 238), consists of a shaft across the rear end of the carriage, carrying the eccentric rollers, placed in the under and rear side of the brackets. A cog-wheel on the inside, worked by levers on the outside, acts on a V-shaped cog when on the eccentric axle, throwing the eccentric rollers in and out of action. A pawl, or releasing lever (Fig. 238), is provided for holding the eccentric in action. The latest carriages have their eccentric rollers worked by an hydraulic jack, X, on one side, and cog-wheels and drum on the other (Fig. 243); with the jack the heaviest gun may be easily lifted by one man.

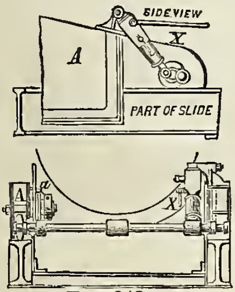


FIG. 243.

1005. *The In-and-Out Gear* (N, Fig. 237).—The carriage, being lifted out on its rear eccentrics as before described, is run in and out by means of spur wheels and pinions fixed to the rear end of the slide on each side, worked by winch-handles, which drive a shaft across the rear end of the slide. Two endless chains, O, run around *spocket-wheels* fitted to this shaft, and the forward end of the slide (that forward having an elastic shackle) by which the chain is kept taut at all times, the upper part of the chain passing through holes in the carriage. When not in use, the chains are not attached to the

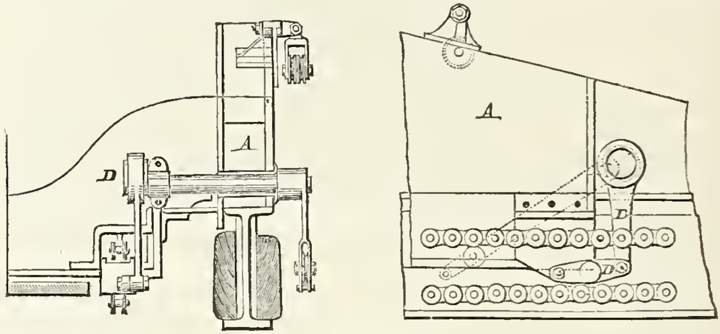
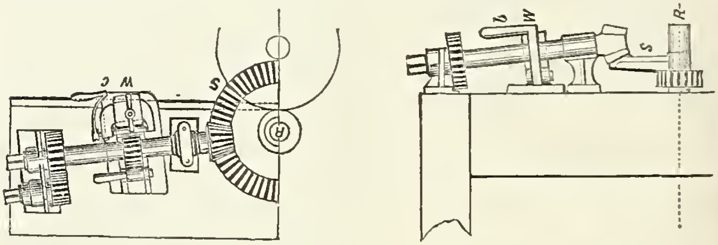


FIG. 244.

carriage; but when required, the upper part of each chain, O, is caught by an arrangement called *the chain-nipper*. (See Fig. 244, D.) This consists of an eccentric in the bottom of the carriage, worked by a lever, by which the eccentric catches the chain in the teeth fitted to the upper side of the box in the bottom of the carriage, and through which the chain passes. When the In-and-Out Gear is moved with the chain caught, it carries the carriage with it, either in or out. By throwing the lever up, the chain is released, and the carriage ceases to move.

Buffer Blocks, Z (Fig. 237), of india rubber are placed at each end of the slide to receive the carriage should it move out



Plan. FIG. 245. Elevation.

or in violently. Eye-bolts are fitted to the carriage, to be used with tackles should occasion require it.

1006. *The Training Gear*, R, S, T, W, (Figs. 238, 241, 245), consists of a crown-wheel and bevel pinions, fixed to the rear end of the slide, worked by winch-handles, which drive a shaft, R, extending forward beneath the slide, and armed at its forward end with a cog-wheel, working in the cogged track, K, on the deck.

For Extreme Train, when the vessel is rolling deep, or at any time that additional power is required, a second driving-pinion is provided, giving twice and a half the power of the single pinion; a pawl, to lock the training-gear, when the gun is stationary, and a brake, W, to control the rapidity of training. The latter consists of a diminutive bow compressor applied to the training-gear, near the winch-handle (Fig. 245, W). Eye-bolts for training are fitted to the slide to be used with tackles.

1007. ADVANTAGES OF MECHANICAL CARRIAGES.—*The shock of recoil* is received by metal ribs cast on the upper surface of the heavy solid metal tracks, H, and by a strong metal hook, G, attached to the front end of the slide, which ties it down to the deck by the hook, taking under the strong metal lip of the front track, H′. By this means the shock of recoil is not received at any single point, but is distributed over the surface of the three tracks, and thence to the deck, and thus the tearing or rending effect is much less at any one of these points than it would be on a single pivot-bolt. Again, the compressor wedges, E and M, are not only wedge-shaped vertically, but are slightly so longitudinally, by which arrangement the recoil is gradually checked or absorbed, instead of being suddenly resisted as with ordinary compressors.

1008. *The Bow Compressor*, B, is self acting, from its peculiar construction. The compressor-plates being wedge-shaped both vertically and horizontally, lifting the carriage must necessarily ease them; lowering the carriage, the reverse occurs. Therefore the wheel being set to a point (determined by practice) and pawled, the mere running out of the gun, in one case, and firing in the other, operates the compressor. So that the compression by the wheel having once been determined, the gun may be fired a long time without the compression being altered.

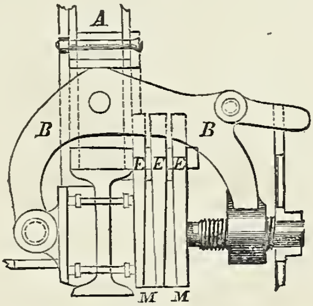


FIG. 246.

Experiments prove that one man may set the wheel so taut as to reduce the recoil to 3 feet, one half that allowed by the slide. By this arrangement the danger occurring with most compressors, viz., that the compressor-man will set the compressor too taut or not enough, is entirely obviated; and any compressor not self-acting is liable to be worked so, and the gun and carriage seriously injured thereby.

1009 *Training Gear.*—As this gear is attached to the rear end of the slide, it is much less exposed to an enemy's shot than at the ship's side, or in any other position about the slide. And at night, or when smoke and noise would hinder the men at the side of a gun worked by tackles from seeing or hearing their gun-captain, the captain of a gun, fitted with mechanical training gear, regulates the movements of the slide with the greatest ease, as the motive power, viz., the men at the winch-handles, are within a few feet of him. Again this position of the motive power enables him to train and keep his gun on the object as it is being run out, and save much valuable time, especially in firing at a moving object. In practice the controlling brake, W, has answered its purpose very well, and the training gear greatly increases the rate of firing under any conditions, its advantages being best shown in bad weather. With it and the in-and-out gear, much manual labor is saved, the crew being reduced thereby to one-third. In training guns by tackles and handspikes, the motion is very irregular, the guns being many times jumped beyond the desired point, while with the Mechanical Gear the greatest nicety is obtained.

1010. *High and Low Carriages.*—The effect of reducing the height and increasing the length of carriages may be illustrated by assuming an extreme case. Imagine a very high and short carriage on one slide, and a very long and low carriage on another. The gun being fired horizontally, the shock of recoil in the first instance will be communicated by a lever, represented by the vertical height and length of the carriage, and the leverage being great, the shock will be more powerful, while with the long, low carriages the leverage is much reduced, and consequently the shock on the slide, and a longer surface is provided for absorbing the recoil. Hence the same decks will sustain the firing of heavier guns by the use of long, low carriages and high slides, preserving the axis of the gun at the same height above the deck.

1011. The Depression Carriages (Fig. 247).—These were designed by Capt. Scott, R. N., for the smaller upper guns of Broadside vessels, as an auxiliary defence against Torpedo or attacking boats very near or alongside the vessel, as at such times the main-deck guns do not possess sufficient depression to protect her against them. Referring to Fig. 247, the slide, A, is of iron and has an inclination of 10° to the front. To the slide is at-

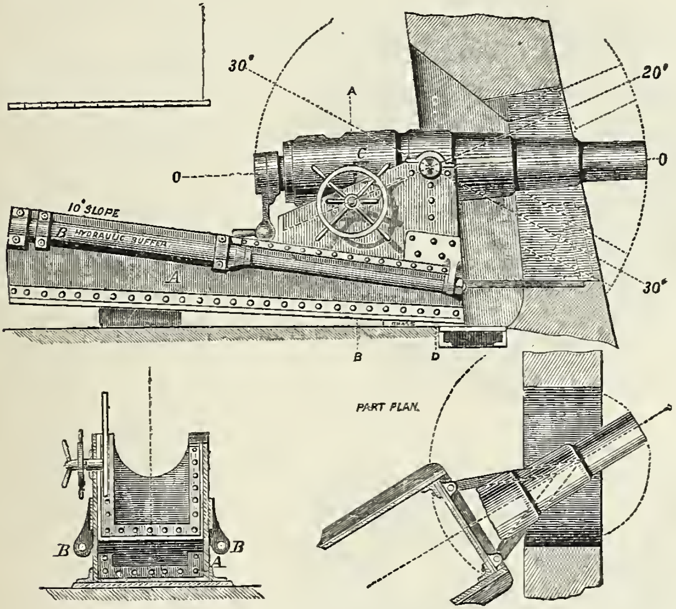


FIG. 247.

tached the cylinder of an hydraulic compressor, B, the piston being fixed to the front end of the carriage, which is of iron; an elevating arc, C, attached to the gun and worked by a pinion and wheel instead of the drum and handspikes in use with heavy guns, permits of 20° elevation and 30° depression. A clamp fitted to the axle fixes the gun as desired. Thus with the ship on an even keel, projectiles may be thrown 100 ft. high, at 100 yards' distance, or into a boat as near as 13 yards from the ship's side. The great amount of depression obtained makes them a very useful addition to Broadside Iron-clad armament, as with the utmost depression obtainable with the Broadside carriages, the shot would fall over twice as far from the ship's side. Without these depression carriages, there would be left around the vessel a free zone of fire of considerable size, in which attacking boats might lie with perfect immunity from the vessel's heavy guns.

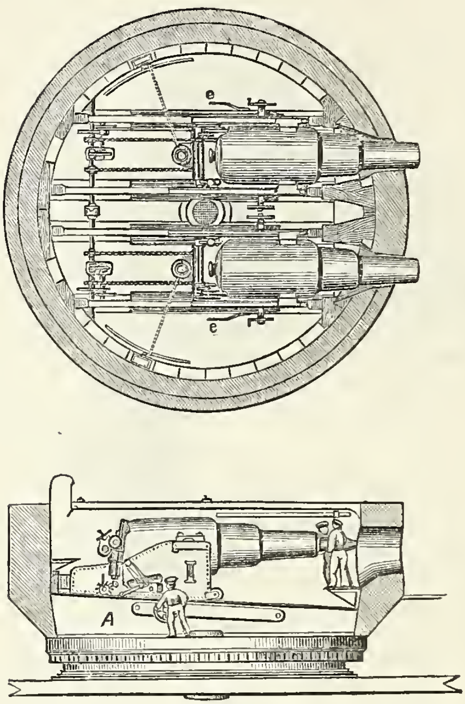


Fig. 248.

1012. The English Turret Carriage. (Figs. 248, 249.)

The Slide consists of four wrought-iron girder beams, A, built into the Turret below the deck (see Fig. 248), constituting strengthening struts, and forming a part of the ship. These fixed girders have an inclination of about 3°, and form slides on which are mounted two compound pivoting gun-carriages, the training being effected by the revolution of the Turret itself.

The only point of principle in which the Turret differ from the Broadside carriages, is in their possessing compound vertical pivoting gear, to minimize the vertical area of the port. To accomplish this, the carriage and slide with the gun were lifted bodily to set heights by means of screws working irregularly, involving considerable loss of time. It is now obtained by lifting the gun only. This is effected by supporting the gun in wrought-iron blocks, susceptible of vertical motion in the brackets. These blocks are united beneath the gun by a curved transom acted on beneath its centre by the ram of an hydraulic jack attached to the bottom plate of the carriage, which raises the gun bodily about 6 inches per minute. Iron props of different lengths are used to support the trunnion-blocks in the different positions in which it is intended to fire.

1013. *Elevation.*—On each step the elevation and depression is regulated by elevating gear, differing from the Broadside gear, in that it is adapted to use with the axis of the gun at the three different heights; a single man at the cascabel of the gun works the pinion and spur-wheel, which raise or lower the gun along the cogged arc, or elevating-bar. The steps are so arranged that the upper gives no elevation and 7° depression, the bottom step 15° elevation and no depression; the middle or ordinary fighting step gives 9° elevation and 2° depression. This division of step may be changed at any time, by substituting iron props of other heights.

1014. *The Carriages* are adapted to the circular form of the turret by lengthening the minor bracket of each, and both are so reduced in front as to leave considerable space between them and the turret, thus rendering them, like the broadside carriage, independent of concussions or indentations of the armor.

1015. *Recoil.*—The shock of recoil on the trunnion-blocks is distributed over large bracket surfaces by the wrought-iron guides in which they move. That from the carriage is conveyed to the girders by the long brackets of the carriage, whose inner plate of cast-iron resting on the girders form excellent frictional surfaces.

1016. *The Turret* has a spindle at its bottom extending downward a short distance into a strong framework built for it; the lower edge of the turret rests on coned rollers, connected by rods with a flange or collar on the spindle. The whole being protected by a shield (Fig. 248). It is revolved by machinery worked by steam or by hand power; usually both are provided. If worked by hand, the handles by which the power is applied are placed on the deck below, outside the turret, requiring with eighteen men about eighty seconds to perform one-half revolution; with steam, eighteen seconds.

1017. *The In-and-Out Gear* consists of a shaft carrying two endless chains, connected and detached from the carriage in the same way as with the Broadside carriage. The shaft extends through the iron girders and the sides of the turret, to which handles are fixed to be worked by the men outside. It is arranged in halves and connected by a coupling, so that each gun may or may not be worked separately. As nearly twice the power is required to run in and out a Turret gun as a Broadside, the gearing is arranged to multiply the manual labor to the desired extent, with the Turret one hundred and fifty times and Broadside ninety.

Elastic Buffers are placed at each end of the girders or slide, to check the gun should it go in or out violently.

1018. *Pointing* is effected by sights on top of the turret, on which allowance is made for the height above the gun. Inaccuracies in the parallelism of the sights and axis of the gun are so far compensated for by the greater distance between the front

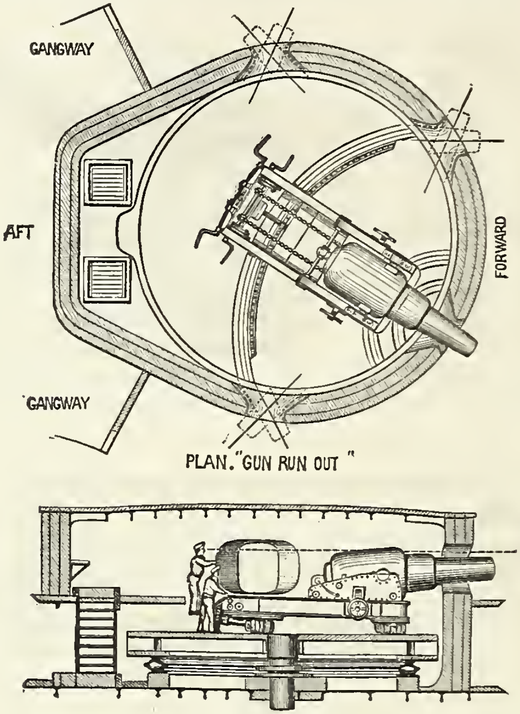


Fig. 249.

and rear sight (Turret), that with rolling motion, better shooting is sometimes made than with the short radius sights on the gun itself. By reference to the figure, it will be seen that the same compressor and in-and-out gear are used with both Turret and Broadside carriages. When the Turret is fixed and the gun movable, the latter rests on a turn-table worked by steam, which brings the gun to the port, the training being effected by the mechanical gear.

1019. The Turret Indicator.—With Turret guns, extreme depression can only be given when aiming directly abeam, and as the gun is pointed forward or abaft the beam, a corresponding reduction of the extreme beam depression occurs. There is also great liability of firing through the decks or shooting away rigging, etc. To obviate this danger and enable the person pointing the gun, either on top or in the turret, to point the gun at night or in the day-time, clear of the deck and all obstruc-

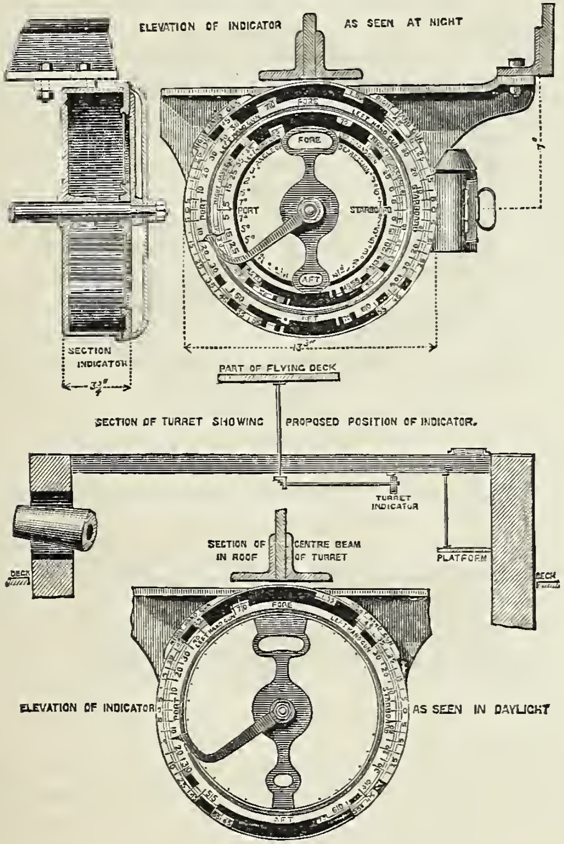


FIG. 250.

tions, an instrument has been devised called the Turret Indicator, (Fig. 250), fixed either on the turret or in it. By which is seen at a glance, by day or night, the angle of depression at which both or either of the guns can be fired at every bearing, clear of the deck and all obstructions.

1020. Referring to Fig. 250, it will be seen that the indicator consists of a hollow disk, with a rod through its centre carrying a pointer; it is graduated near its outer circumference to indicate the arc of train that the gun makes with the beam. The number of degrees marked on the inner circle, as seen by daylight, indicate the amount of safe depression which may be given at that arc of train, the gun right or left being marked on the disk; also the fore and aft and beam points, the black spaces indicating the obstructions to fire.

1021. *For use at night*, the clear space of the disk as seen by daylight is illuminated, by which, although it appears blank by day, at night it shows the same graduated arc of train and corresponding amount of depression as the outer disk, the fore and aft points being indicated by illuminated letters seen through the open space in the upright piece. By machinery or hand power the pointer is made to follow the movements of the Turret, recording the arc of train and corresponding depression.

1022. THE MONCRIEFF SYSTEM OF GUN-CARRIAGE.—The principle on which this carriage is constructed may be shortly stated as that of utilizing the force of the recoil in order to lower the whole gun, so that it can be loaded out of sight and out of exposure, while retaining enough of that force to bring the gun up again into the firing position.

This principle belongs to all the carriages; but the forms of these carriages, as well as the method in which this principle is applied, vary in each case. For instance, in siege guns, where weight is an element of importance, the recoil is not met by counterpoise. With heavy garrison guns, on the other hand, which when once mounted remain permanent in their positions, there is no objection to weight. In that case, therefore, the force of gravity is used to stop the recoil, because it is a force always the same, easily managed, and not likely to go wrong.

The great difficulty arising from the enormous destructive force of the recoil of heavy guns is here overcome.

1023. That part of the carriage, E (Fig. 251), which is called the elevator, may be spoken of and treated as a lever; this lever has the gun-carriage axle at the end of the power-arm, and the centre of gravity of the counter-weight, C, at the end of the weight-arm, there being between them a moving fulcrum.

When the gun, G, is in the firing position, the fulcrum on which this lever rests is almost coincident with the centre of gravity of the counter-weight, C, and when the gun is fired the elevators roll on the platform and consequently the fulcrum, or point of support, travels away from the end of the weight-arm towards the end of the power-arm, or in other words, it passes from the counter-weight, C, towards the gun, G.

When the gun is fired, its axle passes backwards on the upper or flat part of a cycloid. It is free to recoil, and no strain is put upon any part of the structure, because the counter-weight commences its motions at a very low velocity. As the

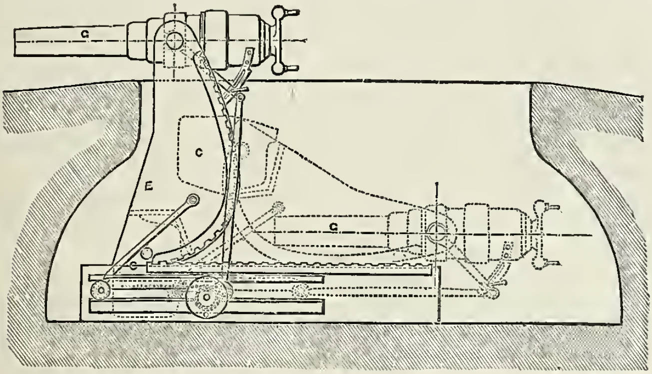


Fig. 251.

recoil goes on, however, the case changes completely, for the moving fulcrum travels towards the gun, making the weight-arm longer and longer every inch it travels. Thus the resistance to the recoil, least at first, goes on in an increasing progression as the gun descends, and at the end of the recoil it is seized by a self-acting pawl, or clutch.

The recoil takes place without any jar, without any sudden strain, and its force is retained under control by the men at the gun, to bring it to the firing position at any moment they may choose to release it. The recoil, moreover, however violent at first, does not put injurious horizontal strain on the platform.

1024. Hydraulic Appliances.—The hydraulic system of

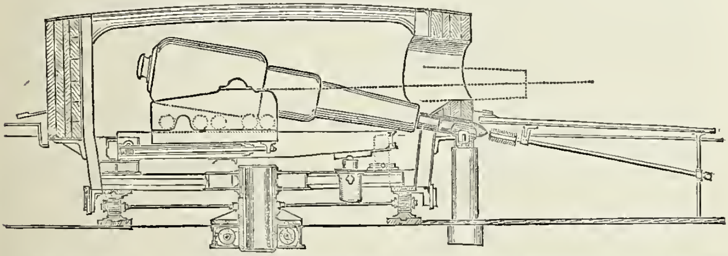


Fig. 252.—Turret with two 38-ton guns, showing loading from below under port, and hydraulic buffer.

loading and working guns as applied to the turret of the *Thunderer*, is illustrated by Fig. 252.

The principal mechanism of a gun-carriage mounted on a slide is that for absorbing and regulating the force of recoil, and for moving the gun from loading to firing position, or back. In the usual English type of carriage the former office is performed by a peculiar and very powerful brake, known as the compressor, and the latter usually by winch-gear, giving motion to an endless chain so placed beneath the carriage that it may be seized at any point by a clutch on the carriage.

1025. In the hydraulic arrangement all this mechanism is replaced by the press or cylinder seen in the figure; this press acts both to check recoil and to give motion to the gun-carriage on the slide. It is fixed on the slide in the line of recoil, with its piston-rod permanently attached to the carriage.

1026. *Running In or Out.*—To run the carriage in or out it is only necessary to admit to one side or other of the piston the water delivered from the steam-pumps. When the gun recoils the water is driven out of the press through a loaded and partly balanced valve, the resistance of which to its passage arrests the recoil, and can be adjusted at a moment's notice, so as to regulate the extent of recoil under different conditions. In its office of checking recoil it is self-acting, and always ready for use without any preparation. Whatever the weight of the gun, no men are required for running in or out beyond the one whose duty it is to open and close the valves which allow the water-pressure to act.

1027. The gun is made partial muzzle-pivoting by hinging the slide horizontally at the rear, the front end being free to be raised or lowered upon suitable chocks from the floor of the turret, at the different heights required to give the desired range of elevation to the gun in the port.

1028. *Loading.*—The loading is effected by turning the turret so as to bring the muzzle of the gun opposite either one of two distinct sets of loading-gear placed on the main deck, and locking it in this position by a catch. The gun is at the same time depressed, so that the charge may be raised to the muzzle and pushed home in the bore at an inclination from below the upper deck.

The projectile is brought up to the loading-place on a small railway-truck controlled by a friction-plate, which clamps it to the rails whenever the truck-handle is lowered. It is then run on to a hoist which rises with it out of the main deck until arrested by stops placed so as to bring the hoist to rest when the projectile is in line with the bore of the gun. It is then pushed off the truck into the muzzle, and rammed home by an hydraulic rammer, consisting of a parallel tube in which runs a piston-rod armed with a rammer-head.

1029. *Sponging.*—The same rammer is used for pushing home the charge and also for cleaning the bore after each round. For this purpose the head of the rammer is formed like an ordinary sponge, and it contains a self-acting valve, which opens when pushed against the end of the bore, so as to discharge a strong jet of water within the gun. In loading, this valve does not act, because it does not then come in contact, owing to the peculiar form of the rammer-head.

The same form of rammer has been made telescopic to reduce its length. A wad pushed home with the projectile prevents it from running forward when the rammer is withdrawn.

1030. *Advantages.*—The advantages claimed for this method are:

1. The loading operation is transferred from a confined space and exposed position in the port, to a roomy and convenient place on the main deck, where the apparatus is completely protected.

2. The dimensions, and consequently the weight, of the turret required to protect any given gun are greatly reduced, because the minimum diameter that will take in the length of the gun is all that is necessary, without additional space for loading.

3. Instead of a large gun's crew, one man in the turret and one outside may direct and control all the movements of the heaviest gun, and may load and fire it without other help than that involved in bringing up the ammunition; and, finally, far greater rapidity of fire is obtained than would be possible by manual power.

The loading positions are duplicated, to give a reserve in case of accident, or to enable that one to be selected which may best keep the turret-port out of the line of the enemy's fire. In the event of accident to the hydraulic loading-gear, the gun may be loaded from below by hand.

The carriages are arranged so that recourse may be had to hand-power for working the guns, should any accident to, or failure of, the hydraulic system occur. For this purpose the mechanical means of working by hand have been retained side by side with the hydraulic apparatus, and it has been necessary to adhere generally to the usual mode of mounting a gun. But it is thought that where this condition is not imposed, great advantages in simplicity and strength of the apparatus required, and in the safety with which exceptionally heavy guns may be worked, can be obtained by a radical change in the method of mounting the gun.

CHAPTER VIII.

EXPLOSIVE AGENTS.

*Section I.—General Consideration of Explosives.**

1031. Definitions.—An *explosion* may be considered as the result of a chemical change in the solid or liquid body, by which is suddenly, or very rapidly, produced from it a great volume of highly expanded gas.

Explosives may be defined as a class of bodies, the molecules of which are in such a state of unstable equilibrium, that a slight disturbing agency will cause chemical change among them; the effect of which change is to produce suddenly a very large volume of highly expanded gas.

1032. Explosive Effect.—*Explosive reaction* is the term applied to the chemical change which takes place in explosive bodies when their equilibrium is destroyed, while the blow or impulse given by the sudden production of the large volume of highly heated gas is termed *explosive effect.*

1033. Explosive Compounds.—An explosive compound is a single definite chemical compound, the particles of which rearrange themselves to form the gases evolved by explosion.

The more important of the explosive compounds in extensive use for various purposes are:

Fulminate of Mercury,
Fulminate of Silver,
Nitro-glycerine,
Gun-cotton.

Explosive compounds are much more sudden and violent in their action than explosive *mixtures.*

1034. Explosive Mixtures.—An explosive mixture consists of combustibles and supporters of combustion, mixed so that by their mutual action a large quantity of gas is developed. The most important explosive mixture is *gunpowder.*

1035. The combustible bodies that may be used are very numerous, but practically there are only two bodies which are used to supply the oxygen necessary for burning the combusti-

* *Extracts from Lectures of Prof. W. N. Hill, U. S. Torpedo Station.*

ble. These are *potassium nitrate* or saltpetre, and *potassium, chlorate*. Therefore all mixtures may be divided into two classes, namely: nitrate and chlorate mixtures.

Nitrate Mixtures.—The most important one under this head is that composed of saltpetre, sulphur, and charcoal (Art. 1047). In various proportions this mixture is employed for very many purposes; the action is the same in all cases, so that the explosion of gunpowder fully illustrates them all. Nitrate mixtures are not greatly susceptible to friction, concussion, or percussion. In general the explosion of these mixtures is comparatively slow.

1036. *Chlorate Mixtures.*—In general, the explosion of these mixtures is much more sudden and violent than that of nitrate mixtures, and they are also much more sensitive to percussion, concussion, and friction. Generally speaking, all chlorate mixtures are unsafe, and dangerous to handle or transport on account of their susceptibility to accidental explosion.

1037. As examples of this class may be mentioned, potassium chlorate mixed with resin, galls, gambia, tan, etc.; such as Hosley's, Oriental, Erhardt's powders, etc.; with sugar, potassium ferrocyanide, or ferricyanide; such as white or German gunpowder; with sulphur as used in explosive bullets.

1038. A *gaseous* explosive mixture is nearly as sudden in its action as an explosive compound, for it contains particles in a state of perfect mixture, each gas acting as a vacuum to the others. This is not the case with *solid* explosive mixtures; therefore these latter are less sudden and violent in their action than either gaseous mixtures or explosive compounds.

1039. Intensity of the Explosion.—Explosion may be of different degrees of intensity, from that where the body is converted into gas by gradual combustion up to *detonation*, where the whole mass of the body is suddenly and violently converted into gas; as for example: when gunpowder is ordinarily fired, each grain commences to burn on the surface, the burning gradually extending to the interior, until the whole is consumed, while nitro-glycerine seems always to detonate, which partially accounts for its excessive violence.

1040. Means of Causing Explosion.—The application of heat either directly or indirectly is the principal means of causing an explosion. Directily, as by a match, a red-hot iron, etc. Indirectly, by friction, where the mechanical energy of rubbing is converted into heat; by percussion, where heat is generated by the direct application of a blow; or by concussion, where heat is generated by a jar or shock communicated *through* a second body.

1041. Method of Producing Explosion.—The circumstances under which an explosion takes place create a marked difference in the effect produced. Every one is familiar with the different effects produced by firing gunpowder in the open air and firing it in a confined space; but, apart from this, the *mode* by which it is fired exercises immense influences, both upon the force and the rapidity of its explosion.

Suppose that a quantity of *fulminate of mercury* be exploded within a mass of any other explosive; apart from the flame produced, a blow will be given by the gas suddenly formed by the fulminate, which will act upon the surrounding explosive *percussively*, like the blow of a hammer upon an anvil. The very rapid motion of the particles of gas will give them a force, as regards any resisting body, similar to that exercised by a solid, having a great velocity, against any obstacle in its path.

1042. DETONATION.—When the flame of the fulminate is applied directly to the explosive, the chemical change is initiated at the point of application, and, if the flame alone were considered, would gradually spread from this point through the mass; but the percussive blow is extended through all parts of the body with very great rapidity, enormously expediting the speed of the explosive charge. In certain cases the effect is practically simultaneous throughout the whole mass of the body exploded, thus producing *detonation*, the effect of which is much more powerful than that of an ordinary explosion.

1043. Explosives Capable of Detonation.—Each explosive body that has been experimented with seems to have a particular mode of detonation, and probably all explosives may be detonated if the right method of doing so be known. Guncotton seems to have a greater range of susceptibility to different modes of firing than any other explosive agent. It can be made to burn slowly without explosion, and the rapidity of its combustion can be increased up to the point of detonation. Nitro-glycerine, as before stated, appears always to detonate. (It is not sensitive to flame as directly applied.) Fulminate of mercury is a detonating substance, but the quantity of gas given off is comparatively small, hence the limited range of its destructive effect. Gunpowder is said to be capable of detonation, but it is more difficult to obtain detonating effects with it than with any of the others.

1044. Detonation, how Produced.—Detonation can only be produced by the application of the requisite blow or shock, and this is usually accomplished by means of a detonating fuze containing the required amount of fulminate of mercury, the amount differing for each explosive.

Fulminate of mercury has been found to be by far the best agent for producing detonation ; less of it is required than of any other explosive. Nitro-glycerine is much more powerful than fulminate of mercury, but while a certain amount of the latter will detonate gun-cotton, seventy times as much nitro-glycerine will not accomplish it. *Chloride of Nitrogen* and *Iodide of Nitrogen* are much more violent than fulminate of mercury, yet a larger quantity of them are required to produce detonation. These facts indicate that there is some peculiarity in the impulse given by the firing of fulminate of mercury that affects other explosives more powerfully than that given by any other body, though the latter may be the stronger. It may be considered that this is owing to a peculiarity of vibration, or *wave motion*, due to the explosion of fulminate of mercury, which causes greater disturbance among the molecules of other explosives than the vibrations produced by any other explosives.

1045. Nature of Detonation.—Detonation is really only an exceedingly rapid explosion. In an ordinary explosion like that of powder in a gun, much force is lost by the slowness of the action. As gases expand heat is absorbed, so that if the gases can expand as they are formed, much of the heat of the chemical reaction is absorbed, diminishing the sharpness of the explosive effects, which is therefore not sudden but gradual. With a force gradually generated and exerted, we have a propulsive effect, but a detonation has a disruptive violence, which may become almost irresistible.

1046. Illustrations of Explosion by Detonation.—The practical value of this mode of developing the force of explosive agents is very great. The necessity of confining gunpowder and other explosive materials in strong receptacles for the purpose of developing their explosive force, is greatly reduced, and indeed entirely dispensed with in the case of charges fired under water, when detonating fuzes are used as the exploding agents.

Masses of hard material of great size or strength, such as blocks of hard rock, large iron castings, or thick bars of iron, may be broken up by simply placing upon one of their surfaces a comparatively small charge, quite unconfined, of compressed gun-cotton, or of a nitro-glycerine preparation, and exploding it by means of a detonating-fuze.

In such operations the destructive effect of the detonation will be increased by covering the charge with sand or other material, but in hurried operations good results may be obtained with either of the materials specified by detonating them when freely exposed to air.

For hasty demolition of buildings and of military works, the explosion by detonation affords most important facilities, reducing the difficulties, dangers, and cost of such operation to a minimum.

Section II.—Manufacture of Gunpowder.

1047. GUNPOWDER is the agent employed for the firing-charge of all ordnance, and for the bursting-charge of all projectiles.

Its use depends upon the fact, that at the moment of ignition, violent deflagration takes place, accompanied by the evolution of a large volume of gas. It is evident that if the explosion occur in a limited space, a vast pressure accumulates and becomes a propulsive force. The gas produced by the explosion of good gunpowder occupies nearly 900 times the volume of the powder itself; but, owing to the high temperature, the space occupied by the gas at the moment of formation is probably 3,000 times greater than the volume of the powder.

It has been found that no composition fulfils so many requisites for charging fire-arms as a mixture in due proportions of *nitre*, *charcoal*, and *sulphur*, and it is this composition which constitutes gunpowder.

The ingredients should be of the greatest possible purity, both for the quality of the powder and the prevention of disastrous accidents in the manufacture.

1048. INGREDIENTS OF GUNPOWDER.*—The ingredients for the manufacture of gunpowder should be supplied in the rough state, and refined and prepared for use at the factory, in order to insure as far as possible uniformity of results in manufacture and safety in carrying it on.

It is manifestly useless to attempt to obtain powder possessing uniform qualities unless measures are taken to insure the uniform purity of its constituent elements; and although presence of chemical impurities may be readily detected in samples of refined saltpetre and sulphur supplied by contract, and though it might be possible to devise a series of practical tests for the various physical qualities by purchase, there can be no guarantee for the purity of the former and uniformity of the latter equal to that of careful supervision during the actual processes of preparation and refining.

* Smith.

A manufacturer who refines his own saltpetre and sulphur, and burns his own charcoal, has means of insuring the purity and uniformity of the ingredients of which he makes use, far superior to that of any system of testing, however careful.

1049. The additional security against accidents in the course of manufacture, gained by careful exclusion of all foreign matter from the ingredients during the processes of refining, is of even greater consequence in the manufacture of gunpowder. The question, how far the too frequent explosions in powder factories are dependent on the presence of minute particles of foreign bodies introduced into the ingredients after refining and before they come into the hands of the mixer, has not received the attention which it deserves. But it is too often found that though care be taken to exclude any fragments of sand, grit, etc., from the powder from the time it leaves the mixing-house till the time that it is finished, the same vigilance is not exercised in excluding minute particles of foreign substances from the unmixed ingredients, by which negligence the subsequent precaution is altogether thrown away.

1050. Those engaged in removing saltpetre from the refinery to the mixing-house should be scrupulously careful not to step into the bins where it is stored without putting on clean magazine shoes, and should not make use of any shovels, barrels, etc., but those kept specially clean and free from grit for the purpose; and the same precautions should be taken in handling sulphur and charcoal, the latter of which should be picked over by hand, piece by piece, before being ground, and after that treated with the same care as the other ingredients. If precautions to avoid accidents are worth taking at all, they must, to be effectual, be commenced whenever the ingredients are taken in hand, and maintained to the end of the manufacture.

1051. Refining Saltpetre.—*The principle on which the process depends*, is that saltpetre is greatly more soluble in hot than in cold water, while the impurities generally found in it do not present the same disparity in their solubility at different temperatures. Thus a saturated cold solution of crude saltpetre will, as its temperature is raised, take up a much greater additional quantity of saltpetre proportionately than it will of the other salts present. Hence if a boiling saturated solution of the impure salt be made and allowed to cool, it will deposit the excess of saltpetre and retain the other salts in solution. Boiling water will take up 39.61 parts of chloride of sodium, and about 240 of saltpetre. Water at the temperature of 70° will take up about 36 of the former and about 32 of the latter. Consequently, if a boiling solution saturated with saltpetre and chloride of sodium be cooled to 70°, it will deposit about 208 parts of the former to about 3.6 of the latter.

All, therefore, that has to be done in refining saltpetre is to make a concentrated solution of this crude material at a high temperature, to run the solution into flat troughs, to keep it in constant agitation as it cools down, and then to remove from it the saltpetre as it crystalizes out of the mother liquor.

1052. DESCRIPTION OF THE REFINING PROCESS.—*Solution.* —About two tons of crude saltpetre are pressed in a large open copper pan capable of holding about 500 gallons of water, and about 270 gallons of water are added to it. This is generally done over night, and the fires are lighted under the copper early the following morning. Over the bottom of each pan is placed a false bottom of iron perforated with holes of an inch in diameter, to allow the sand and insoluble impurities to fall to the bottom. In about two hours the whole of the saltpetre will be found to be dissolved and the solution boiling, and the specific gravity of the solution being about 1.49, it reaches the temperature of 230° F. The false bottoms are pulled out just before the solution begins to boil, and the scum, containing the greater part of organic impurities, is removed from the surface. The solution is allowed to boil for about half an hour longer, until no more scum rises to the surface; the copper is then filled up with cold water, and the solution again boiled briskly for a few minutes, after which it is allowed to cool down to become of a proper temperature for being pumped into coolers.

1053. *Filtering.*—The filtering process is almost always used when refining saltpetre for gunpowder-making, but is sometimes omitted when refining for other purposes. In the latter case the solution is made of extra strength and consequently denser, and the cooler being placed below the level of the coppers, the solution is run directly into it through a pipe, the orifice of which in the copper is placed at a certain height above the bottom, to prevent the sediment running out with the clear liquor. But filtering affords a much more certain plan of obtaining a clear liquor for crystallization, and presents little difficulty and causes very little loss of time.

1054. When the temperature of the solution has fallen to 220° F., with a specific gravity of about 1.53, it is ready for pumping into the filters. When the solution has arrived at the proper temperature for the process, a common hand-pump is lowered into the copper, and the solution is pumped into a wooden trough leading to another larger one, termed the *supply-trough*, furnished with six holes in the bottom, beneath which the filtering-bags are suspended. Wooden plugs are provided for these holes in the bottom of the supply-trough, so that if the bags become clogged, the flow of solution may be stopped till they are replaced by clean ones.

1055. The bags are suspended on iron hooks underneath the holes in the supply-trough. They are always rinsed with hot water before the filtering commences, and require occasionally a little poured over them to prevent the formation of crystals during the process, which would clog the canvas and prevent the solution running.

Occasionally a solution is found to contain so much organic impurity, that it will not run through the filters. In this case a little glue, about 1 lb. to 2 tons of saltpetre, is added to the solution in the copper, which has the effect of throwing up a great part of the impurity as a scum, which can be removed before the liquor is pumped out.

1056. The filtering of a copperful of liquor, of the strength described (Art. 1052), takes about three-quarters of an hour. As soon as it is all removed from the copper, the pumps, which are suspended overhead on a small pulley, are pulled up and the coppers, if necessary, cleaned out. The sediment, consisting principally of sand in the proportion of about ¼ per cent. of the crude, is washed and the washing reserved for evaporation. A wooden trough placed directly underneath the filtering-bags receives the solution as it runs from them, and conducts it directly into the cooler. When all the solution is filtered, the bags are rinsed with hot water into the evaporating-pots, and then washed and hung up to dry.

1057. *Crystallization.*—The cooler, or crystallizing cistern, is a large, shallow, flat trough of sheet copper, being about 12 feet long, 7 feet wide, and 1 foot deep. By the time the solution runs into it the temperature will have fallen to between 190° and 180° F. As the temperature continues to fall, the excess of saltpetre crystallizes out, leaving, of course, a considerable quantity still in solution, and along with it the chemical impurities of the crude salt, the chlorides and sulphates.

If the solution were left to crystallize without agitation, the salt would be deposited in the form of large crystals, each of which would enclose a small quantity of this impure mother liquor. To prevent this, the liquor in the coolers must be kept in constant agitation, to cause it to deposit the salt in the form of *flour*, or minute crystals. This is effected by a workman who, for the first hour or so, until the temperature of the liquor falls to about 90°, keeps it constantly stirred by means of a large wooden hoe, with which also the flow is drawn to the side of the cooler, to be shovelled out with a copper shovel.

As it is removed, it is first thrown into an inclined board, or *drainer*, to allow the excess of liquor to run back into the cooler. It remains on the drainer for some minutes, after which it is transferred to the washing-vat.

1058. When the liquor falls in temperature to about 90° F., the agitation is discontinued, because the crystals are deposited much more slowly, so that the cost of labor would be considerably increased. The crystals which are deposited at a temperature below this also contain a much larger quantity of mother liquor. About three quarters of the entire quantity of saltpetre is removed from the solution, if the agitation be stopped at 90° F.

The crystallizing process may be very materially hastened by artificial cooling. In some refineries, where a good fall of water can be obtained, a stream of cold water is made to run under the bottom of the cooler. This reduces its temperature very rapidly, and causes the flour to be deposited with less loss of time.

1059. The mother liquor is left to cool down after the proper amount of flour has been removed from it. As soon as its temperature approaches that of the atmosphere, large crystals are deposited in the cooler. The liquor, still, of course, a saturated solution containing all the original soluble impurities, is run off and reserved for subsequent evaporation. The crystals are scraped off and transferred to the refinery copper with the next charge of crude salt.

The following is an analysis of a sample of the salts left in solution in the liquor:

Saltpetre	77.40
Chl. Sodium	18.51
Sulphate of Soda	3.39
	99.30

—which should be compared with the anaysis of the crude salt.

1060. Washing.—The washing-vat, to which the saltpetre flour is transferred, is of wood, about 6 feet long, 4 wide, and 3½ deep. It is provided with a false bottom pierced with small holes, underneath which is a plug-hole which can be closed or opened as required. In this vat the saltpetre receives three washings, the first being given at once, as soon as it is raked from the strainers into the vat, to remove the excess of mother liquor still adhering to it. About 70 gallons of water are run through the vat, and, escaping from the plug-hole underneath the false bottom, are conducted into an underground tank. The second washing is done by covering the crystals with water and allowing it to stand for half an hour, the plug being in, and then allowing it to run off into a second underground tank. The crystals are allowed to drain for half an hour after this washing. The third washing is given by running about 100 gallons of water through the crystals, as in the first washing, the plug-holes remaining open.

The water from the third washing runs into the tank which receives the second, the contents of which, being comparatively free of impurities, are used in the refining coppers. The water from the first washing is only used in the evaporating-pots. It is, of course, most important that the purest water should be used for these washings. Distilled water should, if possible, be alone employed. The washings, as they run off, are saturated solutions of saltpetre; but they take up, in passing through the salt, any traces of chlorides remaining in it.

1061. Tests.—Supposing all the foregoing operations to have been properly carried on, the saltpetre will be found to be perfectly pure. Should it be deemed necessary to test it for impurities, it should be subjected to the following. A solution should be tested:

1. With blue and red litmus paper, for the presence of an acid or alkali.

2. With a solution of nitrate of silver, for the presence of chlorides, which would throw down the insoluble chloride of silver.

3. With a solution of chloride of barium, for the presence of sulphates, which would give the insoluble sulphate of baryta.

4. With a little oxalate of ammonia, for lime, which would give oxalate of lime.

In the ordinary practice of a refinery, the second test, viz., that for chlorides, more especially the chloride of sodium, is the only one ever used.

1062. The saltpetre is transferred to the store bins generally the day after it is refined. In removing it from the washing vats, about six inches deep at the bottom is left, as it contains a great deal of water. After remaining in the bins three or four days, it will be found to contain from three to five per cent. moisture, according to the season. It remains in the bins till required for use in the mixing-house, the saltpetre used for powder-making being always used moist.

1063. *Drying.*—Should a supply of refined saltpetre be required for storage or transport, the salt is generally dried before being placed in barrels. This is done in a hot-chamber: a small room with a stone floor, underneath which runs a flue; and provided with racks inside, on which are placed the flat copper trays containing the saltpetre.

The hot-chamber is capable of containing two or three tons of saltpetre, and the temperature is generally raised to about 220° F., which dries it completely in from four to six hours. The salt is covered in a flat tray, placed outside the store before being barrelled up.

1064. Extraction of Saltpetre from Damaged Powder.—The extraction of saltpetre from powder sweepings, a considerable quantity of which accumulates in the course of manufacture, and from powder which may have been accidentally wetted or damaged by long storage in damp magazines, forms a part of the ordinary nature of duties in a refinery of saltpetre. Copper pans are used for stirring the sweepings, and any damaged powder which may be sent to the factory is also placed in pans. As a precaution, the contents of each pan are carefully and thoroughly melted, and the supply is not allowed to become dry by evaporation.

1065. *The Operation.*—About 240 gallons of water are pumped into a copper of 400 gallons capacity, and brought nearly to the boiling-point. Pure water must be used for the first day's operation, but afterwards the liquors obtained in filtering the previous day's work. About 900 bbls. of the damaged powder are then thrown in, care being exercised that it is thoroughly wetted throughout before being brought into the extracting-house. The mixture is stirred and boiled for three-quarters of an hour, after which the fire is damped and the solution ladled into filters of coarse sheeting. From the first series of filters, the solution passes to a second row, through which it passes, clear, into a tank. From the tank it is subsequently pumped into the evaporating-pots and boiled down. The saltpetre being of course pure, the boiling is merely to drive off a certain quantity of water. When sufficiently reduced it is again filtered and crystallized in small copper pans. The crystals obtained are used as crude saltpetre. The carbon and sulphur obtained are thrown on the waste-heap, being of no value.

1066. The whole process of extraction is dirty and troublesome, and the expediency of carrying it on to any great extent depends on the price of saltpetre at the time, and the price which can be obtained in the market for damaged powder. Powder sweepings should of course always be extracted, as they are liable to contain particles of foreign substances; but provided powder be merely old and dusty, it may still be well adapted for blasting operations, and may command a good price.

1067. About 94 per cent. of the saltpetre contained in powder can always be obtained by extraction, against the value of which must be set off the cost of the men's wages employed in the process, the amount of fuel expended, etc.

1068. SULPHUR.—The sulphur used in gunpowder-making is imported from Sicily. The finest quality is alone employed. As imported, the sulphur contains from three to four per cent. of earthy impurities, having already undergone a rough purification by distillation before it comes into the merchant's hands. It is finally and carefully purified at the factories by a second distillation.

1069. The substance exists in several distinct conditions or forms, two of which require special notice, viz., the soluble, or electro-negative form, and the insoluble, or electro-positive. Distilled sulphur consists almost entirely of the former. Sublimed sulphur, contains a large proportion of the latter. Distilled sulphur, as used in the manufacture of gunpowder, consists of masses of clear yellow crystals in the form of rhombic-octahedra, and is readily soluble in bisulphide of carbon. Sublimed sulphur, known as *flowers of sulphur*, is a pale yellow powder, composed of minute particles which do not present a crystalline structure, but which are merely minute granules consisting of insoluble sulphur, enclosing a small portion of the soluble variety. This latter form of sulphur is to a great extent insolble in the bisulphide.

1070. *Description of Refining Apparatus.*—The apparatus employed consists of a large pot of cast-iron, A (Fig. 253), set in brick work, the metal being very thick. Round the top edge is shrunk a strong ring or tire of wrought-iron, to prevent splitting by explosion. On the top is fitted a large dome-shaped cover, also of cast-iron, secured to the pot by three wrought-iron tie-rods, which are secured by screw-bolts to a wrought-iron ring passing round the neck of the cover. At the top of the cover is a circular opening fitted with a heavy cast-iron lid, the weight of which is sufficient to keep it in its place during the refining process. In this lid is an iron plug-hole having considerable taper, through which the pot is charged. The cast-iron plug which closes it fits sufficiently tight to prevent escape of sulphur-vapor, particularly if a little sand be thrown over it; but at the same time it acts as a safety-valve, being lifted out if an unusual pressure of vapor is exerted inside the pot.

1071. From the dome-shaped cover two pipes proceed at right angles to each other, one to the subliming-dome, the other to the distilling-tank, or *receiving-pot*. The first pipe is furnished with a throttle-valve (Fig. 254), D, which can be closed or opened by a handle from without. The other pipe is encased in a water-jacket, and can also be closed or opened by means of

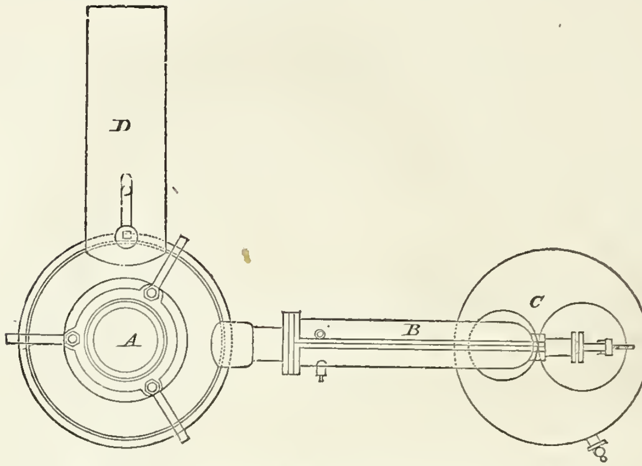


FIG. 253.—Ground Plan of Sulphur-refining Apparatus.

A. Melting Pot.
B. Pipe with Water Jacket leading to C.
C. The Receiving Pot.
D. Pipe leading to Subliming Dome.

a valve. When distilling, a constant flow of water is maintained through the water-jacket (Fig. 255). An escape pipe fitted to this jacket allows of the escape of water when there is a sudden development of steam caused by the heat of the sulphur vapor.

1072. The receiving-pot, C, is merely a large circular vessel of cast-iron, which is set on a frame inserted in small trucks, to allow of a slight movement when the pipe which connects it with the melting-pot becomes expanded and lengthened by the heat of the sulphur vapor passing through it. There is a large circular opening in the lid through which the melted sulphur can be ladled out when necessary. This opening is closed by an iron lid similar to that of the melting-pot, in which is also a small plug-hole through which the depth of melted sulphur in the receiving-pot can be gauged with an iron rod. A small pipe leads from another opening in the lid of the receiving-pot into a square wooden chamber lined with lead to receive any new condensed vapor, and saves it to deposit its sulphur in the form of *flowers*. This chamber is provided with a tall chimney, also of wood, containing a series of steps or traps to catch as much of the *flowers* as possible.

1073. The subliming-dome is a large dome-shaped building of brick, E (Fig. 254). The pipe for the sulphur-pot enters it

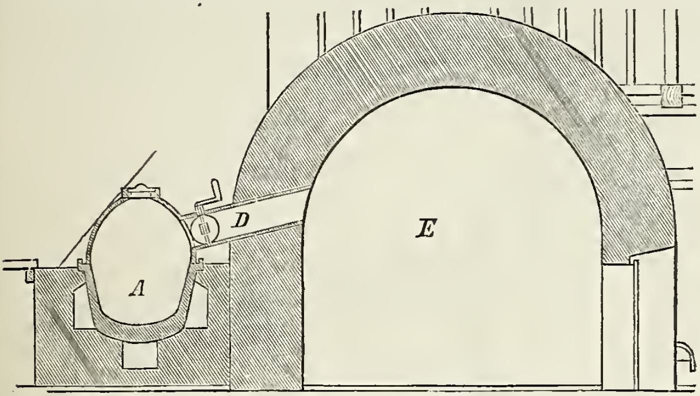


FIG. 254.—Sulpur Refining Pot and Dome.

near the top. The chamber is lined with flag-stones, and the floor is covered with sheet-lead. It is provided with two doors, an inner one of iron, an outer one of wood lined with sheet-lead, both close fitting, through which passes a pipe to allow the escape of air. This pipe terminates in a vessel of cold water.

1074. *Process of Refining.*—If distillation alone is to be carried on, about 5½ cwt. of crude sulphur are placed in the pot each morning. An extra hundred-weight must be put in, if both distillation and subliming are to be carried on together. The fire being lighted, the conical cast-iron plug is left out of the hole in the lid of the pot, the passage into the dome is opened, and that into the receiving-pot closed. The heat is maintained for three hours till the sulphur is of a proper temperature for distillation. The vapor which first rises from the pot is of a pale yellow color, and as much of it as passes into the dome falls down condensed as *flowers of sulphur.* But at the end of three hours the vapor becomes of a deep reddish-brown color, showing that the temperature of the melted sulphur has reached the proper point.

The plug must then be inserted in the lid, the communication to the dome closed, and that leading to the receiving-pot opened, allowing the heavy vapor to pass through the pipe surrounded with the water-jacket, by means of which a constant circulation of cold water is kept up round it. In this way the sulphur vapor is condensed, and runs down into the receiving-pot as a clear orange liquid resembling molasses in color and consistency.

1075. The person who watches the operation knows, by gauging the depth of the melted sulphur in the receiving-pot, when the greater part of the material has distilled over. He then lowers the fire, opens the communication into the dome,

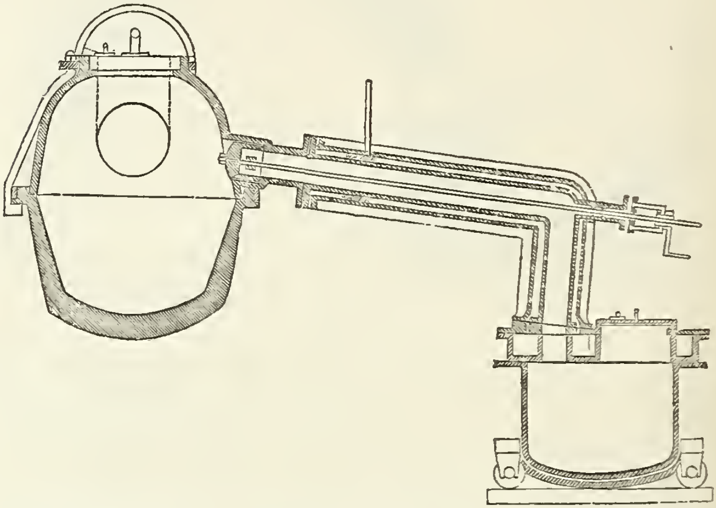


FIG. 255.—Sulphur-refining Apparatus. Section through Pipe leading to Receiving-pot.

and cuts off that leading to the receiving-pot, allowing the remaining sulphur to pass off into the dome as flowers. A low fire is maintained till the whole has been driven off, leaving the earthy residue quite free from it, and consequently loose like coal-ashes, so that it may be easily ladled out before recharging the pot.

1076. When both subliming and distillation are carried on at once, the first part of the process would be exactly as described above; but when the distillation was finished the fire would be maintained for the remainder of the day, but somewhat lower, to drive off the quantity required into the dome. And in this case the subliming process would be carried on for several days, and the pot and dome never allowed to cool down altogether till the required quantity of flowers of sulphur had been obtained.

1077. It is of the greatest consequence that the fires should be carefully regulated in all cases, for if the heat become too great and the temperature of the melted sulphur be allowed to rise to 836°, the vapor disengaged at that temperature is highly explosive when mixed with common air; and if the plug be driven out by the pressure of the vapor, or if air be drawn into the pot through some leakage in the pipes, an explosion invariably happens.

1078. When the distilled sulphur in the remaining pot has cooled down sufficiently, which it will do in the course of an hour or two, it is ladled by hand into wooden tubs and allowed to solidify. These tubs are constructed of a number of loose staves held together by broad wooden hoops, which can be struck off when the sulphur has *set*, allowing the staves to fall asunder and leave it as a solid cylindrical mass.

1079. Distilled sulphur immediately after being removed from the tubs is placed within a boarded-off enclosure, to guard against coming in contact with any fragments of grit or sand which might thus enter the powder, and is broken up into larger lumps, which are sent up to the factory to be ground under a small pair of millstones. After being ground it is reeled through 32-mesh wire-cloth, and is then fit for the mixing-house.

1080. *Testing.*—Its fitness for use as an ingredient of gunpowder may be readily tested:

1st. By burning a small quantity on porcelain, when the amount of residium should not exceed 0.25 per cent.

2d. By boiling with water and testing with blue litmus paper, which it should only very feebly redden.

1081. *Use as an Ingredient of Gunpowder.*—As an ingredient of gunpowder, sulphur is valuable on account of the low temperature (560° F.), at which it inflames, thus facilitating the ignition of the powder. Its oxydation by saltpetre appears also to be attended with the production of a higher temperature than is obtained with charcoal, which would have the effect of accelerating the combustion, and of increasing by expansion the volume of gas evolved.

1082. Charcoal.—The woods from which charcoal is now manufactured for powder-making, appear to have been in use from a very early period. Modern research has shown that there was a good reason for their selection, and that the cause of their superiority over all other woods is probably that their charcoal when burnt with saltpetre and sulphur yields larger volumes of gas than any others.

1083. *The Woods Used.*—The woods generally used for the best gunpowders are the *willow*, the *alder*, and what is popularly known as the *black dogwood.* The more rapidly a wood has been grown, the less dense will it be, and the better for powder-making when converted into charcoal. The *willow* is one of the softest and lightest of woods; it is of very rapid growth, nearly white, and has a tolerably large circular white pith. The *alder* is somewhat harder and denser in texture than the willow, and is not of such rapid growth. Its color is reddish-brown, and the pith is triangular in section. The *dogwood* is dense and tough, of slow growth, and having circular pith of a reddish color.

1084. Small wood of about ten years' growth is preferred for powder-making. Alder and willow of this age will be probably four or five inches in diameter, dogwood about one. The wood must be straight, perfectly sound, and entirely free from bark, and must be felled in the spring. Great stress is laid on the cleanliness of the wood. Any traces of bark adhering to it are not to be tolerated. If the wood is cut in the spring when the sap is rising, the bark is easily removed, and the wood is left perfectly clean. Wood cut at any other season of the year is just as good, only in this case the removal of the bark is a much more difficult matter.

1085. *To Convert the Wood into Charcoal.*—Wood is con-

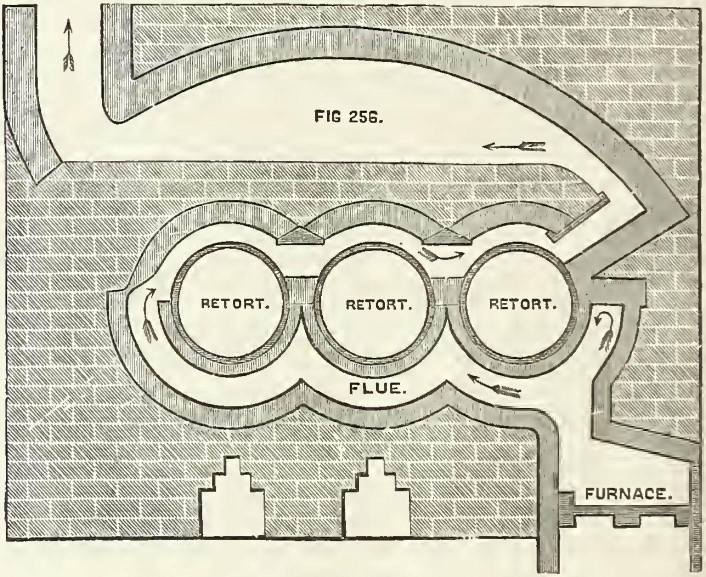


FIG. 256.

verted into charcoal in iron retorts or cylinders, set into brick-work. Fig. 256 shows a transverse section of a set of cylinders, giving the arrangement of the flues, by which the flame is made to play all around them; and Fig. 257 shows a longitudinal section of one cylinder, showing how the second cylinder, or slip, A, containing the wood is placed in its interior, and the arrangement of pipes by which the gaseous matter evolved from the wood is conducted into the fire.

1086. Each cylinder is made of cast-iron, having two pipes passing out at the inner end of it. When set, the lower one of these is closed with brick-work, the upper one only being used, and the lower one being only intended for use should the cylinder be turned round and reset. To the uppermost pipe is attached a branch pipe leading to a horizontal pipe extending behind the whole set of cylinders, from one end of which another pipe descends perpendicularly, joining another leading directly into the former. Each cylinder has a false bottom of brick-work, in front of which is bolted on a piece of wrought-iron plate having a cylinder hole corresponding to the uppermost pipe of the cylinder. The cylinders are closed with tight-fitting iron doors secured by a powerful screw, much in the same way as the ends of gas retorts are fastened.

1087. For convenience of handling, the wood is placed in

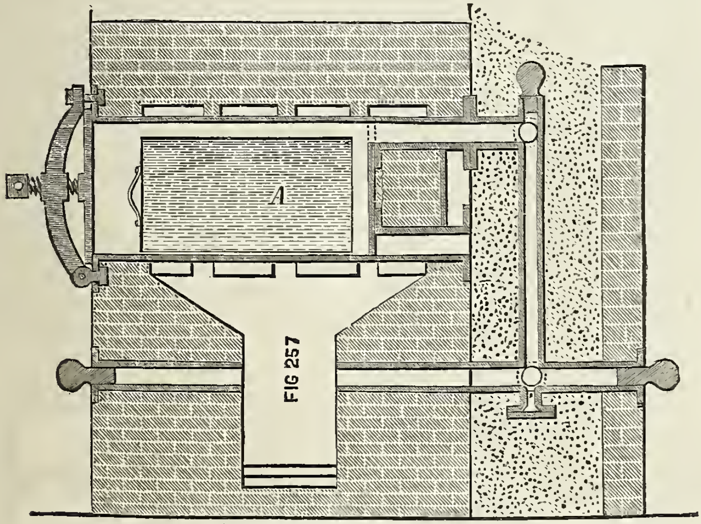


Fig. 257.—Longitudinal Section of Retort.

small cylinders of sheet-iron, A, termed *slips*, which are placed on small iron travelling carriages, on which they can be run up directly to the mouth of the cylinders and shot in. The back end of each slip is provided with a handle to facilitate withdrawal. The slips are a little over three feet in length so as just to take the cord-wood in easily.

1088. Provided the cylinders are hot, the wood is thoroughly charred in two or three hours. The plan of conducting the gas and tar from the wood into the fire is found greatly to economize fuel, and to be the readiest means of ascertaining when the charring is properly and thoroughly done. This is shown by the flame which issues from the pipe leading into the fire becoming of a violet tint, indicating the formation of carbonic oxide.

As soon as this is observed the doors of the cylinders are opened, the slips are hoisted out and lowered into large iron extinguishers having close-fitting lids, in which they remain for half a day, after which the charcoal is shot into *coolers*—large cylindrical cases of sheet-iron fitted with lids—and sent to the charcoal store. Wood yields about 25 per cent. of charcoal.

1089. *Effect of Temperature employed in Conversion.*—It is of the highest importance that the charring of the wood should always be conducted as nearly as possible at the same temperature; for the chemical composition of the charcoal and the temperature at which it will ignite is undoubtedly affected by the temperature at which it has been charred. Charcoal prepared at a low temperature is softer, more inflammable, and contains more gaseous elements than charcoal prepared at a higher heat, and the gunpowders made from these charcoals would be similarly affected. It is hopeless, therefore, to attempt to obtain uniform results in manufacturing powder, unless means be taken to insure uniformity in the preparation of charcoal.

1090. *Qualities of Charcoal.*—The fitness of charcoal for gunpowder depends on its chemical composition, which is indicated by its physical qualities. If properly made it should be jet-black in color, its fracture should show a clear, velvet-like surface, and it should be light and sonorous when dropped on a hard surface.

Underburnt charcoal, that is, charcoal that is prepared at a very low temperature, is at once known by its reddish-brown color; overburnt charcoal, by its hardness and density. The former is greatly more inflammable than the latter, charcoal prepared at a temperature of 500° F. being readily ignited at a temperature of 640° F., while charcoal prepared at 1800° F. requires a temperature nearly double the last to inflame it.

1091. Underburnt charcoal has found favor for some small-arm powders. It certainly appears to render the powder more inflammable, and consequently quicker, but it has the disadvantage of being more hygroscopic than denser charcoal, and of rendering the powder therefore more liable to suffer damage from damp. That underburnt charcoal produces a very marked effect on gunpowder there can be no doubt. Recent experiments have proved that if two powders be made identical in all other qualities, the one with black charcoal, the other with red or underburnt charcoal, the latter will give a higher velocity to the projectile than the former. Powder made from underburnt charcoal can be readily distinguished, when crushed to fine dust, by its color.

1092. Proportions of Ingredients.—In determining the proportions in which the constituents should be mixed, the circumstances in which it is to be used must be considered.

A vast number of experiments have been made at various times to discover the proportions of nitre, sulphur, and charcoal best adapted for the production of gunpowder. It has been found that no general rule can be given which shall fulfil every requirement, yet all nations appear to have found by trial the proportions most generally useful for ordinary purposes, and they all approximate to the percentages required by the formula

$$2KNO_3 + S + 3C,$$

supposing the charcoal to be pure carbon.

The percentage composition is generally thus:

Nitre	74.8
Sulphur	11.9
Charcoal	13.3

The percentage of nitre varies from 70 to 80; that of sulphur and charcoal from 10 to 15 each.

The best powder is intended for war and sporting purposes, and contains usually a little less sulphur and a little more charcoal than the above.

1093. The proportions required by regulation for gunpowder in the United States services are:

Nitre	75
Charcoal	15
Sulphur	10

These proportions are not those which theoretically would give the greatest amount of gas. The charcoal is in excess, to allow for ash, and the sulphur is diminished, as it acts injuriously on the metal of the piece by the formation of a sulphide of iron, which eats away the surface of the bore.

When the proportion of charcoal is greater than that contained in common powder it will be less completely and rapidly burned.

1094. Blasting Powder, for example, contains a greater proportion of charcoal and less nitre; its action is consequently slower, and if used in fire-arms, not only is the piece very soon rendered foul, but the ball is projected to a much less distance.

This alteration in the proportions is mainly on account of the great reduction in price thereby effected.

1095. Preparing and Mixing the Ingredients.—Before the ingredients can be mixed, they must be reduced to a powder sufficiently fine for the purpose. It is important to bear clearly in mind the meaning of the terms *mixing* and *incorporating*, as they are used by gunpowder-makers. Though gunpowder is really only a mixture, very intimate, no doubt, of the three ingredients, and not a new chemical substance formed out of them, yet by mixing is understood only the stirring together for a few minutes of the saltpetre, sulphur, and charcoal, to get them perfectly distributed amongst each other; and by incorporating, the long-continued trituration and grinding which the mixture undergoes under heavy edge-runners, by which a mass of the ingredients becomes transformed, from a mere mixture of three different substances into gunpowder. A preliminary mixing, such as is employed at most gunpowder-works, *may* be dispensed with; incorporation, whether performed by pestle and mortar, in the stamping-mill, or under edge-runners, never.

1096. If the saltpetre is used moist, an allowance for this must be made in weighing. The percentage of moisture in the quantity used is ascertained by drying and pressing a sample, and comparing the weight before and after the operation. In this country it is found highly advantageous to have the saltpetre dried and pulverized before weighing out.

1097. Occasionally dried, refined saltpetre may be employed for manufacture in the case of a stoppage in the saltpetre refinery. In this case the dried salt is first ground under a pair of small stone-edge runners, fitted with scrapers to prevent the salt adhering to them, and then passed through a slope reel covered with 28-mesh wire, that which passes through the wire being used for mixing, the larger fragments being reground.

1098. The sulphur is ground in quantities of $2\frac{1}{2}$ cwts. at a time, under a pair of iron edge-runners, also fitted with scrapers, and sifted in a slope-reel covered with 32-mesh wire.

1099. Charcoal, after being carefully hand-picked, to guard against the introduction of any fragments of foreign matter and underburnt knots of wood, is ground in a mill resembling a coffee-mill in action. (Fig. 258.) It consists of a cone working in a cylinder, each being furnished with diagonal ribs, or teeth, which are widely apart at top, but approach closely to-

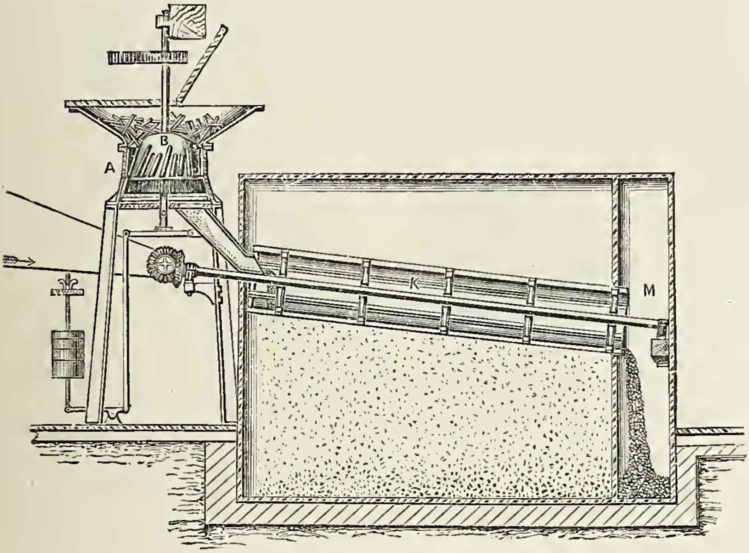


FIG. 258.—Charcoal Mill and Reel.

A.—Cylinder. B.—Cone. K.—Reel.

gether at bottom. The charcoal, which is shot in at the top, passes out at the bottom into a slope-reel, covered with 32-mesh wire, all fragments which do not pass through being transferred again to the mill.

1100. An important caution must be mentioned in connection with the grinding of charcoal. After being burnt it should be allowed to stand for a considerable time—ten days to a fortnight—before being ground; for when ground fresh after burning, the finely powdered charcoal absorbs and condenses oxygen so rapidly as to generate a great amount of heat; enough, in so bad a conductor, to cause spontaneous combustion. Instances of fires in gunpowder factories from this cause are on record, fresh-ground charcoal having been left overnight in wooden bins.

1101. *Mixing-Machine.*—The relative proportions of the three ingredients are weighed out in quantities of 50 lbs., and transferred to the mixing-machine. (Fig. 259.) This consists of a hollow drum of gun-metal, which is made to revolve at a

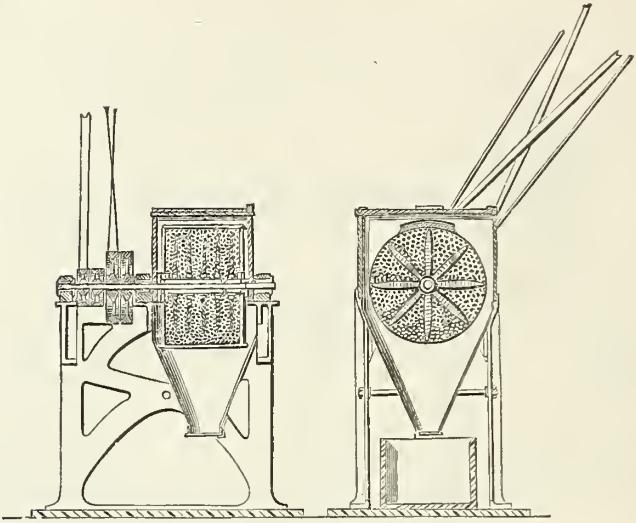


FIG. 259.—Mixing-machine.

speed of 40 revolutions per minute. The bearings of this drum are hollow, to receive a shaft which passes through them. This shaft carries in the interior of the drum a series of 44 arms, or fliers, the points of which just clear the interior of the drum, and revolves at twice the speed of the drum, and in the opposite direction.

1102. A 50-lb. bag of ingredients is emptied into the drum through a square opening at the top of it, and the drum and shaft carrying the fliers being set in motion for five minutes, the saltpetre, sulphur, and charcoal are thoroughly mixed together. The opening at the bottom of the drum allows the mixed ingredients to fall down the shoot into a tub, from which they are transferred to an 8-mesh wire sieve placed over another shoot having a composition-bag placed beneath it. On the sieve the charge is carefully sifted by hand, to guard against any foreign matter, such as splinters of wood from the saltpetre bins, etc., passing into it, and falls through into the bags, in which it is tied up tightly and transferred to the charge-house, ready for the incorporating-mill.

1103. INCORPORATION.—Incorporation is unquestionably the most important of all the operations in the manufacture of gunpowder. Without it there would be no manufacture, for the charge of saltpetre, sulphur, and charcoal goes to the incorating-mill a mere mixture, and leaves it gunpowder. Nothing that can be done to it afterwards will add to its strength or explosiveness; no future treatment can remedy defective incorporation. By incorporation is, of course, meant the long-continued grinding together of the ingredients which blends them together and brings them into such close juxtaposition, that they appear to form a new substance. Unless this be done perfectly, perfect mutual decomposition of the constituents of the gunpowder cannot be expected on combustion. The more thoroughly it is effected, the stronger will be the resulting gunpowder.

1104. Upon the thorough and effectual incorporation which it receives depends mainly the excellence of powder. Great attention is paid to the process, not only for military, but for sporting purposes, and the most powerful mills are always used. It has been carried to the highest pitch of excellence, and in many cases it is carried on for an unnecessary length of time; some of the finer sporting powders are said to be incorporated for twelve hours. Provided the incorporating-mill is sufficiently powerful, and is worked at a sufficient speed, a most thorough incorporation can be effected in a few hours, after which there is no object in continuing the process. But as imperfectly incorporated powder cannot fail to be of inferior quality, and to foul the gun under most circumstances, it is best to incorporate the materials as thoroughly as possible; and if the powder is thus rendered too explosive, this quality can be reduced by increasing its density and hardness, and by varying the shape and size of its constituent grains. (Art. 1114.)

1105. *Imperfect Incorporation.*—What may be expected of an imperfectly incorporated powder may be at once seen by burning small quantities of different powders, varying in the amount of incorporation they have undergone, on plates of glass or porcelain. A perfectly made powder flashes off, leaving nothing but some smoke-marks; an imperfectly worked powder will coat the plate with specks of undecomposed saltpetre. This *flashing test* is a simple and effectual way of ascertaining the amount of working which has been bestowed on the powder in the mills, and is the only safe and infallible test of incorporation. This test must be performed by an experienced person, and no powder which does not stand it can be expected to shoot either strongly, uniformly, or cleanly.

1106. The Incorporating-mill.—In order to effect a close and intimate reunion between the saltpetre, the sulphur, and the charcoal, they must be rolled and ground together for a

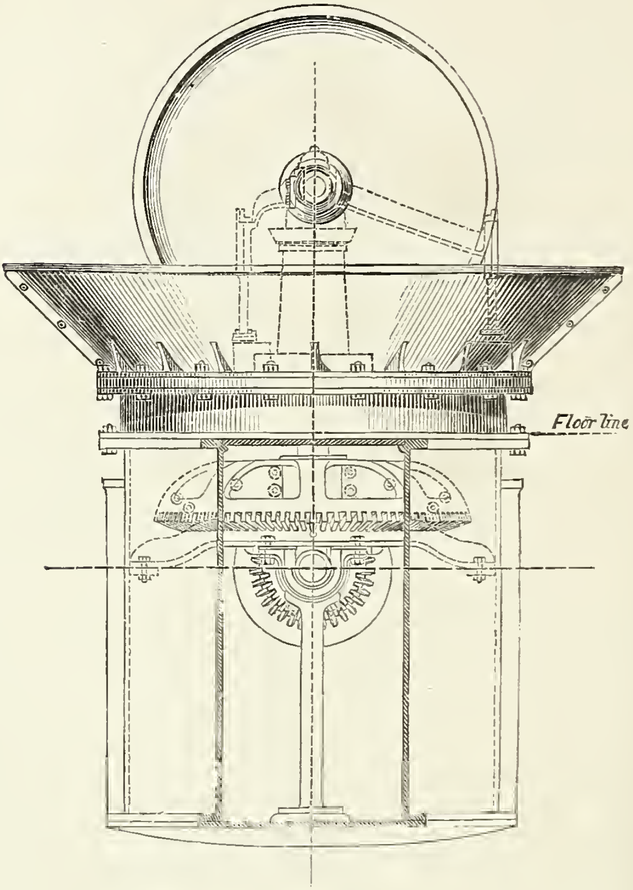


FIG. 260.—Incorporating-mill. (Elevation).

length of time; and the gunpowder-maker finds the most effectual way of accomplishing this, is to grind the materials together under heavy edge-runners of stone or iron, which by their motion—a compound of rolling and twisting—soon work them into a homogeneous mass.

1107. The mill generally used consists of a pair of large, heavy edge-runners of iron or stone, which revolve on a strong circular bed, the bed being, of course, stone for the stone, and iron for the iron runners. (Figs. 260 and 261.) The runners are of

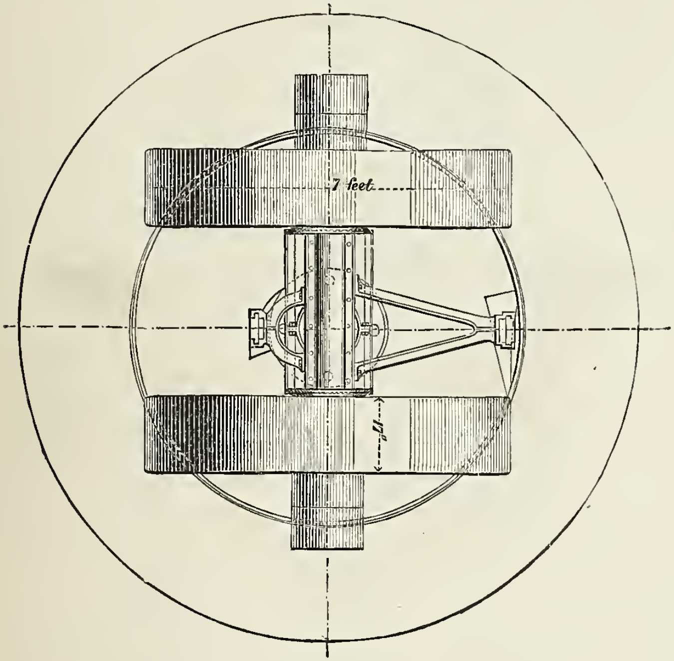


Fig. 261.

various sizes, weighing from 3 to 4 tons each, and being from 4 to 7 feet in diameter. Those of the smaller diameter are better than the larger, as the latter cause a greater twist on the bed, and are therefore more apt to cause accident. The face of the runners should be nearly flat, with a slight bevel towards the edge.

1108. The runners are connected by a powerful spindle of wrought-iron, which rests in brass bouches placed in the cross-head, so as to allow the spindle and runners to rise and fall according to the thickness of the layer of material on the bed. The spindle is placed in the cross-head, so as to bring one runner nearer to it than the other, and therefore cause them to describe different paths when in motion.

1109. The cross-head is fixed on a vertical shaft, on which is fixed, underneath the flooring of the mill, a wheel driven by a pinion on the driving-shaft, which passes underneath the whole group of mills. By this arrangement the whole of the

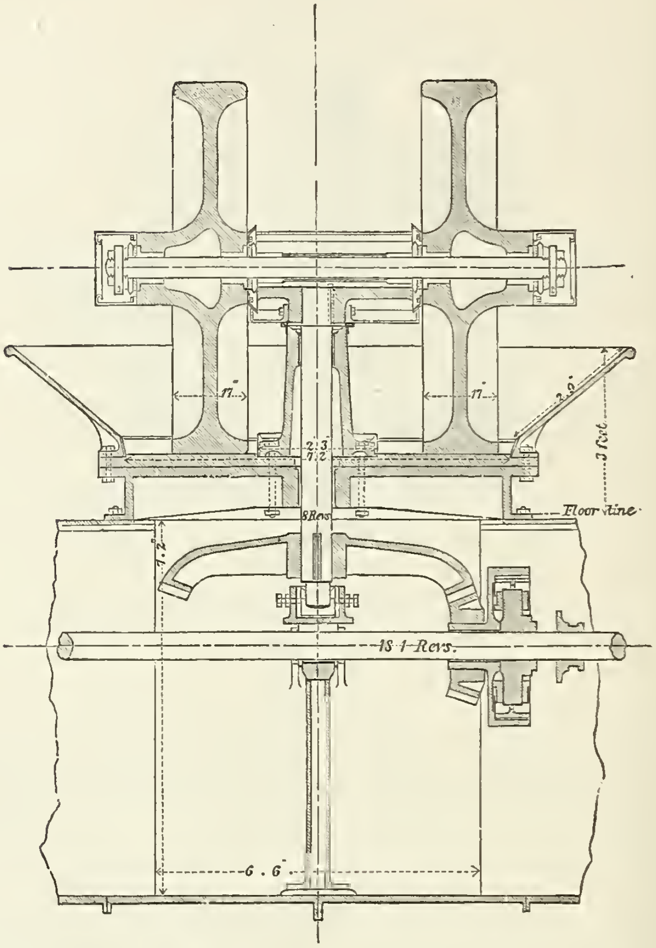


Fig. 262.—Incorporating Mill. (Section.)

machinery is kept underneath, and out of reach of damage from explosion. The cross-head is fitted with a bracket on each side, to carry a *plow*, or wedged-shaped piece of wood shod with felt and leather, which travels round on the bed immediately in front of the runners, and thus keeps the composition from working away from them.

The bed has a curb or edge round the outside, formed by a sloping rim or casing fixed all round it; that on the inside is formed by the circular base of the conical socket, down which the vertical shaft of the cross-head passes. Both the inside and the outside curbs have gun-metal rings round them for the plows to work against. Every fitting and bolt is arranged with the greatest care, so as neither to break nor become loose from the jolting of the mill, and thus drop into the charge.

1110. *Tools Used.*—The instruments used are a wooden *rake*, to distribute the charge over the bed; a *shover*, or flat board on the end of a staff, to push off the charge from the bed occasionally; a copper *chisel*, to be used in getting the charge off the bed when finished; a *brush* for brushing the materials into the centre of the bed; a wooden *mallet*, to break up any caked powder which may adhere to the runners or bed; and a copper *watering-pot*, used for watering the charge.

1111. *The Operation.*—The charges, which have been carefully sifted in order to avoid the possibility of foreign matters getting into the mill-bed, are thrown one half on each side of the bed, and distributed evenly over it. The runners are then moved round a quarter revolution, and the piece of mill-cake left under them from the former charge is broken off and distributed over the fresh charge.

1112. This portion of mill-cake is of course finished powder, and quite hard, if the runners have been left standing on it. It is broken up and distributed to prevent its adhering to the bed and causing too much friction. The runners are usually left on the portion of powder on which they stop when the incorporation is complete, as the attempt to move them off on to a leather placed on the mill-bed involves the risk of a portion of the runner coming down in contact with the bed, and thereby igniting some of the powder-dust with which every crevice is filled.

1113. Before starting the mill about two pints of pure water are sprinkled over the charge. The runners are then started at a speed of about eight revolutions a minute. The millman does not remain in the mill, but only goes in from time to time to push up the charge from the bed and to add a little more water according to the state of the charge. From two to three pints are generally found to be necessary in very damp weather, and as many as eight or ten in very bright days. The watering of the charge is left to the millman's judgment.

1114. *Time Required for Incorporation.*—The times of incorporation vary with the power of the mills. Thus, cannon powder requires 3½ hours working under stone runners weighing 3½ tons, and making 7½ revolutions a minute, but only 2½ under iron runners of 4 tons, making 8 revolutions a minute. Small-arm (dog-wood) powders require 5½ hours in the former mills, and 4 in the latter.

Taking about 50 lbs. as the maximum amount which it is best to incorporate at one time under one pair of runners, it is easy to calculate the capacity of a gunpowder factory. A certain amount of work can be obtained from them, and no expedient can produce more; no extra time or work can be expended on the process.

1115. The powers of a gunpowder factory are therefore known, being regulated by the numbers of pairs of incorporating runners which it possesses. The manufacture of gunpowder cannot be hastened, and even if it could, an explosion may happen at any moment which may cripple a factory for the greater part of a year, so that an extensive store of gunpowder is always required to be kept on hand in case of war.

1116. *Mill-cake.*—As the process of incorporation approaches completion, the charge requires to be carefully watched, in order to ensure each finished charge leaving the mill in as nearly as possible the same state as regards moisture. The appearance of the powder when finished depends mainly on the state in which the charges leave the mill. The finished charge usually has from two to three per cent. of moisture. If too much moisture be present as the incorporation draws to a close, the charge must be repeatedly pushed up with a *shover;* if too little, some more must be added from the watering-pot. The color of the charge gives a very good indication of the amount of moisture present.

1117. When the process is finished, the charge, now known as *mill-cake*—being partly in the state of soft cake, and partly of dust—is scraped and swept up from the mill-bed, placed in wooden tubs, and transferred to the charge-house to await inspection. If the charges are found to be of a proper color and consistency, samples from each are taken, which, after being roughly granulated by hand, and dried, are flashed on a glass plate to ascertain the thoroughness of the incorporation which they have undergone. This flashing is more a matter of form than anything else, for the mill-cake seldom fails to give satisfactory results.

1118. *Danger of Incorporation.*—As incorporation is the most important of all the operations in the manufacture of gunpowder, so it is by far the most dangerous. Accidents in the subsequent processes, where large quantities of powder are subjected to treatment at one time, are fortunately rare; but in the incorporating-mills they may be expected from time to time. It is hardly possible it can be otherwise, considering the enormous friction to which the powder is subjected in them.

1119. The amount of water added to the charge does not reduce the ingredients to a pasty mass, and so lessen their explosiveness; on the contrary, the charge when it approaches completion is highly explosive. If a large amount of water were added, the saltpetre would be partly dissolved, and all the incorporation previously effected would be undone.

1120. It is difficult to conjecture how accidents do happen, unless it be from the charge adhering to the runners and leaving the bed bare, in which case the friction between the runner and the bed is so great as to cause a spark. Of course the more obvious causes of accident, such as some foreign body falling into the bed, are not alluded to here, but only those causes which are as yet unknown, and which no amount of vigilance can altogether avert.

1121. *Drenching-apparatus.*—Admitting, therefore, that occasional explosions in the incorporating-mills are inevitable, the object of the manufacturer is to render them as harmless as possible. As the mills are generally built in groups, an explosion in one, is very apt to spread amongst all the others round it. To prevent this a *drenching-apparatus* (Fig. 263), is erected over each pair of runners.

1122. The apparatus consists of a large shutter pivoted on a spindle, which runs through the whole group of mills. To this spindle the shutter in each mill is attached, and the spindle passes through bearings in the partition-walls, so that the lifting of the shutter lifts all the others. Balanced on the pivot-edge of the shutter is a large copper vessel full of water. This vessel is so arranged that the slightest lift of the shutter capsizes its contents into the bed of the mill beneath it.

1123. An explosion in one mill, therefore, lifts the shutter above it and throws down the water into the mill-bed, and though, of course, too late to do any good in the mill which has exploded, the movement of the shutter turns the spindle and drowns the charges in all the adjacent mills, and thus saves them from explosion. This drenching-apparatus is found to answer very well.

1124. The explosion of a green charge does not, in some cases, do much damage to the structure of the mill or the machinery; that of a worked charge is very violent, and leaves generally no part of the structure standing. Consequently all mills should be made of very strong framework, covered with light boards, which can be quickly replaced if destroyed by an explosion. Fortunately the men do not require to be always in

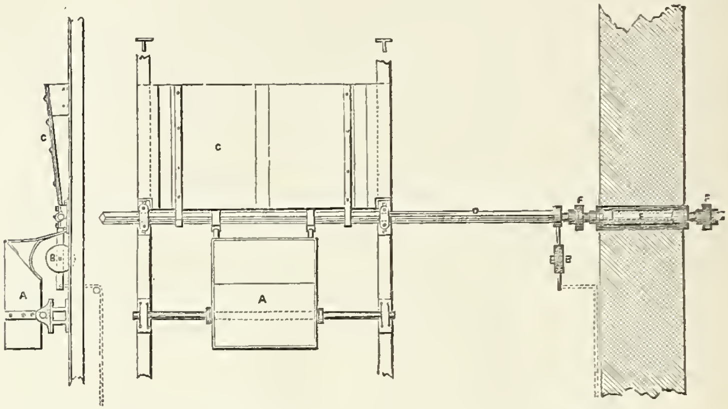


FIG. 263.—Drenching-apparatus for Incorporating-mill.

A.—Cistern made of copper to hold 40 gallons.
B.—Weight made of cast-iron to balance the shutter.
C.—Shutter made of wood. When lifted by an explosion relieves the foot of the cistern, A, causing it to turn over, drenching the mill, and also turning over all the cisterns in connection with the shaft, D, which passes through the stuffing-box, E, it being built in the wall.
F.—Couplings connecting the shafts on both sides of the wall.

the mills; on the contrary, they only enter them from time to time for a minute or so—either to *liquor* the charge, or to see that all is going on well.

1125. PRESSING.—Gunpowder leaves the incorporating-mill partly in the state of soft cake, partly dust. The cake hardens very considerably, if allowed to stand for a few days. In this form it would be unfit for use. The cake may be broken up into grains, but such grains are too soft to stand much handling or transport without crumbling to dust. Powder made from mill-cake will always be found to be dusty, and such powder must always be irregular in action. It will also be much more liable to absorb moisture, and therefore to cake and become lumpy.

1126. To ensure uniformity and good-keeping qualities, and freedom from dust, powder must be converted into firm grains. This is done by compressing the soft material into hard masses by pressure alone, and then crushing up these masses into the description of grain required. The object of pressing, then, is to convert the soft dusty mass of incorpotated ingredients, now gunpowder, into hard cakes of the particular density which is found to give the best results when the powder is finished. After the cakes are formed they can be broken up by various contrivances into grains of any size, all of which will have a uniform density and hardness, and which can be freed from dust, and glazed and polished so as to bear handling and transport without breaking or crumbling.

1127. Gunpowder is generally pressed in layers between plates of gun-metal or copper, in a hydraulic press. Screw-presses are sometimes used, and there are different ways of placing the powder in the presses used. The best results are found to be obtained by pressing in thin layers.

1128. Description of Press.—A convenient form of hy-

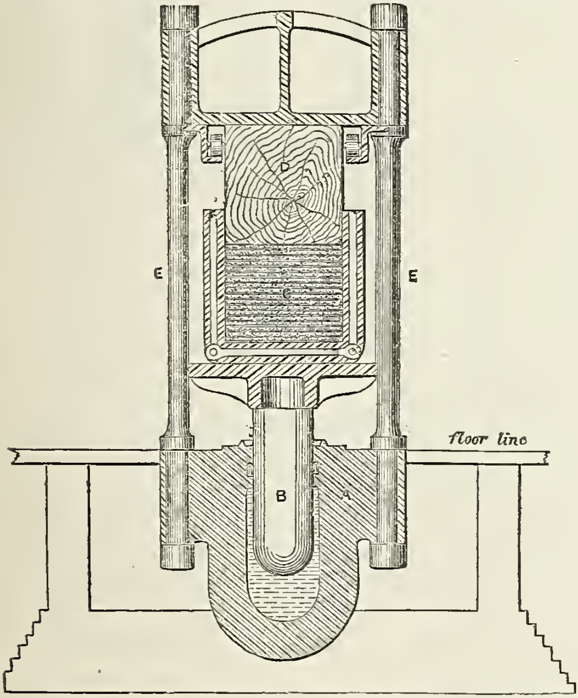


Fig. 264.—Press. Elevation and section showing press in action.

A.—Cylinder. B.—Ram. C.—Press-box.
D.—Overhead-block. E E.—Standard.

draulic gunpowder-press is shown in Figs. 264 and 265. The press-box is made of gun-metal, lined inside and out with oak boards, and is of great strength. The bottom and one side are

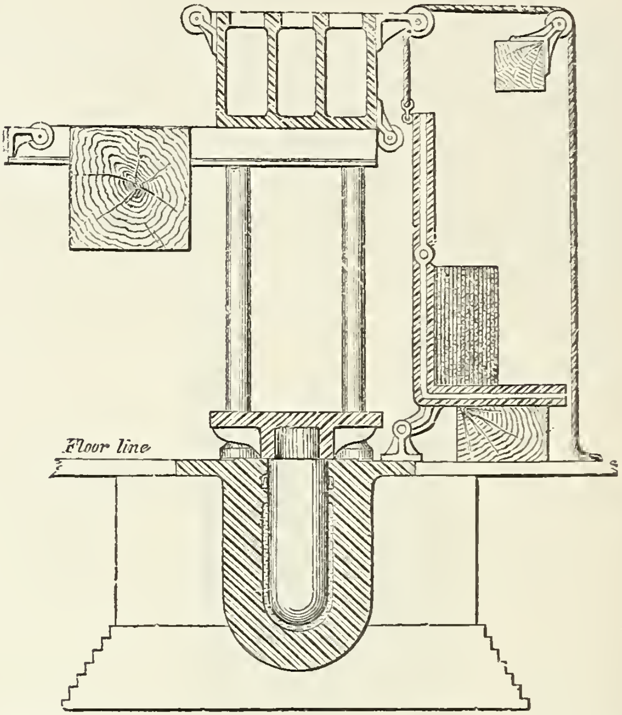


Fig. 265—Press. Elevation and section showing press partly unloaded.

permanently attached to each other. The other three sides are hinged to the bottom, so that they can be opened out to facilitate unloading. When closed they are secured with short, coarse-threaded screws of gun-metal. The box has two projecting gun-metal claws, which hinge on to a fixed horizontal rod of the same metal, so that the box can be turned on it, on the table of the hydraulic press, when filled and ready for pressing, or outwards when it has to be unloaded.

1129. *Loading the Press.*—Being first turned down on its side, the open top is closed temporarily with a piece of board which is fitted to it. What is now the uppermost side is uncovered and raised, and the other two sides are fastened in their places. Gun-metal racks to hold the press-plates, having perpendicular grooves in them ½ inch apart, are then slid in on each side, and the plates being put in, the powder-meal is shovelled in and falls down readily between the plates till the box is full; the racks are then drawn out, leaving the plates free, with layers of powder between them. The excess of powder being carefully swept off the edge of the box, the upper side is lowered and screwed to the other three; an overhead-block and tackle are made fast to the gun-metal eye on the side of the box, and the box is turned over on the press-table.

1130. The box now stands on its bottom, and the temporary board with which the top has been closed during charging being lifted off, the powder and plates will be found to have settled down several inches by their own weight. The vacant space at the top is filled up by shovelling in a few more layers of meal, placing a plate by hand on each in succession, till the press-box is full. The overhead-block, which exactly fits into the press-box, is now run into its place, over and nearly touching the contents of the box, and secured there, when everything is ready to apply the pressure until the box rises to a sufficient height.

1131. *Unloading the Press.*—After the designated pressure has been attained, the press-table, carrying the press-box, is allowed to descend. The pumps are in another building, separated from the press-house by large traverses, and here the workmen remain while the pressure is being applied. The workmen now re-enter the press-house and proceed to unload the box. The overhead-block is first run out of the way, and the block and tackle being attached to the box, it is turned over on its side. The fixing-screws are now taken out of their sockets, and the three hinged sides of the boxes opened out, leaving the powder and press-plates standing in a solid mass. Each plate, with a layer of hard slate-like cake adhering to it, is separated from the one beneath it, and, being lifted into a wooden bin, gets a few knocks with a wooden mallet, which cause the cake to fall off in irregular fragments, which are broken into pieces of the size of a man's hand, shovelled into tubs, and removed.

1132. *Uniformity of Results.*—To obtain pressings of equal density, equal quantities of powder-meal must be compressed equal distances. It is a matter of considerable difficulty to ensure uniformity of results in pressing powder. It is of the highest importance that the density obtained should be uniform, for recent experiments have proved conclusively that the qualities and explosive effect of gunpowder are materially affected by comparatively slight variations in density. It is perfectly possible to manufacture powder of uniform density, and such powder will give accurate and uniform results, both as regards pressure in the gun and, consequently, velocity imparted to the projectile. The density of powder is given in the press; the importance of accuracy in pressing, in which the shooting qualities of powder therefore entirely, or at least mainly, depend, is evident.

1133. As the powder-meal possesses varying degrees of elasticity and resistance to pressure, depending to a great extent on the moisture it contains, and, as far as can be judged by experience, on the state of the atmosphere at the time, equal pressures will not always have equal effects. It is therefore very necessary to have all the conditions made as nearly as possible the same in each experiment. If equal quantities of meal containing equal quantities of moisture could be compressed to the same amount in equal times and under the same atmospheric conditions, then there is little doubt that tolerable uniformity of density would be attainable. But it must be always a matter of the greatest difficulty to fulfil all these conditions exactly. In the first place, the moisture in the powder-meal depends mainly on the amount of liquoring the charges have received. This is usually left to the judgment of the workman, who is guided by the state of weather. And though the charges may be uniform as regards moisture, on leaving the mills, it is obvious that variations of temperature between the days of incorporation and pressing will affect them unequally. In the next place, the bulk of the meal is affected by the moisture contained in it, so that fill the press-box as carefully as we can, we do not get equal quantities to be subjected to pressure each time.

1134. If the quantities operated on were very small, it might be possible to devise some method of equalizing the moisture contained in them; but when large charges are required to fill the press-box, it becomes a much more difficult matter. It is necessary, when examining the densities of press-cake in order to ascertain if it is fitted for the manufacture of a particular powder, to have it previously dried.

1135. It is found in practice that though absolute uniformity cannot be guaranteed in pressing, very close results can be obtained. To attain absolute uniformity in the finished powder, the density of every pressing, after it has been converted into grain, is taken, and the different pressings are then mixed in the proportions to give the density required. Thus if the density fixed for the powder be 1.67, and the densities of the pressings be found to be 1.70 and 1.64, they would be mixed in equal proportions, and would give a powder of 1.67 density. Powders which differ to a great extent in density are never mixed.

1136. GRAINING.—The press-cake must now be converted into the particular size of grain required. And the means employed to break up the press-cake must be so arranged as to crush it up as nearly as possible into the size or sizes of grain wanted, without reducing much of it to dust. The smaller the size of grain, the larger will be the percentage of it obtained from granulated press-cake; hence with the small size of grain formerly used with cannon, any of the older and ruder appliances for effecting granulation gave good percentage of grain. But as recent experiments have conclusively proved that much larger-sized grains should be employed in large charges for heavy ordnance, new and improved granulating-machines have been introduced. Large powders have been made by throwing the press-cake on a table and breaking it up by hand with mallets; but there is little doubt that arrangements and alterations can be made in the machines so as to enable them to granulate powders of any size of grain.

1137. GRANULATING-MACHINE.—The granulation is effected by passing the press-cake between revolving toothed rollers of gun-metal. The machine contains four pairs of such rollers arranged in a slanting direction, one above the other. (Fig. 266.)

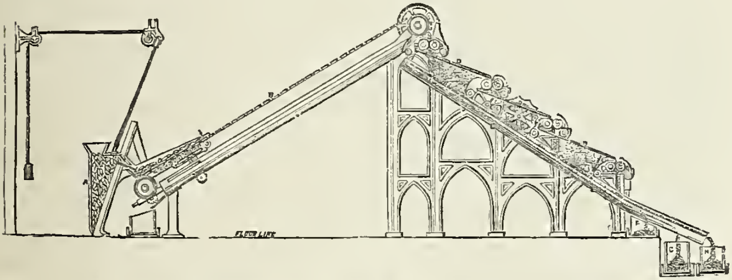


FIG. 266.—Granulating machine. (Elevation and Section.)

A.—Hopper with raising arrangement.
B.—Endless Band.
CCCC.—The 4 pairs of Rollers.
DDD.—The Short Screens.
EE.—Long Screen.
F.—Box for Dust.
G.—Box for Grain.
H.—Box for "Chucks."

These rollers are set in the two strong side-frames of gun-metal which form the framework of the machine. Each pair is adjusted at the proper distance apart by set-screws; but the back roller of each pair works in a sliding bearing, which is kept up against the bearing of the other roller by a weighted lever, so as to admit of the rollers opening out and admitting an excess of material to pass through without injury to the machine. The two upper pairs of rollers have coarser teeth than the lower pairs.

1138. Slanting rectangular sieves or screens are placed underneath each of the three upper pairs of rollers to the top of the next, to convey any fragments which escape proper crushing in one pair into the teeth of the next pair. Underneath the whole is a long rectangular frame carrying two long screens to separate the proper size of powder, and a board underneath to receive the dust and carry it down into a tub placed to receive it. Both the short screens and the long frame are attached to the framework of the machine, and receive a vibratory motion by means of appropriate mechanism.

1139. Attention must be paid to the angles at which the different screens are placed; this varies in different machines, and the proper inclination can only be ascertained by experiment. These screens will of course require to be changed for each different size of powder that is being made.

1140. *Action of the Machine.*—The general action of the machine will be understood from Fig. 266. The press-cake is placed in a hopper at the back of the machine, and carried up by means of an endless band of canvas having strips of leather sewed to it to catch the cake. The band passes under a scraper which prevents too much cake being carried up at once. The cake falls between the first pair of rollers, which work at a speed of about thirty revolutions per minute, and is immediately crushed up into granular fragments which fall in the first short screen. The whole of the grains, except the fragments which are too large, fall through this screen directly on to the surface of the upper long screen underneath, and fall through it likewise to the second, which permits the dust and minuter particles to fall through on to the sloping board underneath, down which they slide into the tub placed to receive them, but which retains the proper size of grain, which in turn rolls down it into another receptacle at the bottom.

1141. The larger pieces which escaped proper crushing in the first pair of rollers are shaken down by the first short screen into the second pair, to undergo the same process as at first, and so on with the third and fourth pairs of rollers. Some fragments of too coarse a size will escape all the rollers, and consequently require a third box to receive them in front of the other two placed to receive the dust and grain respectively. These pieces, termed *chucks*, require to be passed through the machine again.

1142. When the hopper has reached the limit of its travel upwards, and all the cake has fallen out into the band and been conveyed up to the machine, a clutch is relieved which stops the upward travel of the hopper, and a bell is rung in the watch-house where the workmen remain during the time the machine is working. The machine, being self-supplying, requires no watching when working. As soon as the bell rings the work-men re-enter the house and place the grain and dust in tubs ready for transmission to the proper store-rooms.

1143. *Danger of the Process.*—To judge from the large proportion of accidents which take place in granulating-houses, the process would appear to be specially dangerous. It is difficult to account for the fatality which accompanies granulating-houses. In any well-regulated factory the operation is not considered to be any more dangerous than any of the other processes, but statistics show beyond doubt that it must be specially dangerous. The probable explanation appears to be that if there has been any negligence anywhere in keeping fragments of foreign matter from the powder as it progresses through the various stages of manufacture, the granulating-house, in which the powder undergoes more crushing and grinding than it does anywhere else, and where there are a number of metal axles and bearings at work, is the place where such negligence will most surely tell.

1144. Dusting and Glazing.—The granulated powder as it comes from the machine contains amongst it a large quantity of dust. This is formed by the crushing action of the granulating machine, and must of course pass through the various sieves and screens with which the machine is provided along with the grain. The grain itself is not in a condition to be made use of as powder, being rough and porous on the surface and very angular in shape; and moreover, the presence of a large quantity of fine dust amongst it would render it not only most inconvenient to handle, but would also render it more liable to absorb moisture, and to deteriorate.

1145. A rough, unpolished angular grain would also very speedily rub down into dust, if subjected to much shaking in transport. It becomes necessary, therefore, to free the granulated powder from all traces of dust, and to polish or give a surface to the grains themselves to enable them to bear a great deal of friction without deterioration.

1146. Powder is freed from dust by placing it in revolving reels covered with cloth or wire mesh of various degrees of fineness, through which the dust escapes. It is *glazed* by causing the grains to rub against each other in revolving wooden barrels. The extent to which the operations of dusting and glazing are carried, and the nature of the appliances used, depend entirely on the density, hardness, and size of grain of the powder operated on.

1147. Large-grained, dense, hard powder will bear a great deal of knocking about in the reels without becoming disintegrated and forming fresh dust; and will, moreover, bear a great deal of friction in the glazing barrels, acquiring speedily a high degree of polish. But when operating on a small-grained, soft powder of low density, the dusting must be carefully conducted, as the process will develop as much fresh dust as it removes; and the amount of friction the grains will bear in glazing must be likewise carefully regulated.

1148. It is found in practice that powder may be divided into two general classes, each of which requires different treatment in dusting and glazing, viz., the *cannon powder* of all classes, and the *small-arm powder* of all classes. The former is not only pressed to a higher density, but is made of a larger size of grain; the latter generally is of lower density and much smaller size.

Modern cannon powder, being of large-sized grains and of firm consistency, admits of a comparatively open-meshed reel-covering being used in dusting, and of the process being continued as long as required without risk of injury to the grain. The powder can therefore be rendered perfectly free from dust, and sufficiently glazed at the same time, coming out of the reel as finished powder at one operation.

1149. The Dusting-reel.—There are two classes of reels in use, the *horizontal* and the *slope*, the former usually employed with powder of large grain, and the latter with fine-grain powder. Different powders take different lengths of time to be freed from dust, and require different descriptions of reel-coverings. It is impossible, therefore, to lay down exact rules in such matters, and it would be tedious to go over all the particulars of the numerous dustings that all kinds of powders undergo.

1150. A horizontal reel (Fig. 267), consists of a cylindrical skeleton of wooden hoops supported on a shaft by radial arms, the skeleton being covered with canvas or wire cloth. The reels are made in halves for convenience of repair and re-covering. The shaft is of iron, covered with wood; the radial arms are of gun-metal; the ends are formed of two short disks of wood screwed upon the shaft. One end can be unscrewed and drawn back. The bearing of the reel-shaft next this movable end is fixed in a block which can be lowered if necessary, so as to put the reel for the time being on a slope. In the middle of the reel is a square opening closed with a wooden door, through which the powder is placed in the reel, being run through a hopper at the top of the parallel wood-casing in which the reel is placed to confine the dust which escapes from it.

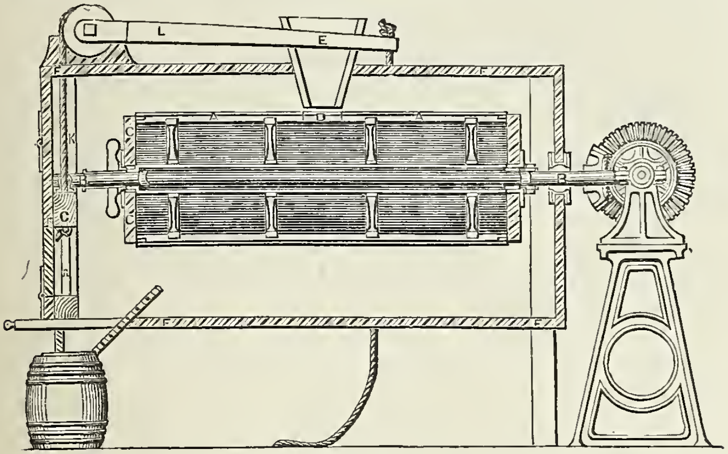


Fig. 267.—Horizontal Reel. (Section.)

AA.—Reel Covering.
B.—Shaft.
CC.—Movable End.
D.—Opening for loading.
E.—Hopper for loading.
FF.—Reel Case.
G.—Block carrying the bearing of the lower end, which can be raised or lowered by means of the rope, K, and Lever, L.

1151. Horizontal reels are intended to receive a quantity of powder for a certain length of time, and to revolve with it, shaking it against the reel covering, and thus forcing the dust through the meshes. When a reel has run the required time, say a half-hour, making forty revolutions, with a charge of powder, the driving-wheel is made to revolve very slowly, the end of the reel is lowered by means of a rope and lever, and the movable end of the reel is unscrewed and drawn back. As the reel slowly revolves the powder runs out into a hopper and is conducted into the barrels.

1152. Slope reels are not intended to retain the powder, but only to extract a certain portion of dust as it runs through them. They resemble the horizontal reels in general construction, except they have no ends and the shaft is set at a permanent slope. Each reel is provided with a feeding-hopper at its upper end; attached to which is a loose spout for guiding the powder into the reel.

1153. The Glazing-barrel.—Glazing-barrels consist of large strong wooden barrels (Fig. 268) supported on an iron shaft which runs through their centre. The barrels, two of

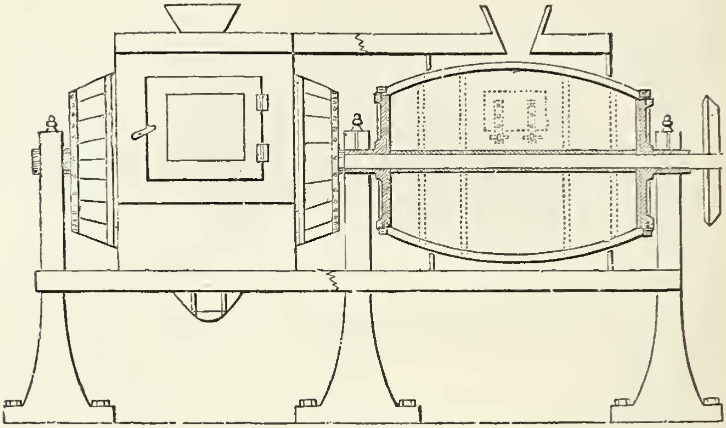


Fig. 268.

which are generally placed in line on one shaft, are made of oak, and are about 5 feet long and 2½ in diameter; the shaft is cased with wood where it passes through the barrels. Each barrel is provided with a small square door for charging and uncharging.

1154. The barrels are found to be peculiarly well adapted for the purpose, owing to their shape. Formerly wooden cylinders with straight sides were used, but it was found that the different sizes of grain had a tendency to separate in them, so that all did not receive an equal amount of polishing. But in the barrels, which are larger in diameter at the centre, there is a constant intermingling of the grain and a more uniform action.

1155. With large-grained powders sometimes a little graphite is used to obtain a better surface. This gives a fine silvery surface to the grain, but care must be taken to use the proper description of black lead. This is really an impurity, and should therefore be sparingly supplied to powder. It is never used with any of the fine small-arm powders, but only with powders intended to be used in large charges and with the express intention of giving them a surface which will, if anything, retard rather than quicken ignition. Inferior blasting-powder is sometimes polished in this way to a high degree of brilliancy, but the lustre is no test of its quality.

1156. The friction of the grains in the glazing-barrels necessarily generates a good deal of heat. Some of the fine-grain powders which require a long time in glazing come out so hot as hardly to admit of the hand being plunged in them. In all cases the heat generated is so great as to cause the powder to part with almost all its moisture; but as there is little or no escape for it, it condenses on the interior of the barrels and forms a hard coating with the powder-dust.*

1157. The glazing process not only polishes the grains, but tends to rub off their more prominent angles and to bring them to a rounded form. It generates a little dust, and requires, therefore, a second dusting, after which it has only to be dried to be ready for use.

1158. Drying.—The drying-rooms consist of large chambers having an arrangement of steam-pipes running along the floor, and provided with double doors which can be closely shut, and with ventilators at top and bottom which can be closed or opened from without. The temperature is maintained at from 125° to 130° F., and regulated by a large thermometer inside, which can be read from without.

The chambers are fitted with wooden racks, on which are placed the trays containing the powder. The powder is generally kept one day in the drying-room. In the case of large-grain powder, when withdrawn it is placed in barrels and headed up for issue. But in the case of fine-grain powders, a third dusting is sometimes requisite to remove all traces of dust and fit them for service. This is termed *finishing*, and is done in a horizontal reel.

Explosions of drying-rooms are comparatively rare.

1159. Special Powders.—On the introduction of the mammoth modern ordnance it became apparent that the ordinary powders in use were too sudden in their action for the power of the guns. This led to the making of special powders in the shape of prisms, cylindrical pellets, spheres, etc., with a view of modifying the explosiveness of the charges.

1160. Large-grain powder for heavy guns was first adopted in this country in 1861, at a time when other nations continued the use of small-grain. This great improvement in the mode of manufacture was the result of careful study and experiment. The invention of Rodman's "perforated cake," or prismatic powder, which has been adopted by, and is now in use in both Russia and Germany, and the "pebble" powder, similar to our "mammoth," adopted by England, created that revolution in the manufacture of gunpowder, based upon purely scientific

* Glazing barrels are now fitted with ventilating bungs which open at each revolution, and allow the heated air, surcharged with moisture, to escape; thus preventing "sweating."

principles of combustion and evolution of gases, that has enabled all nations to increase the size of their ordnance.

The question of variations of the density of powder and of the effect which such, especially when combined with variations in shape and size of grain, could not fail to produce, soon began to attract general attention. Those who studied the subject soon became aware of the immense advantage to be derived, not only from increasing the density of powder, and thereby lessening explosiveness and consequent strain on the gun, but from uniformity of density and shape of grain as affecting regularity of effect.

1161. EXPERIMENTS are still being made with a view of determining the description of gunpowder whose employment in large charges is attended with the least risk of overstraining the heavy guns in service.

The projecting charge should be so related, in its rate of combustion to the form of the gun from which it is fired, that, with a given convenient thickness of metal and length of bore, the maximum velocity of projectile attainable from such gun should be produced.

In comparing one gunpowder with another, the radical question is, which contains the best supply of gases, and which maintains this supply most advantageously at the required tension. The tension may be too low as well as too high; what is wanted is an elastic force which will not strain the gun more than is needed to give to the projectile the required terminal speed.

The causes which affect the quality and character of gunpowder, and the phenomenon which attends its application to projectile purposes, depend upon the concurrence of a variety of conditions, not a few of which are unknown.

In powder-making, ability to reproduce results will always be the important question; so many disturbing causes tend to affect its final qualities that, after every precaution has been taken to remove them, perfect uniformity in the finished article produced from day to day cannot, with our present means and knowledge, be surely counted upon.

1162. TERMS APPLIED TO DIFFERENT KINDS OF POWDER.—Gunpowder for the Naval Service is known and designated under the following heads: Hexagonal, Mammoth, Rifle, Cannon, Shell, and Small-arm; classed according to the size of the grain. They are all, as a general rule, made of the same proportion of ingredients, although the size and density of the grains, hardness, and amount of glazing is different with each.

These points are now being experimented on, and change of classification about to be made.

1163. Mammoth Powder.—This is an irregular, large-grained powder about 0.8 inch in diameter, which is used for large charges in heavy guns.

The large-grain powder greatly diminishes the strain on the gun, in producing a given velocity, from that due to ordinary cannon powder, because of the longer time required for the complete combustion of each grain. The larger the grain, other things being equal, the less will the maximum exceed the mean pressure, and the greater will be the charge required to produce a given velocity.

1164. Prismatic Powder, or perforated cake-powder (Fig. 269.)—This is ordinary powder made in the form of regular hexagonal prisms about one inch thick and 0.8 inch in the side, perforated with seven holes about 0.1 inch in diameter.

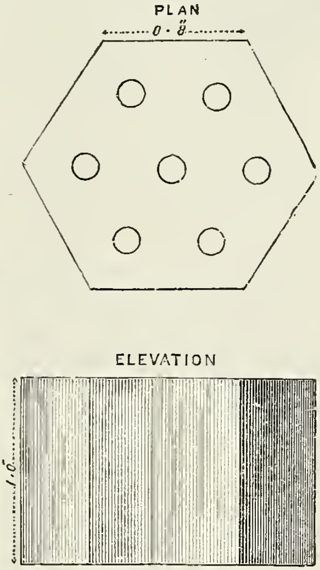


Fig. 269.

The cakes are formed by placing mealed powder, moistened sufficiently with water, in a mold of the proper form, and subjecting it to the required pressure.

In making up charges of this powder the prisms are built up regularly in the cartridge-bags like honeycomb, which are then tightly tied at the mouth, so that the grains are kept in place. These perforations thus form long tubes through the charge, by which the gas permeates the whole mass.

This powder, originally from the United States, has been introduced into the German, Russian, and Austrian services, and finds many advocates elsewhere. This form of powder is based on the theory that the grains, being ignited through the perforations, burn outwardly, producing a progressively increasing surface of ignition, thereby evolving greater volumes of gas, as the velocity of the projectile is increased, and the space through which the gas develops is augmented.

1165. Hexagonal Powder.—This powder, represented in

Fig. 270, is about 0.7 inch in diameter, and made by Dupont & Co. It has lately been introduced, and has given very good results. The granulation is very uniform. It is called "Hexagonal" by the manufacturers probably because it is nearly so in cross-section.

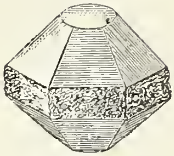


FIG. 270.

1166. WAFFLE POWDER.—This powder proposed by Commodore Jeffers, has been experimented with to some extent in the navy, with excellent results. It is pressed between plates with projecting ribs similar to "waffle-irons," which furnish a simple means of obtaining regular granulation, and thus controlling the surface. The fracture of the press-cake takes place along the grooves thus formed, dividing the cakes into squares, or rather truncated pyramids, precisely as in Fig. 271, and of about the same general size as the hexagonal powder.

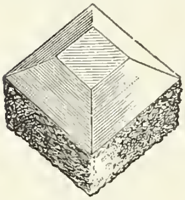


FIG. 271.

1167. PEBBLE POWDER—so called from its resemblance to small black pebbles. This is an English powder, similar to our Mammoth powder. It consists of irregular cubes, having edges from five-eighths to four-eighths inch in length, made by cutting up the press-cake into the required form.

1168. PELLET POWDER.—This is an English term applied to a large-grained powder. The pieces of the Pellet powder are all of uniform size and cylindrical shape, about one-half inch long and three-quarter inch diameter, with a perforation at one end to give greater igniting surface. (Fig. 272.)

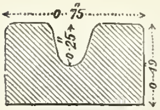


FIG. 272.

1169. RIFLE LARGE GRAIN powder, or "R. L. G." powder, is an English service powder, in grains which pass through a sieve of four meshes, but are retained in one of eight meshes to the inch.

1170. MACHINES FOR MAKING SPECIAL POWDERS.—The fundamental parts of every machine, for making this class of powder, are: 1st, a mold in which to place the powder-meal; 2d, a punch accurately fitting the mold, with which to compress the powder; 3d, some appliance for pressing the finished pellets out of the molds.

1171. A safe arrangement for combining these three is shown in Fig. 273. A is a small charge of powder placed in

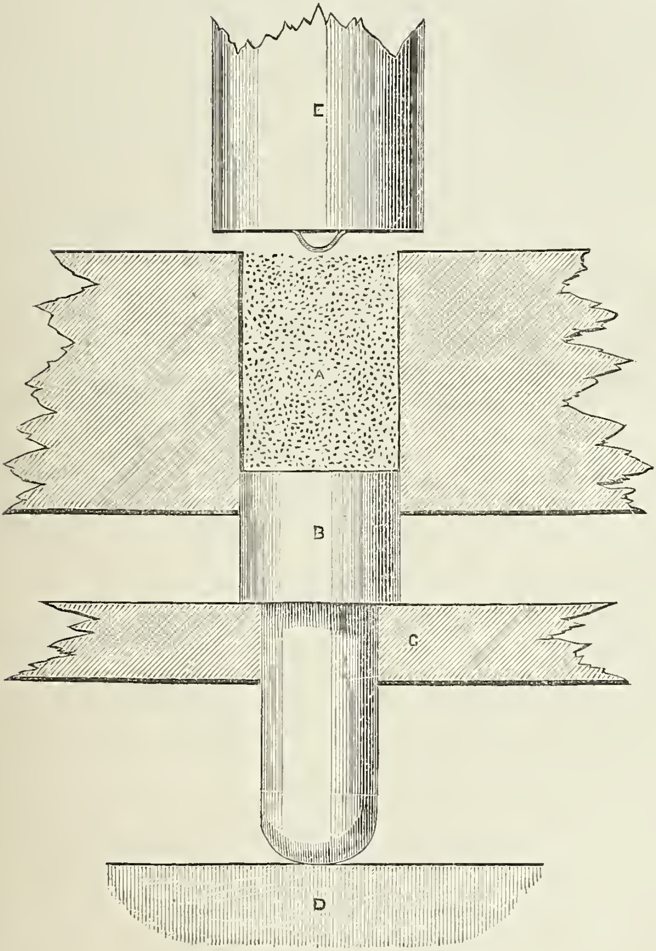


FIG. 273.

the mold, B, which fits it accurately. This punch has a shoulder on it on which it rests loose on a second plate, C, underneath the mold-plate. The lower end of this punch rests on the upper surface of the hydraulic ram, D. An upper descending punch, E, of larger diameter than the mold, can be brought down to the surface of the mold-plate either by a screw or by a hydraulic pressure, so as to close the mold.

With such an arrangement a pellet can be safely made, firstly, by bringing the top punch down on the plate and fixing it there so as to confine the powder; secondly, by raising the lower punch, by means of the ram, till a proper amount of compression has been given to the powder; thirdly, by stopping the pressure from beneath and raising the upper punch; and, fourthly, by raising the finished pellet out of the mold by the pressure of the ram underneath.

1172. It is plain that any form can be given to the pellets by altering the shape of the molds and punches, and that hollows or perforations can be made in the pellet if required. There is no difference really in any of these powders, except in the shape. A machine exactly similar to this could be used for making powder into hexagonal prisms perforated with holes. However, machines of different descriptions are employed in different countries and by different makers. Whatever arrangement is used, it must be always remembered that the only safe way of ensuring tolerable uniformity of density is to compress a certain amount of meal into a certain space; and that giving each pellet the same amount of pressure in pounds does not necessarily turn out powder of uniform density.

1173. EXPLOSION.—The phenomenon of explosion of gunpowder may be divided into three parts, viz.: *ignition*, *inflammation*, and *combustion*.

By ignition is understood the setting on fire of a particular part of the charge; by inflammation, the spread of ignition from grain to grain; and by combustion, the burning of each grain from its surface to centre.

1174. IGNITION.—Gunpowder may be ignited by the electric spark, by contact with an ignited body, or by a sudden heat of 572° F. A gradual heat decomposes powder without explosion, by subliming the sulphur. Flame will not ignite gunpowder unless it remains long enough in contact with the grains to heat them to redness. Thus the flame from burning paper may be touched to grains of powder without igniting them, owing to the slight intensity of the flame and the cooling effect of the grains.

1175. It may be ignited by friction, or a shock between two solid bodies, even when they are not very hard. Experiments show that gunpowder may be ignited by the shock of copper against copper, copper against iron, lead against lead, and even lead against wood; in handling gunpowder, therefore, violent shocks between all solid bodies should be avoided.

1176. The time necessary for igniting powder varies according to circumstances. For instance, damp powder requires a longer time than powder perfectly dry, owing to the loss of heat consequent on the evaporation of the water; a powder the grain of which has an angular shape and rough surface will be more easily ignited than one of rounded shape and smooth surface; a light powder more easily than a dense one.

1177. INFLAMMATION.—When grains of powder are united to form a charge, and fire is communicated to one of them, the heated and expansive gases evolved insinuate themselves into the interstices of the charge, envelop the grains, and ignite them one after another.

This propagation of ignition is called *inflammation*, and its velocity, *the velocity of inflammation*. It is much greater than that of combustion, and it should not be confounded with it. When powder is burned in an open train, fine powder inflames more rapidly than coarse; such, however, is not the case in fire-arms, owing to the diminution of the interstices. If a charge were composed of mealed-powder, the flame could no longer find its way through the interstices, and the velocity of inflammation and combustion would become the same.

1178. Now supposing one grain or particle alone be ignited, it will first be inflamed over its whole surface, and the progressive combustion will take place from the exterior to the interior. Its *rate of combustion* will therefore depend upon both its shape and size, leaving out entirely, for the present, the question of density and hardness. A particle of spherical or cubical form will expose less surface to ignition in proportion to its volume than one of an elongated or flat shape, and will consequently require a longer period for the combustion of its entire mass; the larger the particle, also, the longer will be the time required for its combustion.

1179. Looking, then, at one grain of powder by itself, we may say that the larger it is, and the more nearly its form approaches a sphere, the longer will its combustion take and the slower will be the evolution of the gas. When, however, we come to regard the action of an aggregation of such particles, as in the charge of a gun, the *rate of ignition* of the whole charge is also affected by the size and shape of the grain.

1180. The part of the charge first ignited is that near the vent, and the remainder is inflamed by contact with the heated gas generated by the combustion of this portion, so that the rate of ignition of the whole mass will be regulated by the greater or less facility with which the gas can penetrate throughout the charge, which is itself dependent upon the shape and size of the interstices between the grains. If the grains be spherical and regular in form, the interstices will be comparatively large and uniform, and the gas will penetrate the mass with facility; again, the larger the grains, the larger the interstices between them. If, on the other hand, they be flat or flaky and irregular in shape, the passage of the gas will be more difficult, and the rate of inflammation of the charge reduced.

1181. We see, therefore, that the considerations which affect the more or less rapid combustion of an individual grain of gunpowder, also affect the rate of ignition of a charge of such grains, but in an opposite direction; so that a form of grain which will individually burn rapidly may offer an increased resistance to the passage of the heated gas through the charge, and thereby retard its ignition, while a grain which will burn more slowly may allow of the charge being more rapidly ignited.

1182. By varying the size and shape of the grain alone, a powder may therefore be obtained, a charge of which shall be ignited rapidly throughout, but burn comparatively slowly, or one which shall be ignited more slowly, but when once inflamed burn very rapidly. It is necessary to draw a clear distinction between a rapidly-igniting and a quickly-burning powder.

1183. *Ratio of the Charge.*—The heat developed increases with the charge, and as the velocity of the gases increases with their temperature, it is therefore evident that a large charge is consumed quicker than a small one; it is also true that the loss of heat absorbed by the surface of the bore is much less sensible when the charge is great than when it is small, that is, the quantity absorbed is proportional to the surface, or the square of the calibre of the gun and the heat developed increases as the cube of the calibre.

1184. *The Resistance to be overcome.*—When the projectile offers a great resistance it is not so quickly displaced as when the resistance is slight; its motion in the first instance is then less rapid, and it evidently follows that the inflammation takes place in a space more confined as the resistance to be overcome is greater. The smaller this space is, the more heat is concentrated, the higher the temperature of the gases is raised, and consequently their velocity is increased, the inflamed gases have a less distance to expand through, and there follows from all these causes a train of effects which accelerates the inflammation of the charge.

1185. *The Place where the Fire is Communicated to the Charge.*—When a quantity of powder is contained in an enclosed space, all the sides of which offer an equal resistance, it is evident that the complete inflammation will be the quickest possible when the fire is applied to the centre of the charge.

In cannon, however, the force developed does not meet with the same resistance in all directions; the projectile yields as soon as sufficient force acts upon it, and as the combustion of the powder requires a definite interval of time, it follows that a great part of the charge is not consumed until after the displacement of the projectile.

Now the position of the interior orifice of the vent may influence the time required to displace the projectile, and this influences the inflammation of the charge. For example, with the regulation vent, it is the upper part of the charge which first takes fire; the inflammation is communicated to the adjacent parts and promptly reaches the projectile; the gases expanding displace it, and the inflammation takes place in a larger space than that at first occupied by the charge.

1186. *The Glazing* of the grains facilitates the rapid transmission of the flame through the mass.

1187.—COMBUSTION.—The velocity of combustion is the space passed over by the surface of combustion in a second of time, measured in a direction perpendicular to this surface. The diameter of the grains in "cannon powder" does not exceed 0.15 inch; the time required for combustion of such grains, therefore, is altogether too transient to be ascertained by direct observation.

1188. The velocity of combustion may be determined by compressing the powder composition into a tube and burning it, or by burning the *press-cake*. In the latter case take a prism of the cake of convenient length and about one inch square at the base, smear the sides with hog's-lard and place it on end in a shallow dish of water. The object of the lard is to prevent the spread of the flame to the sides, and the water is to prevent the lower end from being ignited by burning drops of powder. Set the upper end on fire and note the time of burning of the column with a stop-watch beating tenths of seconds.

In either way it will be shown that the composition, if homogeneous, burns in parallel layers, and that the velocity of combustion is uninfluenced by the size of the columns or by the temperature and pressure of the surrounding gas.

1189. Now take a spherical grain of powder of homogeneous structure, and so hard pressed that the gas cannot penetrate it. Apply fire to any part of its surface; the flame will immediately envelop it, and burn away the first spherical layer; the radii of the grain undergoing equal reductions in equal successive portions of time. Then at the end of half the time required for the total combustion of the whole grain, there will remain unconsumed a sphere of which the radius is one half the original radius, but the volume will be only one-eighth the original volume (spheres being to each other as the cubes of their radii.) At this epoch, therefore, seven-eighths of the grain will have been consumed.

1190. It will be seen from this, that for equal intervals of time, those taken in the first period of combustion give forth very much larger amounts of gas than those taken in the last; and that with a charge of such grains the gas is evolved in the inverse order desired: the evolution being greatest while the velocity of the projectile is least, and least while that velocity is the greatest; thus giving rise to excessive pressure at and near the seat of the charge. This may be remedied in some degree by increasing the size of the grain, the effect of which will be to diminish the amount of gas evolved in the first instant of time, and thereby diminish the pressure in the gun.

1191. It may be shown by direct experiment that the burning of a grain of powder in a fire-arm is progressive, and that the size of the grain exerts a great influence on the velocity of the projectile. For instance, if *one* piece of the *press-cake* was placed in a small mortar and fired, little or no motion would be given to the projectile. If this piece be divided into seven or eight parts, the projectile will be thrown a short distance, and by increasing the number of the parts or grains, so will the effect of the powder on the projectile also increase.

1192. The progressive burning of powder is further confirmed by the fact, that burning grains are sometimes projected from the gun with sufficient force to perforate screens of paper and wood at considerable distance. It is even found that they are set on fire in the gun and afterward extinguished in the air before they are completely consumed. The large grains of powder used in the fifteen-inch gun are sometimes thrown out burning to a distance of one hundred yards.

1193. THE VELOCITY OF COMBUSTION VARIES with the *purity*, *proportions*, *trituration*, *density*, and *condition* of the ingredients, also with the pressure under which the powder is burned.

Purity of Ingredients.—To secure the greatest velocity of combustion, it is necessary that the nitre and sulphur should be pure or nearly so.

This can always be effected by a proper attention to the prescribed modes of refining; but with charcoal it is different, for the part which it plays in combustion depends upon certain characteristics which are indicated by its color and texture. The velocity of combustion will be greater for red charcoal than for that which is black and strongly calcined; and for light and friable charcoal, than that which is hard and compact.

1194. *Proportions.*—By varying the proportions the velocity of combustion is varied.

The increase of sulphur tends to make a more violent explosion and a more quickly kindling mixture, as the sulphur is the kindling ingredient. Too much charcoal causes too slow burning. The diminution of the sulphur or nitre checks the rapidity of combustion, but may be made up by using more inflammable charcoal. The quality of the charcoal is powerfully affected by the temperature at which it is made. That made at a low temperature, or red charcoal, contains more hydrogen and less carbon, is more inflammable, and burns more rapidly, but, from its smaller proportion of carbon, must be used in greater quantity. It may be said that the charcoal is the varying ingredient; so that the proportions used at any time will depend upon the *quality* of the charcoal. In all naval powder, great care is taken to get a uniform quality of black coal, giving the nearest attainable approach to pure carbon.

1195. *Trituration.*—Gunpowder, unlike nitro-glycerine, fulminate of mercury, and other detonating substances, is not a chemical compound but only a mechanical mixture. By the incorporating process during manufacture the three substances of which powder is composed are so intimately mingled that the eye cannot detect the presence of any particular one. They are, notwithstanding, only mixed, and the saltpetre can be readily dissolved out by water, or the sulphur sublimed in the form of a vapor, by the application of a moderate heat, leaving in either case the other two ingredients chemically unchanged. The more intimate the mixture, the more nearly does gunpowder approach to a chemical compound, and the more violent is its combustion; but there always must remain a vast difference between the most complete mechanical mixture and the most unstable chemical compound. For this reason the combustion of gunpowder is only very rapidly progressive and not instantaneous, as is the case with the violent explosives mentioned above. It is this difference that renders gunpowder so valuable as a propelling agent, for were it not for its comparatively mild action, no gun could be made sufficiently strong to resist its force. The material of the cannon would be broken before the inertia of the projectile could be overcome.

1196. *Density.*—The density and hardness of the grains of powder are of quite as vital importance as their size and form, in determining the rate of ignition and combustion of a charge.

By density is meant the quantity of powder actually present in a given bulk.

It is important that this quality should not be confounded with hardness. A substance may be very hard and yet be of a low density. A powder with a very hard surface may be really less dense than another, the surface of which is softer. Of course very high density cannot be communicated without producing a considerable degree of hardness; but powder can be made hard without rendering it very dense, by pressing the dust in a comparatively dry state.

1197. *Hardness* seems to bear a direct relation to the power exerted in compressing, while density does not. Powder-dust, at a high degree of moisture, say 6 per cent. can be made very dense by application of moderate pressure, while that of 1 per cent. can only be brought to the same point in density by the exertion of enormous force. Of the two the latter will be the harder powder.

1198. Explosive Force.—By using a slower burning powder less heat and pressure are evolved at first, and, the waste of heat in the stage of initial pressure being less, more heat remains for expansive action. Hence the slower burning powder is weaker at first but stronger afterwards; and although the total quantity of gas be only the same and the pressure not so great at any point, yet the aggregate pressure throughout the bore may equal that of the more energetic and more dangerous powders.

1199. The question of the instantaneous explosion of gunpowder is one of extreme importance, for, independently of the increase of the actual amount of pressure which it would cause in a gun, this pressure when suddenly applied will have twice the destructive effect that the same pressure would have if slowly applied.

1200. The objects to be attained in regulating the size and density of the grains are, the greatest possible velocity of projectile combined with the least strain on the gun. These cannot be obtained by one set of conditions for all natures of ordnance. A small projectile moves quickly and relieves the strain in a still greater ratio. A heavy projectile not only moves slowly, but even a considerable motion does not relieve the strain in a proportionate manner, because the column of powder is larger in a large gun than in a small gun. With small-arms, consequently, we must use fine-grain powder, but large-grain powder with heavy guns.

1201. Owing to the effect which heat and pressure have in accelerating combustion, the size and density of grain that will suit any particular gun, and as a consequence the actual pressure in the gun itself, can only be determined practically.

1202. The explosive force of gunpowder may be calculated from the products of combustion, on the assumption that certain laws hold good, such as that the tension of a gas varies with its density and also with its temperature. It must, however, be remembered that these laws have been verified only within certain limits of pressure and temperature; and therefore, when we come to such very great pressures and temperatures as are met with in the explosion of powder, any conclusions founded on them must be received with caution, until the results have been confirmed by experiment.

1203. It is of little practical utility to attempt to determine the exact value of the explosive force of gunpowder, for the nature of the action in charges of equal weights will vary considerably not only from atmospheric causes, or in consequence of imperfections in the manufacture or in the qualities of the ingredients, but with the *size, form*, and *density* of the grains and the *form* of the cartridge.

1204. PRODUCTS OF COMBUSTION.—It was formerly supposed that in the combustion of gunpowder the whole of the oxygen of the nitre entered into combination with the carbon, forming carbonic acid, the nitrogen being set free, while the potassium combined with the sulphur, forming potassium sulphide, thus:

$$2KNO_3 + S + 3C = K_2S + 2N + 3CO_2.$$

Although the proportions indicated by the first term of this formula would coincide very closely with the proportions in which the ingredients are ordinarily mixed, *if the charcoal used were pure carbon*, that coincidence disappears when the actual composition of the brown charcoal generally used is taken into account. Thus the formula would give:

$2KNO_3$..................	202.1	= 74.84 per cent.
S..........................	32.	= 11.84 " "
3C........................	36.	= 13.32 " "

If, however, we substitute for C the constituents of brown charcoal as given below, we have:

Nitre...............................	74.84 per cent.
Sulphur.......	11.84 " "
Carbon............................	9.69 " "
Hydrogen..........................	.39 " "
Oxygen............................	2.97 " "
Ash..................................	.27 " "

Wherein the O 2.97 per cent. corresponds to 6.2 per cent. additional nitre.

It has been found, too, that the actual products of the combustion are much more complicated than this theory would indicate, and that they vary greatly with the conditions of the pressure and temperature under which the explosion takes place.

1205. The elaborate investigations of the products of combustion of gunpowder made some years since by Vogel, by Bunsen and Schischkoff, by Link, and by Korolyé, all coincided in proving that very little potassium sulphide is formed, but that it becomes oxydized to potassinm sulphate and hypo-sulphate, and that notable quantities of potassium carbonate are produced.

It results from this that a much smaller volume of gas is generated than the old theory calls for; only $\frac{5}{9}$ as much, according to Bunsen.

Bunsen found that one gramme of gunpowder yielded 193 cubic centimetres of gas reduced to 0°C, at the normal atmospheric pressure.

1206. The experiments referred to above were made under conditions differing widely from those obtained in actual practice, and since the above researches were made, experiments have been instituted both in America and Russia so as to imitate the condition of pressure and temperature which exist where powder is fired in guns. They agree in finding that when gunpowder is exploded at a low temperature, K_2SO_4 is formed, but under high pressure and great heat the sulphate is partially reduced to sulphide, thus accounting for the well-known fact, that if a gun be washed out after a discharge a large amount of potassium sulphide is found in the solution. Potassium carbonate seems to be formed under all conditions.

1207. The following is the result of an analysis of the residue obtained from firing a cannon loaded with shot, with a charge of 3 pounds of powder:

K_2SO_4	15.00
K_2CO_3	37.00
$K_2S_2O_3$	8.29
K_2S	38.18
K_2C_yS	.33
C	.09
Sand	.82
	99.71

Composition of the powder used:

KNO_3	74.175
S	9.890
Charcoal	14.835
Moisture	1.000
	99.900

Composition of the Charcoal:

C	72.5
H	2.9
O	22.3
Ash	2.3
	100.0

The composition of the residue was found to vary considerably in experiments made with different kinds of fire-arms, and with different charges of powder and shot, but the general conclusion was, that the increased pressure, by prolonging the time of interaction of the ingredients, and by augmenting the heat, gives rise to more gas and leaves less oxygen fixed in the residue.

1208. Berthelot, in an important research made during the late war in France, "On the Explosive Force of Gunpowder," draws attention to the importance of bearing in mind the phenomena of dissociation, according to which, the products found after cooling do not exist at the high temperature produced by explosion, but are replaced by more simple compounds.

Section III.—Inspection of Gunpowder.

1209. Inspection.—Before gunpowder is received from the manufacturer it is inspected and proved. As it may have the required strength and still be incapable of being long preserved, it is necessary to inquire into the manner in which the mixing, pounding, and other manipulations have been performed, for upon these the powder depends in a great measure for the preservation of its qualities.

1210. General Qualities.—Gunpowder should be of an even-sized grain, angular and irregular in form, without sharp corners, and very hard. It should be free from dust; and when flashed in small quantities in a copper plate, it should leave no bead or fouling. It should give the required initial velocity to the projectile, and not more than the maximum pressure on the gun, and should absorb but little moisture from the air.

1211. Examination by Hand will determine the firmness, crispness, and shape of the grains, and their freedom from dust; which can also be ascertained by pouring a portion of powder quickly from one vessel to another.

1212. Flashing.—This is done by firing about ten grains with a red-hot iron. Should there be many sparks, or should white globules or beads appear, or any spots be left on the plate, it would indicate that the incorporation had not been effectually performed, or that the proper proportion of ingredients had not been employed.

1213. Size of Grain.—The size of the grain is tested by standard sieves made of sheet-brass pierced with round-holes. These sieves are five in number, two being used for each kind of powder. Nos. 1 and 2 for rifle, 2 and 3 for cannon, and 4 and 5 for shell powder.

The holes are of the following diameters, viz.:

No. 1,	.3	of an inch	Rifle.
No. 2,	.15	"	
No. 2,	.15	"	Cannon.
No. 3,	.10	"	
No. 4,	.06	"	Shell.
No. 5,	.02	"	

The size of the grain is required to conform to the following:

Pass through	No. 1..........	all	Rifle.
Remain on	No. 2..........	all	
Pass through	No. 2..........	all	Cannon.
Remain on	No. 3..........	all	
Pass through	No. 4..........	all	Shell.
Remain on	No. 5..........	all	

Ten per cent. of variation is tolerated.

1214. Gravimetric Density is the weight of a given measured quantity; it is usually expressed by the weight of a cubic foot in ounces. The cube box is constructed with great accuracy, and the powder is simply poured into it until filled. A flat ruler is then drawn across the surface, and the box with its contents weighed. The weight of the box when empty being deducted, that of a cubic foot of the powder under examination is ascertained.

This cannot be relied on for the true density, as the size and shape of the grain may make the denser powder seem the lighter.

Cannon-powder should have a gravimetric density of about 875 oz., and not exceeding 900 oz., to the cubic foot. It varies with different makers from 875 to 975.

1215. Specific Gravity.—Assuming the usual values assigned to the elements of gunpowder in the scale of specific gravity, the absolute density of a homogeneous mass of the mixture is 1.985. This point is never reached in practical manufacture, and even in Government supplies the variation from this standard is such that frequently in a given bulk, powder consists of 25 per cent. of pores, in addition to all air-spaces between the grains.

The specific gravity of gunpowder is generally between 1.65 and 1.75. It is important that it should be determined with the greatest accuracy.

1216. THE MERCURY DENSIMETER,* invented by Colonel Mallet, of the French army, is the best apparatus yet devised for this purpose, and has, with slight modifications, been adopted for testing Navy powder. It is an instrument by means of which, in connection with an air-pump and a delicate balance, the density of a solid may be obtained. (Fig. 274.)

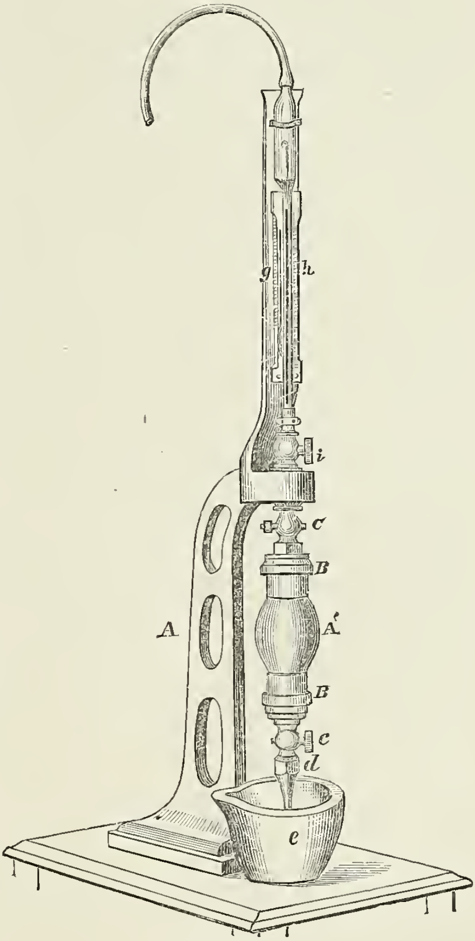


FIG. 274.

It consist of two principal parts—the immovable standard, A, with various fittings, and a hollow ellipsoidal glass vessel, A′, called the vase, having tubular extremities, each furnished with a metallic cap or collar, B, into which is screwed a short iron plug, C, perforated in the direction of its length, and fitted with a stop-cock. The upper orifice of the plug, which screws into the lower end of the vase, is covered with a diaphragm of chamois leather, the lower end of the upper plug being similarly fitted with one of very fine metallic gauze.

* Naval Ord. Papers, No. 1. Lieut. Commander J. D. Marvin, U. S. Navy.

The leather diaphragm strains the mercury, that of wire prevents grains of powder from being sucked up into the barometer-tube. A nozzle, d, screwed to the lower end of the bottom plug, dips into the mercury in the dish, e. The standard is a bracket of wrought-iron mounted on a table of convenient height.

It is fitted with a thermometer, g, a graduated scale for the barometer-tube, h, and a socket with a stop-cock, i, into which the barometer-tube and upper connection of the vase are screwed. A long bulb, which forms a part of the barometer-tube, surrounds and encloses the upper end of the stem. This acts as a receiver for the overflow of mercury, which is liable to be thrown up when leaks occur about the connections of the vase or tube. The bulb, which is in general outline a cylinder, contracts at its top, terminating in a conical point, over which the open end of a flexible India-rubber hose is slipped, thus connecting the tube, and through it the vase, with the air-pump.

1217. *The Ajustments.*—As all of the different connections of the vase where air-tight joints are made, are fitted with leather washers of constantly changing thickness, it follows that a variable degree of screwing up is required in order to make the junctions absolutely perfect. With the plugs which screw into the ends of the vase, it is of great importance that the extent to which they enter should be uniform for any given number of trials with the same powder, that is, they should be run into the same distance when each sample of powder is tried, that they were when the vase was filled with mercury alone; for if not in far enough the capacity of the vase is increased. In order to control this source of error as far as possible, set-marks are put on the collars and on the plugs. So long as these are either brought together or kept separated by a fixed and constant amount at different trials the experiment will be accurate. As coincidence will probably only occur when the washers are new, the separation, as they wear away or become compressed, must be estimated and carefully retained the same at different trials, so long as the same value is assumed for the weight of the vase filled with mercury alone.

In screwing on the nozzle and in screwing in the plugs, both wrenches should be used—one as a spanner, to hold against the other used as a wrench, otherwise the cementing of the collars may be started and leaks produced.

The zero of the barometer-scale is the lower end of the nozzle. The quantity of mercury in the dish and the level on which the dish rests should be so regulated that the immersion of the nozzle will not be greater, when the vase is full, than is necessary to prevent the admission of air. If this precaution be disregarded, the fluctuations in the height of the barometic column are very liable to mislead by attaching suspicion to the working of the pumps or to the closeness of the densimeter connections.

1218. When leaks in the connections of the vase occur they are indicated by air-bubbles, which can be distinctly seen passing up through the enclosed mercury. They can generally be located, if about the junctions, by closing the cocks in succcession from down up, meantime working the pump. If about the tube-connections, the flow of air will continue with all the cocks closed; if below this, the leak can be located between the two cocks. By tightening the junctions with the wrenches, or, if in the cocks, by screwing them up with a screw-driver, the difficulty is readily overcome. It sometimes happens that the cement which holds the collar to the neck of the vase becomes cracked and produces a leak. This can be located by filling the vase, closing both cocks, and then expanding the mercury by holding the vase in the hands or by wrapping a warm cloth around it, the effect of which is to force globules of mercury out at the point where the leak has occurred. A mixture of tallow and beeswax, applied at the same time that the pump is worked, will stop a leak of this kind.

1219. When the vase is unscrewed after the filling, the mercury which remains in the fine tubes of the end plugs must be carefully jarred out. This precaution is very important; for as the amount of mercury which thus remains varies at different trials, the accuracy of the weight taken is sensibly affected, if care is not taken to remove all the mercury outside the cocks. For this reason the globules which adhere to the vase and its fittings should be removed by brushing, before any attempt is made to get the weights. In testing fine powder, both plugs should be unscrewed, and, with the vase, carefully wiped after each trial; with mammoth this is only occasionally necessary.

1220. Whenever the barometer-tube or vase become coated on the inside with sulphuret of mercury, they should be dismounted and washed with aqua regia (by measure, two parts hydrochloric acid to one part of nitric acid). In the event of breaking the barometer-tube, expose the metallic socket, which holds the lower end, to the flame of a lamp, until the cement softens; remove the broken tube, and then screw the socket in place again. Coat the end of the new tube with cement, and insert it in the socket before the latter cools off, taking care that it stands vertical when in place; for if at all inclined it will be difficult to unscrew it for the purpose of cleaning or emptying the overflow-bulb.

1221. The Air-pump.—The air-pump used with the densimeter is of the ordinary construction, and is mounted on a light table. (Fig. 275.)

The vacuum-gauge, *a*, is in an air-tight glass case, which is

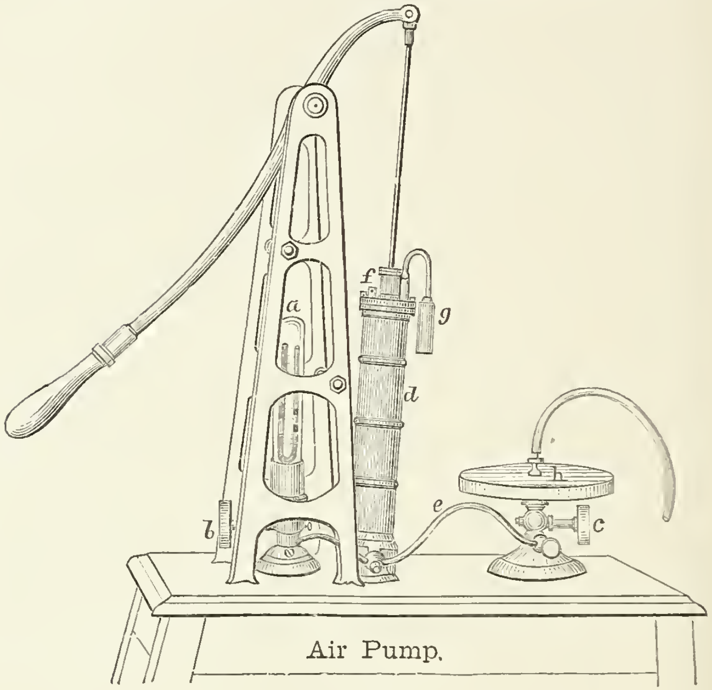


Fig. 275.

placed between the standards on which the brake works. It can be shut off from connection with the cylinder by the cock *b*, and air is admitted to it; and thence to the cylinder, etc., by unscrewing the glass cover, which can be turned by means of a chamfered ring on the brass collar into which it fits. Connection with the densimeter is controlled by the cock *c*. The cylinder, *d*, of brass, oscillates on trunnions at its base; its connections with the vacuum-gauge and the hose leading to the densimeter are through the curved pipe, *e*, which is held against its several bearings by set-screws. The upper cylinder head is fitted with an oil-hole closed by the screw-plug, *f*, and has an overflow-can *g*, to catch oil forced out in exhausting.

1222. *The Precautions* to be observed in using the pump, are: 1. Always keep the piston-rod and piston well oiled. 2. Keep the cocks *b* and *c*, and the connections of the tube, *e*, air-tight. 3. Screw down the vacuum-gauge case securely before commencing to exhaust. To determine whether the pump is tight and working well, close the cock *c* under the bell-glass table, *h*, and work the brake.

The vacuum-gauge will show whether air is admitted, and the leak may be located by the hissing sound made by the air rushing in.

The connections of the India-rubber hose require occasional looking to. The air-pump end is tightened by screwing up; the other can always be made perfect by cutting off a short section, thus getting a new and unstretched portion to adjust over the end of the barometer-tube of the densimeter.

1223. The Balance.—The balance employed in the process of determining density, is a simple beam-scale, constructed with great accuracy. (Art. 388.)

The great convenience of a decimal system of weights has led to the adoption of the scale of grammes in ascertaining the density of powder.

The set of weights used is of 5,000 grammes; approximately 11 pounds. The heaviest, 1 kilogramme, 2,204 pounds; the lightest, 5 centigrammes, 0.75 grains.

1224. The Process of taking the Density.—The powder to be tested, if of mammoth size, will require breaking up to a smaller granulation; for in its natural state it will not readily enter the vase, which is of but one-half-inch interior diameter at the neck. This is readily and safely done by using a light steel hammer, the powder resting on a table of wood.

For convenience of computation, it is advisable to use samples of 100 grammes; or, if employing grain weights, of 1543.3 grains.

Recourse may then be had to tables (see Appendix II.) for finding the density.

1225. *To take the Density.*—Weigh out the sample with great accuracy, taking 100 grammes, if practicable. The vase being mounted, with the nozzle screwed in place and well immersed in the mercury, close the lower cock, opening both the others, and exhaust the air from the tube and vase. When the gauge shows nearly a perfect vacuum, open the lower cock. The mercury from the dish will then enter and fill the vase, rising in the tube to nearly the barometic height, the vacuum meanwhile being kept up by continuous pumping. As soon as the column becomes stationary, close the lower stop-cock and re-admit the air to the top of the tube by unscrewing the casing of the vacuum-guage; close the other cocks and unscrew the nozzle; dismount the vase, jar out the mercury from the tubular spaces outside the cocks, brush the outside clean, and then place the vase on its rest and weigh it. Call this weight of vase and mercury $VM = W$. Empty the vase by opening the cocks, and allow the mercury to return to the dish; also let the mercury run out of the barometer-tube. If the inside of the vase is coated, unscrew both plugs and wipe it out with a cloth; or, if necessary, wash it with acqua regia. With clean mercury, washing is rarely required.

1226. In general practice, after having emptied the vase, one plug is unscrewed, and the sample of powder previously weighed out is poured in. The plug being again securely in place, the vase is mounted and the mercury pumped into it, passing up through the powder, filling its interstices, driving out the air, and rising to the same height in the tube as before. When this point is reached, close the cocks, admit the air, unscrew and weigh the vase as before, calling the weight of powder, vase, and mercury $PVM = W'$. From these two weights, together with that of the powder sample, the density is calculated by the proportion:

Density of mercury: density of powder = weight of mercury displaced by powder: weight of powder: or, if—

W = weight of vase and mercury,
W' = weight of powder, vase, and mercury,
w = weight of powder,
D = density of mercury,
d = density of powder,

then $W' - w$ = weight of mercury, vase, and powder, less the weight of powder, and $W - (W' - w)$ = weight of mercury displaced by the powder, and the proportion becomes—

$$D : d = W - W' + w : w,$$

$$\text{or,}\quad d = \frac{D \times w}{W - W' + w}.$$

The weight of W should be determined at the beginning and end of each set of trials, and the mean be used to correct the result of the whole series.

1227. The occasions will be rare when the accuracy of the results given in the table will be sufficiently affected by temperature to require correction; but if the thermometer varies materially from 66° Fahrenheit, and great accuracy is required, the density of the powder may be calculated by the formula already given, in which D will be the density of the mercury at the temperature of the time of observation, to be taken from the table; or, if no table is at hand, the effect of the temperature can be computed by the formula—

$$Dt = \frac{Do \times 5550}{5550 + t},$$

in which Do = density of mercury at zero centigrade, and t = any temperature above zero; or the correction may be attained with sufficient accuracy for ordinary practice by multiplying the decimal .00245 by the temperature expressed in degrees (centigrade). This product, subtracted from 13.596, gives the density for the temperature under consideration. The proportion given above, viz., $D : d = W - W' + w : w$, must be used to compute the density of the sample, if its weight be other than 100 grammes or 1543.3 grains; and the actual value of D should also enter into the calculation when the temperature varies materially from 66° Fahrenheit. For example:

Suppose $W = 4120$ grammes,
Suppose $W' = 3400$ grammes,
Suppose $w = 90$ grammes,

and the temperature = 90° Fahrenheit, then D = 13.52, approximately, and the density of the sample is 1.502.

1228. *Test of the Quality of the Mercury.*—The mercury used should be of specific gravity—13.55055 at 66° Fahrenheit. Its purity can be tested by comparison with distilled water by the following process:

Clean the vase and its connections thoroughly, and weigh it. Call this weight a.

Mount the vase and fill it with mercury, and again weigh it, calling the result b. Empty clean, and connect it again, substituting a dish of distilled water for that of mercury ordinarily used. Fill the vase by pumping slowly to avoid overflowing. Detach and weigh it again, calling this last weight c; then—

$$\frac{b - a}{c - a} = D,$$

the density of the mercury, which, if up to the standard, will correspond to that given in the table for the temperature at the time of trial.

The mercury used with the densimeter should frequently be strained through chamois-leather to remove impurities which are accidentally introduced into it in experimenting.

Form for recording experiments with the densimeter.

Record Number.	Date.	Class or Character of Sample.	Weight of Samp. *w*.	Weight of Vase and Mercury. VM.	Weight of Powder, Vase, and Mercury. PVM.	Density.	Thermometer.

1229. USE OF THE TABLES.—Tables I. and II. are arranged for use precisely like a table of logarithms of numbers. (Appendix II.)

Example, Table I.—Required the density corresponding to $W - W' + w = 824.5$. Opposite 824, in the left-hand column, will be found in the column headed o= for the first three figures, 1.64; and looking to the right in the column headed .5, the remaining figures 348 are taken, giving 1.64348 for the density.

If $W - W' + w = 821.6$, the first figures are taken from below, as indicated by the bar over 928 in the column headed 6.

EXAMPLE, TABLE II. (Appendix II.)

732.6 grammes = 11304.1 grains.

734.5 grammes = 11333.3 grains.

1230. MUZZLE VELOCITY.—A projectile on leaving the bore of a gun will have acquired its maximum velocity, generally termed the *initial velocity*. This essentially depends upon the powder, and is an important test of its quality.

1231. ELECTRO-BALLISTIC MACHINES.—The accurate determination of the *velocity* of a projectile at any point of its trajectory, has been one of the most difficult problems in the science of gunnery. It has exercised the talents and ingenuity of the best scientific minds of the age, and has given rise to much interesting discussion and many valuable experiments. The wondrous mechanical skill of the day, and our mastery over the powers of electricity, have, however, recently given us instruments which, in their results, more than realize the brightest dreams of the experimenters of a century ago. Their bulky, unwieldy, and expensive machines have given place to the neat and compact chronoscope, which, with its pencil of electrical light, now notes with unerring certainty infinitesimal intervals of time.

1232. BALLISTIC PENDULUM.—The ballistic pendulum invented by Robins, who is justly held to be the pioneer of modern gunnery, was first used in 1740, with the object of measuring the velocity of projectiles and the resistance of the air. It consisted of a tripod, from the top of which was suspended a pendulum vibrating freely on its axis of suspension. The bob was arranged, and of a size, to receive the impact of the projectile. Its prolongation below the bob was so contrived as to register the degree of vibration.

If such a pendulum, being at rest, is struck by a body of known weight, and the vibration which it makes after the blow is known, the velocity of the striking body may thence be determined. The quantity of motion of the body before impact is equal to that of the pendulum and body after impact.

1233. GUN PENDULUM.—The use of the gun pendulum seems to have been suggested by Robins, although Count Rumford first reported, in 1781, the results of various experiments made with it for the determination of the initial velocity of projectiles, and the most advantageous position of the vent. It consisted of a gun suspended in a horizontal position, and vibrating freely; the arc of its recoil being accurately measured when the gun was fired.

The quantity of motion of the gun as a pendulum is equal to that of the projectile, charge of powder, and the air. From this the velocity of the projectile may be deduced.

Extended experiments with both the ballistic and gun pendulums were made in England, from 1775 to 1791, by Hutton; at Metz in 1839 and 1840; and in the United States from 1843 to 1848, by Major Mordecai of the Ordnance Department. The instruments used in this country were the most perfect of their kind, and the importance of the results obtained cannot be too highly estimated. The instruments were, however, very expensive, had to be erected on permanent structures, and were rather limited in their application.

1234. ELECTRICITY.—Professor Wheatstone, in 1840, first suggested the employment of electricity in determining the velocity of projectiles. It was tried in the following manner: Two screens or targets of wire were so placed as to be cut by the ball during its flight. Each screen formed part of the circuit connecting a galvanic battery and an electro-magnet. This last suspended a pencil over a cylinder made to revolve uniformly. The rupturing of the target wire by the ball interrupted the current, and caused the magnet to release the pencil, which made a mark on the revolving cylinder. The time of revolution being known, the angle between these two marks determined the time of the ball's passage between the two targets; and knowing the distance of the targets apart, the velocity could be readily ascertained.

1235. The application of electricity, as seen in this first attempt, depends upon its very great velocity, which may be considered instantaneous for short distances. The greatest difficulty to be overcome lies in the manner of recording and preserving the time of flight, or, rather, of registering the instant the projectile strikes each target. When this is performed with the necessary accuracy, and the time it takes a projectile to pass over a certain distance thus obtained, the mean velocity will be the quotient of the space divided by the time. It may be said, without appreciable error, that this mean velocity is the actual velocity of the projectile at the middle point of the space passed over.

1236. In May, 1843, Professor Henry, now secretary of the Smithsonian Institution, presented and read a paper before the American Philosophical Society, "On a new method of determining the velocity of projectiles." It consisted in the application of the instantaneous transmission of an electrical action. Two wire screens placed in the path of the projectile were made to form parts of galvanic currents, connected with the axis and surface of a revolving cylinder which was covered by a graduated paper. The terminal point of the wire at the surface did not quite touch the paper, and the interruption of the primary current by the rupture of the wire of the screen by the projectile, induced an intense secondary current, on the principle of the common coil machine, which gave a spark that pierced the paper at the instant of the rupture.

To Professor Henry belongs the credit of first proposing the use of the spark from what is now known as the Ruhmkorff coil, which has been since adopted in the most improved and successful instruments.

Attention was thus early drawn to the novel question of devising and constructing a machine based on the employment of electricity, and to serve in solving the most difficult problems in gunnery. We will describe the most successful of the various instruments in use.

1237. Navez-Leurs Chronoscope.—This is probably the most successful of all the pendulum instruments, where the value of the time is expressed in arc. It may be said to consist of two separate instruments: the *pendulum* and the *disjunctor.*

1238. *The Pendulum.*—An upright plate of vulcanite with a graduated arc, A (Fig. 276), mounted on a stand, supports two pendulums, two electro-magnets, a pair of springs, and the

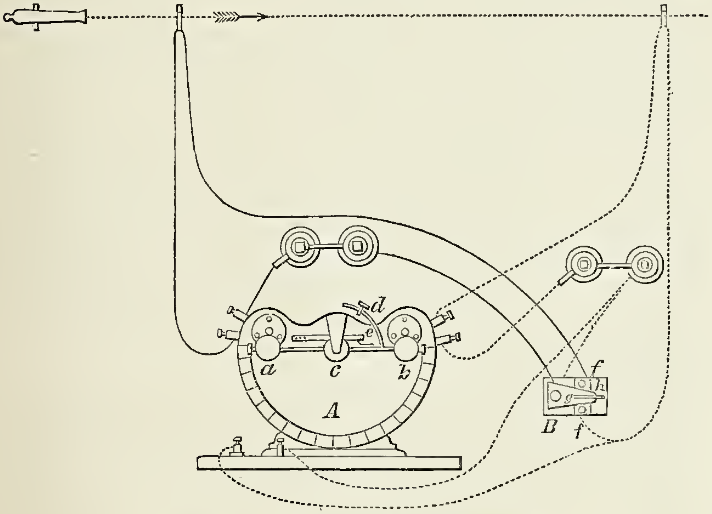


Fig. 276.—Navez-Leurs Chronoscope.

———— Circuit from the battery which magnetizes the chronometer electro-magnet.

.... Circuit from the battery which magnetizes the register electro-magnet.

— — — — Arrangement of the second circuit to investigate the valve of the coefficient x.

pivot upon which the escapement system works. One of the pendulums, a, is termed the *chronometer pendulum*, and the other, b, the *register pendulum*; and the magnets are so adjusted, one behind each pendulum, that when magnetized by a current of electricity they will just sustain the bobs of their respective pendulums, into both of which a piece of soft iron is inserted.

1239. An index-needle, having a vernier at the end to slide along the graduated arc, is riveted to a steel disk, *c*, working in the same axis as the chronometer pendulum, with which it oscillates, simply by friction, until clamped by the action of the escapement.

1240. The springs are attached to the vertical plate, and pass one on each side of the steel disk, *c*; near the ends of the springs are two cleats, one on each spring, between which a wedge-lever, *e*, can be adjusted to keep the springs apart; two other cleats close on the disk of the index-needle, which is between the springs, when the wedge-lever, *e*, is displaced by the face of the stirrup, *d*.

1241. The rod of the register pendulum is provided with an arc carrying a stirrup, *d*, which, in its descent when the pendulum is released, knocks away the wedge-lever, *e*, from between the springs, and so closes them upon the disk, *c*, of the index-needle, thus clamping it.

1242. *The Disjunctor.*—This consists of a small stand, B, on which are two pieces of brass, *f f*, each provided with a pressure-screw, a brass spring, *g*, fastened by another pressure-screw, and a cam, *h*, to work the spring; the brass pieces have platinum points, separated from each other by a very short interval, and the spring has also a platinum point below it, which, when pressed down by the action of the cam, connects the two other points; thus connecting, when requisite, the circuits through the apparatus.

1243. *The Electric Currents* are obtained by means of Bunsen's voltaic batteries, there being two circuits for an ordinary experiment, one (Fig. 276) passing through the magnet of the chronometer pendulum and the first screw, the other through the magnet of the register pendulum and the second screw; as both pass through the disjunctor, the simultaneous disjunction of both circuits can be effected by turning the cam, releasing the spring, and so disconnecting the platinum points.

1244. *Arrangement of Targets.*—The apparatus is placed in a small house at a distance of about 130 yards from the gun, so that it may not be effected by the firing, and the arrangement of the gun and targêts is as follows: The first target (Fig. 276) is placed at a distance of 10 yards in front of the muzzle of the piece, and the second target 40 yards beyond the former; both targets are of the same construction and dimensions; each consisting of a wooden frame having copper wires stretched across in parallel rows by means of pins in the sides of the frame, and these wires are broken by the passage of the projectile through them. In order to protect the wires of the first target from the action of the gas, a wooden screen is placed about 40 inches from this target, between it and the gun; the screen has a circular hole, about $1\frac{1}{2}$ calibres in diameter, through which the projectile passes.

1245. *Operation of the Instrument.*—The gun is fired the projectile passes through the first target, breaks the first circuit, and demagnetizes the magnet of the chronometer pendulum; the bob begins to fall, carrying with it the index-needle. When the projectile cuts the wires of the second target, the second circuit is broken, and the magnet of the register pendulum is demagnetized; the bob falls, carrying with it the arc and stirrup, which in its descent knocks away the wedge-lever and clamps the index-needle.

1246. The time due to this arc of vibration can, by the theory of the pendulum, be readily ascertained, but it must be greater than the time taken by the projectile to pass from one target to the other; for a certain small interval of time elapses between the rupture of the second circuit and the clamping of the index-needle. This small portion of time is found by means of the disjunctor, before the gun is fired, by breaking both circuits at once, and the small arc so found must be deducted from the arc determined by firing the gun.

1247. Benton's Thread Velocimeter.—This is a gravity instrument in which the weights are suspended by the tension of a cord, and it may be worked with common thread in place of the usual electro-magnetic currents.

The principle involved in this arrangement is, that the loosening effect of cutting a taut thread is transmitted to equal distances along the thread from the point of rupture, in equal, or sensibly equal, times. It is a principle that can be applied to others of the large class of machines for measuring small intervals of time.

The peculiar advantages found in the use of threads over electricity are, simplicity and cheapness of the apparatus, freedom from acid and water for the batteries, and the certainty and ease with which it can be operated by a single person, and that person the one who fires the gun.

The Velocimeter may be depended upon to give results sufficiently accurate for all the practical purposes of proving powder and making ballistic calculations.

For the purpose of explanation, the apparatus may be divided into the time-marker, or *pendulum-machine*, the *targets* No. 1 and No. 2, and the *threads*.

1248. Pendulum Machine.—The pendulum machine is shown in Fig. 277. *a* is a bed-plate of metal, which supports a graduated arc, *b*. This arc is placed in a vertical position by means of *thumb-screws* and *spirit-levels* attached to it; and it

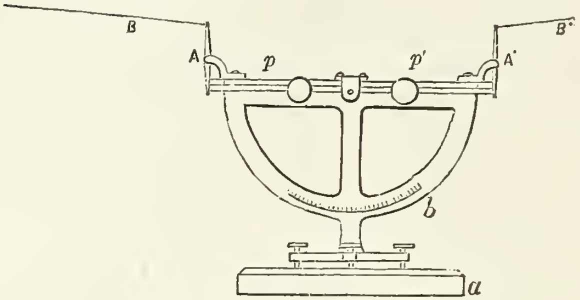


FIG. 277.

is graduated into degrees and fifths, commencing at the lowest point of the arc, and ending at 90°.

p p' are two pendulums having a common axis of motion passing through the centre, and perpendicular to the plane of the arc. The bob of the pendulum *p'* is fixed, but that of *p* can be moved up and down with a thumb-screw, so as to make the times of vibration equal.

1249. The apparatus to record the point at which the pendulums pass each other when they fall is attached to the prolongation of the suspension-rod *p'*, and consists of a small pin enclosed in a brass tube; the end of the pin near the arc has a sharp point, and the other is terminated with a head the surface of which is oblique to the plane of the arc.

As the pendulums pass each other, a blunt steel point attached to the lower extremity of the suspension-rod *p* strikes against the oblique surface of the head of the pin, which presses the point into a piece of paper clamped to the arc, leaving a small puncture to mark the point of passage. An improvement to the foregoing consists in attaching to the pendulum *p'* a delicate bent lever, which carries on its point a small quantity of printer's-ink; the pendulum *p* presses upon this lever, causing the point to touch the arc and leave a small dot opposite to the point where the pendulums pass each other.

1250. *The Compressors.*—The *lever-compressors*, A A', are made to hold up the pendulums by tightening the threads, B B', leading to the two targets. When the threads are severed at the targets by the projectile and slacken, the compressors are forced back by their springs, and the pendulums are released and immediately begin to fall.

The compressors are shown in detail in Fig. 278. They have each a slight notch at the lower end to receive the sharp end of the pendulum-rod, D, and hold it firmly in a horizontal position. At the upper end is also a notch for attaching the thread. C represents the spring which presses the compressor away from the pendulum when the thread is severed.

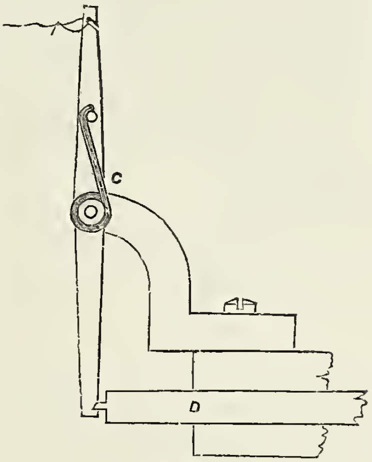


FIG. 278.

1251. The pendulum machine should be placed equidistant from the two targets, and sufficiently remote from the piece not to be affected by the jar of the discharge before both pendulums have commenced to fall. In the case of small-arms, it may be placed directly in the plane of fire; but in the case of cannon, it should be at least 100 feet to the right or left of it. (See Fig. 279.) In the figure, target No. 1 is

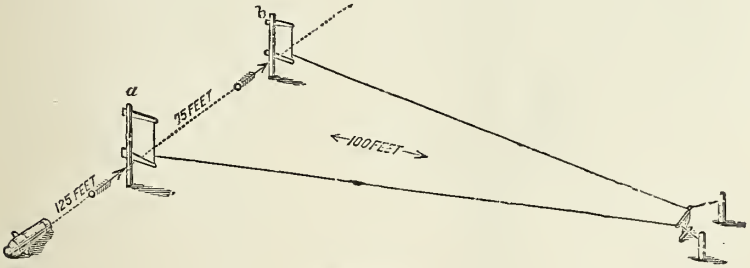


FIG. 279.

placed 125 feet from the muzzle of the piece. At this distance the thread will be severed by the ball before it can be broken by burning grains of powder. For ordinary purposes, however, target No. 1 may be placed directly in the muzzle of the piece, by attaching it to a vertical string stretched across the muzzle. A board supported on two posts may be used to screen the thread leading to the pendulum from target No. 2.

1252. *Targets for Cannon* are similar in construction, and composed of a single post fixed in the ground, to which are attached horizontal arms, as shown in Fig. 279. A thread, *d d* (Fig. 280), is stretched vertically between these arms, to which is attached the thread leading to the pendulum at one side. The point of attachment of this thread should be a little below where the projectile cuts the vertical thread, and is shown at *b*. Both threads to the pendulum pass through the loops of the compressors, and are fastened to posts set in the ground, in such relative positions to each other and the pendulum that the compressors will sustain the pendulums when the threads are tightened, and will relax their hold when broken. When cannon are carefully aimed, the projectile will cut both vertical threads directly; but in the case of small-arms, it is found difficult to ensure the cutting of the thread of No. 2 target without a special arrangement.

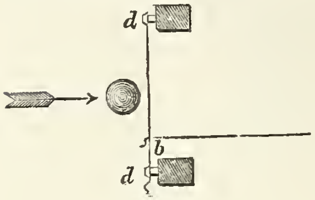


FIG. 280.

1253. *Targets for Small-arms.*—Target No. 1, for small-arms, consists of a piece of board (Fig. 281) with a vertical opening to serve as a rest for the muzzle of the gun. Across this opening, and directly in front of the muzzle, is stretched a short horizontal thread secured to two leather washers.

The thread *a* to pendulum No. 1 is drawn around the middle of the horizontal thread, and secured at the leather washer, b.

The muzzle of the piece is in contact with the intersection of the threads, which should be a little below the centre of the bore. The thread *b* is cut the instant the bullet reaches the muzzle, and the thread *a* slackens, generally, without breaking.

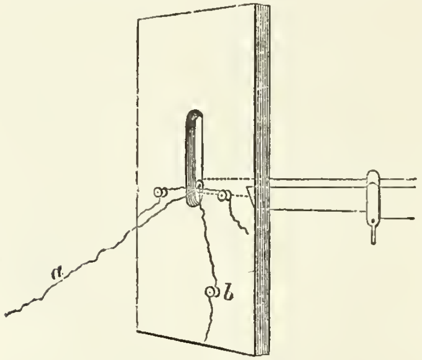


FIG. 381.

Target No. 2, for small-arms (Fig. 282), is composed of an iron target-plate, B, 1 inch thick, which swings freely on horizontal trunnions at its upper edge. The lower back edge of the plate rests lightly against the back of a sharp knife-blade, D, hinged at E. The thread, I, leading to pendulum No. 2 is wrapped around the slitted part in which the knife-blade operates, and fastened to the leather washer, F. C C are two flat-iron bars bolted to a post of wood let into the ground, and serve as supports of the trunnions of the target-plate, B. When the bullet strikes the plate, B, the knife-blade, D, is pressed backwards, cutting the thread, I, and releasing the pendulum. C and H are screens of boiler-plate to protect the thread and knife from fragments of the bullet.

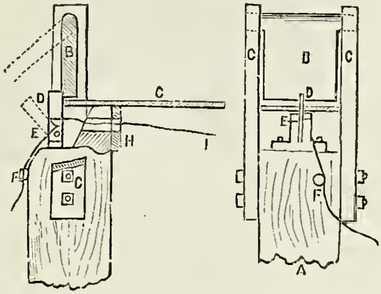


FIG. 282.

The target-plate, B, is made of tough wrought-iron about 6 inches wide, 6 inches deep, and 1 inch thick.

The knife should be made as sharp as possible, so that a slight tap of the finger on the target-plate will suffice to cut the thread.

1254. To Determine the Time.—It is considered that each pendulum begins to move at the instant the projectile cuts the thread, and that the interval of time corresponds to the difference of the arcs described by the pendulums up to the time of meeting.

Let m and m' (Fig. 283) represent the positions of the two pendulums before rupture, and let the interval between the rupture be such that the centres of oscillation will pass each other at i. As the times of vibration are equal, the interval of time will correspond to the arc $i\ i'$, the arc $m'\ i$ being equal to $m\ i'$. A vertical line through the centre of motion bisects the arc $i\ i'$. The reading, therefore, corresponds to one-half of the

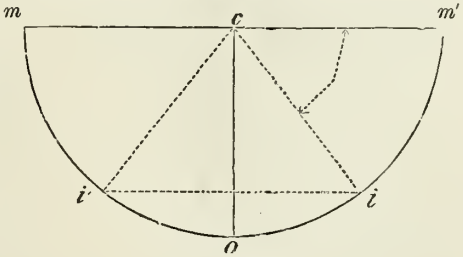


FIG 283.

required time, or time of passage of the projectile between the threads.

To determine a formula for the time that it takes for one of the pendulums to pass over a given arc, let l be the length of the equivalent simple pendulum, v the velocity of the centre of oscillation, or point m', y the vertical distance passed over by this point, x the variable angle which the line of suspension makes with the horizontal, and t' the time necessary for the point m' to pass over an entire circumference, the radius of which is l, with a uniform velocity, v, we have.

$$v = \sqrt{2gy}.$$

Substituting for y its value in terms of the constant angle of half-oscillation and the variable angle x, the above expression becomes

$$v = \sqrt{2\,gl\,cos.\,(90° - x)}\,;$$

from which we see that the velocity of the pendulum increases from its highest to its lowest point, and *vice versa.*

The time t' is equal to the circumference of the circle, the radius of which is l divided by the velocity, v; again dividing this by 360, we have the time of passing over each degree, or

$$t = \frac{2\,\pi\,l}{360\,\sqrt{2gl\,cos.\,(90° - x)}}.$$

To determine l, it is necessary to change the cylindrical arms of suspension to knife-edges, in order to determine the time of vibration through a very small arc. The mean of 500 vibrations will be very near the exact time of a single vibration. Knowing the time of a single vibration, the length of the equivalent simple pendulum can be obtained by the relation $l=l'\,t''^2$, in which t'' is this time, and l' is the length of the simple second's pendulum at the place of observation.

In this way all the constants of the expression for t are known, and by assigning different values to x, a table can be formed from which the times corresponding to the different arcs can be obtained by simple inspection.

1255. Le Boulengé's Chronograph.—In Captain Le Boulengé's instrument, the shot is made successively to cut two currents, and thus to demagnetize two electro-magnets which had previously supported two heavy bodies; the fall of these bodies, under the action of gravity, is the measure of the time taken by the shot to pass over a known distance.

1256. In the Navez-Leurs instrument the weight liberated by the shot is a pendulum oscillating in front of a graduated arc, the angle described by the pendulum being the measure of

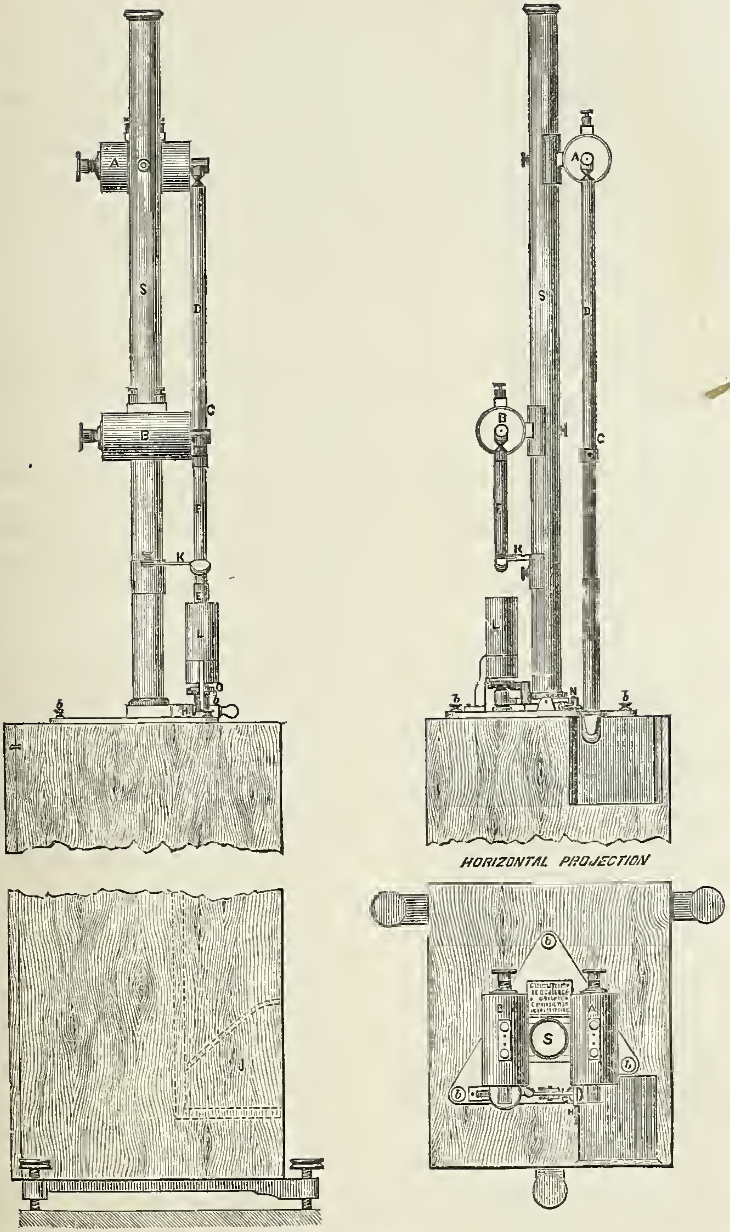


FIG. 284.

the time. In Le Boulengé's instrument, however, the weight falls *freely*, and without any disturbing influence, in a vertical direction, and the distance actually described by it is measured; the corresponding time being readily ascertained, and the velocity calculated.

1257. For cases where extreme accuracy is not required, a scale has been prepared whereby the velocity of the projectile can at once be read off without any calculation, an advantage which this instrument possesses over all others. Every part of the chronograph is of metal, and is consequently little influenced by change of climate, a property which would appear to render it peculiarly suitable for use in countries where vulcanite and other insulating materials rapidly deteriorate. This is probably the simplest and most popular of all the gravity instruments.

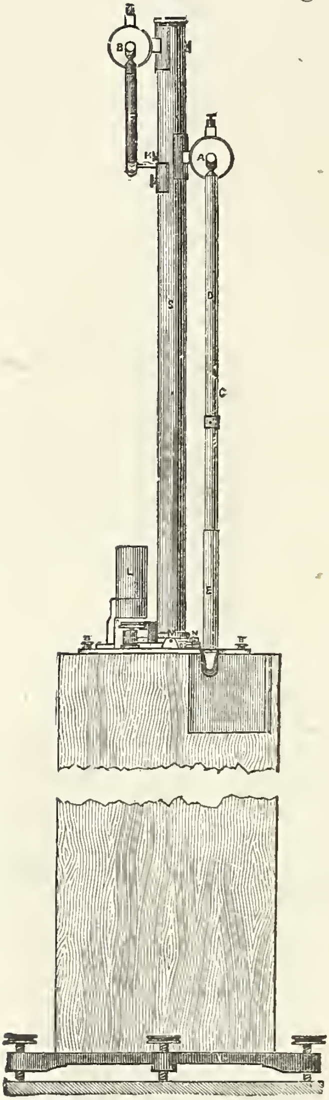


Fig. 285.

1258. The Instrument.*—Le Boulengé's Chronograph has been invented for two distinct purposes, viz.: 1. For taking the velocity of projectiles; 2. For measuring any short intervals of time. The instrument is set up for use as in Fig. 284, showing the arrangement for taking velocities, and Fig. 285 when required for measuring short intervals of time. It consists of a hollow brass column, S, which supports two electro magnets, A, B, and a small bracket, K.

* The instrument is here represented mounted on its transporting box. For accurate work from fixed positions it should be placed upon a pedestal resting upon masonary; and should be established with all the care which characterizes the setting up of astronomical instruments. This point has received great attention at the U. S. Naval Experimental Battery.

The column stands on a triangular base, upon which is fixed the *Trigger*, T. (Fig. 287.)

1259.—*The electro-magnet*, A, supports a long cylindrical rod (Fig. 284) suspended vertically and called the *Chronometer*. This rod is partially covered with two zinc tubes, D E, called *Registers*. *The electro-magnet*, B, sustains a shorter rod, F, named the *Registrar*. The *Trigger* (Fig. 287) consists of a circular steel knife, G, fixed in a recess of the spring, H, by means of the screw, N, which forms an axle upon which it can be turned so as to bring a fresh portion of the edge opposite the chronometer.

The spring, H, can be "cocked," or restrained, by means of the catch on one end of the lever, I. The other end of this lever carries a disk, O, fixed to a screw, by means of which it can be raised or lowered as required.

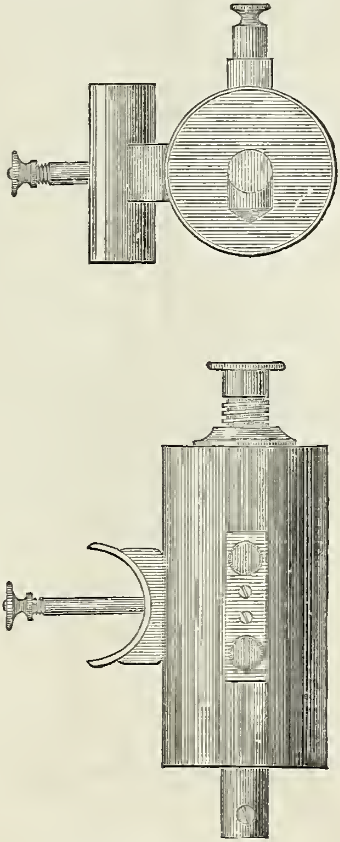


Fig. 286.—Electro-Magnet.

1260. This disk is vertically below the registrar when suspended to its electro-magnet; consequently, when the current through the second screen is broken, the registrar falls on the disk and releases the spring, H. The tube, L (Fig. 284), retains the registrar after its fall.

If it be required to alter the time taken by the registrar to release the knife, it is done by raising or lowering the disk of the trigger by turning it in the direction *with the sun* to *increase* the time, and *against the sun to reduce it*. The screw has a pitch of one millimètre, and the circumference of the disk is divided by notches into ten equal parts in which the pawl, P, works; by this arrangement the disk can be moved any required number of tenths of a millimètre (within certain limits), and is retained in the required position by the pawl.

1261. The screw, M, passes through the lever and acts against the fulcrum supporting it; it is intended for regulating the hold of the catch of the lever on the spring, which should always be as light as possible. This is regulated once for all, but should the spring at any time show a tendency to escape of itself, this defect can be remedied by slightly withdrawing the screw, M.

1262.—The *Disjunctor* (Fig. 288) is composed of a mainspring, t, carrying a cross-piece, covered with insulating material, and passing under the two steel plates, q q′. By pressing the milled-headed screw, z, the spring is compressed and held by the catch, x, allowing the plates, q q′, to come into contact with the metal pins, r r′, and thus complete the circuits by bringing the screws s v and s′ v′ into connection with one another. When the catch, x, is pressed, the mainspring being released, its cross-piece strikes the two plates exactly at the same instant, raises them from the screws, and thus breaks both currents identically at the same time.

Should it be thought at any time that the disjunctor is working inaccurately, the method of testing it, and of correcting it when out of order, is very simple, and will be described under the heading of "Method of correcting irregularities."

1263. The arrangement of the screws and electric current is precisely the same as when using the Navez-Leurs instrument, except that the chronometer battery must be increased in strength (because its electro-magnet is required to support a greater weight than in the Navez-Leurs instrument), and a different method adopted for introducing the disjunctor into the circuit. With the Le Boulengé chronograph, the two wires from the positive poles of the batteries are not joined as with the Navez-Leurs, but are taken to the two connecting screws, s s′, of the disjunctor; and thus the two currents, though passing through the disjunctor, are kept entirely separate.

1264. The electro-magnet, A, is magnetized by the current passing through the first screen; consequently when the shot cuts this screen, the *chronometer* is released and falls freely in a vertical direction. The other electro-magnet is in the circuit through the second screen, so that the *registrar* falls when this screen is cut, and, striking the disk on the free end of the lever of the *trigger*, liberates the spring, which carries forward the knife until it strikes the chronometer in its fall and makes an indent in the upper zinc tube.

1265. A very simple relation exists (as will be seen hereafter) between the height of this indent and the velocity of the projectile. It is evident that the time which elapses after the fall of the chronometer before the registrar is released, is the time taken by the projectile in passing over the distance between the screens; the less, therefore, the velocity of the projectile, the further in advance will the chronometer be, and the higher will be the indent.

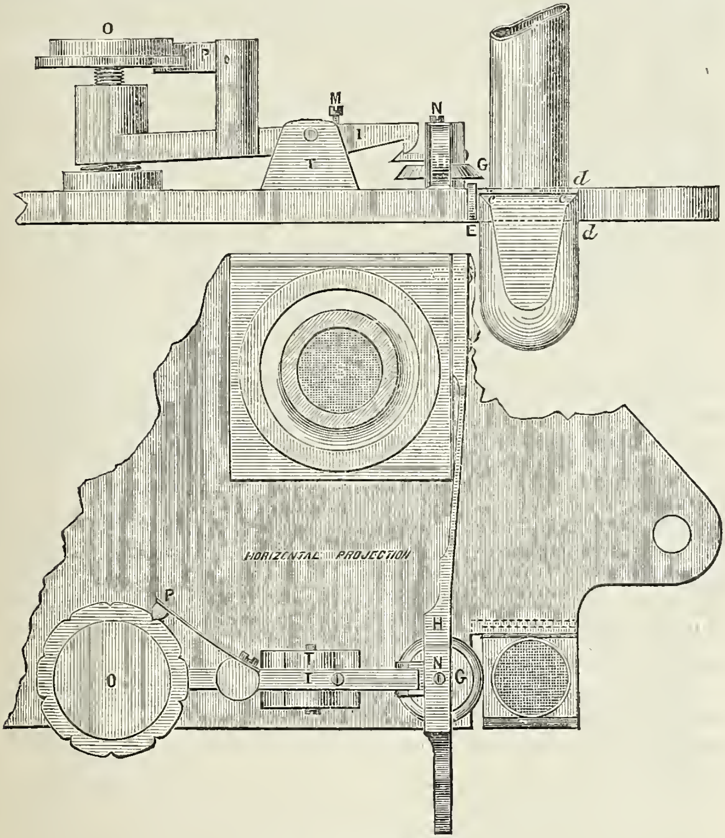


Fig. 287.—The Trigger.

1266. A *Graduated Rule* is used for measuring the height of the indent above the zero-point. It is of brass, and is graduated on both edges; the upper edge is a scale of equidistant parts, divided into millimètres, reading to tenths with a vernier, and is intended for use in connection with the tables. The lower scale is for reading off the velocity of the projectile without any calculation; it is graduated in mètres for a distance between the screens of 50 mètres. The zero-point on the scale corresponds with the *origin*, or the point at which the knife marks the chronometer, if the trigger is set in action when it is at rest. The rule is fitted at the zero-end with a jointed piece having a slightly conical projection, which enters into a recess in the bob of the chronometer, when applied for measuring the marks. Care must be taken not to injure this portion of the scale, or the measurement may be rendered inaccurate.*

1267. THEORY OF THE INSTRUMENT.—As stated above, if the trigger be set in action when the chronometer is at rest, a mark will be made by the knife on the zinc, which point we will call the *origin*, as it is the zero-point from which the height of fall of the chronometer must be calculated.

Let H be the height above the origin of the mark obtained by firing a projectile through the screens. Since the chronometer follows the law of the fall of heavy bodies,

$$T' = \sqrt{\frac{2\,H}{g}}$$

will be the time it was in motion before receiving the impression. Now T′ would be the time required by the projectile to traverse the distance between the screens, supposing that the chronometer commences to fall the instant the projectile passes through the first screen, and further, supposing that it is struck by the knife at the precise instant the shot cuts the second screen. But this is not the case. In fact, after the rupture of the first screen, a certain time, θ, elapses before the electro-magnet is demagnetized sufficiently to free the chronometer; the movement of the chronometer will therefore be delayed, and the observed time consequently diminished, by the quantity θ.

1268. Again, some time elapses between the cutting of the second screen and the moment when the knife reaches the chronometer, viz., the time required for the following operations:

θ' for the demagnetization of the electro-magnet supporting the registrar.

t' for the fall of the registrar to the disk of the trigger.

t'' for the disengagement of the catch.

t''' for the knife to pass over the horizontal distance which separates it from the chronometer.

Now it is evident that the chronometer, before it is struck by the knife, will have been in motion during the sum of the above time in addition to the time taken by the shot in passing

* The rule, being a proportional scale, can be used for any distance between screens. At the U. S. Naval Experimental Battery the interval is a hundred feet, and the reverse face of the rule is graduated to inches and decimals, and tables corresponding are used.

over the distance between the screens. Consequently the observed time, T′, is too great by the sum of $(\theta' + t' + t'' + t''')$. We have also shown above that T′ is too small by the quantity θ, the time required to demagnetize the chronometer electro-magnet. Therefore, to ascertain the true time, T, we must deduct from T′ the quantity $(\theta' + t' + t'' + t''' - \theta)$, which we will call t.

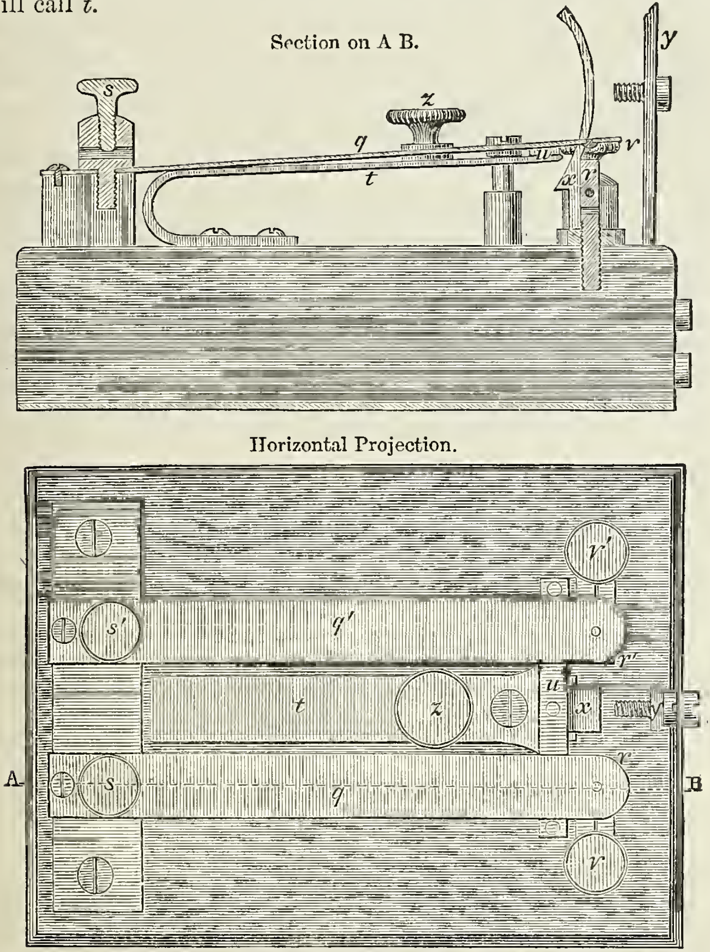


FIG. 288.—Disjunctor.

We have then $T = T' - t$.

1269. Now suppose $T = 0$, or, in other words, suppose the shot to cut both screens simultaneously, then we should have

$T' = t$. From which it appears that t should be the time recorded on the chronometer if both currents were cut identically at the same instant. This we can do by using the disjunctor, and we thus obtain a mark, on the lower zinc tube, at a height above the origin equal to the space passed over in the time t, which we call the *disjunctor-reading;* the time corresponding to this reading must be deducted from the whole time recorded on the chronometer, to arrive at the time taken by the shot to traverse the distance between the screens. As before stated, the disk of the trigger can be raised or lowered so that the disjunctor-reading can be altered (if required) within certain limits, and we can thus regulate the instrument so that the time t shall have a constant value. The value of t for which the velocity scale has been calculated is $0''.15$, and the height of the corresponding mark above the origin is 110.370 mill. (4.248 inches). Starting with this assumption, a scale has been calculated for a distance between the screens of 50 mètres, by means of which the velocity of the projectile can be at once determined without the aid of any calculation. Should it be necessary to place the screens nearer to one another, the velocity can be found by multiplying the number read off on the scale by the fraction $\frac{D}{50}$, D being the actual distance between the screens in mètres.

1270. The method of calculating this scale is as follows:

Suppose the shot to have a velocity of 500 mètres a second, it would take $\frac{50}{500} = 0''.1$ to traverse the distance between the screens.

The instrument will, therefore, mark $0''.15$ (disjunctor-reading) $+ 0''.1$, or $0''.25$, and the corresponding height of fall from the origin will be $H = \frac{1}{2} g T'^2 = \frac{g \times (0.25)^2}{2} = 613.17$ mill.

Conversely, if the mark on the chronometer is 613.17 mill. above the origin, we know that the velocity of the projectile is 500 metres a second. The disjunctor-reading being at a height corresponding to $0''.15$, and the screen 50 mètres apart.

This calculation has been made for a series of velocities increasing from mètre to mètre for all ordinary velocities, and the corresponding heights engraved on the scale supplied with the instrument.

This scale is inconvenient, as it is necessary to use a multiplier in order to ascertain the velocity in feet corresponding to the number read off, and this multipler varies with the distance between the screens.

1271. Method of Adjusting the Instrument.—*Setting up the Chronograph.*—For transport the different portions of the instrument are packed in a box, which can be made to serve the purpose of a stand by means of an iron tripod supplied with it.

This arrangement is no doubt very convenient in cases where it is required to move the instrument constantly and set it up in different positions. For proving powder, or in similar cases, where the instrument is stationary it is advisable to have recourse to a more permanent arrangement, as at the Experimental Battery, Annapolis.

1272. The triangular piece which supports the trigger and the column is fastened to a heavy cast-iron base by the three screws supplied with the instrument. This base is 13 inches square and 1 inch thick, and is supported on four milled-headed levelling-screws, which work in brass V's let into the oak block.

1273. The instrument is permanently fixed to the stand, and is covered, when not in use, by a glass case to protect it from injury, a small beaker containing calcined chloride of calcium being used to absorb the moisture under the case.

1274. The electro-magnets are fixed in position by passing the screwed stems through the column and fastening them with milled-headed nuts (Fig. 286). Two zinc tubes, or registers, are placed on the chronometer; to put on the small one the bob at the lower end must first be unscrewed. The tubes should be pressed slightly out of shape before being put on, to cause them to fit tightly on the rod, and not to shift too easily. It is well to see, from time to time during the operation, that the bottom of the tube is resting against the bob.

1275. The connections with the battery and the screens having been established, and the currents found to pass correctly, and to be of sufficient strength, the next step is to adjust and regulate the instrument.

This consists of three operations, viz.:

1st. Levelling the instrument.

2d. Regulating the power of the electro-magnets.

3d. Regulating the height of the disjunctor-reading.

1276. 1st. *Levelling the Instrument.*—For this purpose the chronometer is used. After having cocked the trigger, suspend the chronometer to its electro-magnet, and bring it into its proper position by means of the levelling-screws.

In levelling from front to rear see that the inclined plane on the bob, on the side opposite the number, rests very lightly against the projecting edge of the triangular base.

To level laterally, the right face of the bob is brought exactly in line with the salient angle formed by the projection above referred to. In this position the left face of the bob is a short distance from the screw, E; the edge of the knife is opposite and slightly behind the zinc tube; and when the chronometer falls, the projecting ring passes clear of the knife-edge. To test whether this is the case, break the circuit, by means of the disjunctor, and notice whether there is any friction, or if anything catches during the fall.

To ascertain whether the chronometer is properly levelled from front to rear, see that the inclined plane on the bob rests along its whole length against the projecting edge; then remove it sideways out of the vertical, by pushing the bob against the screw, E, when it will return into its original position, if properly levelled.

The levelling being completed, and the registrar suspended to its electro-magnet, the inclined plane on the bob, on the side opposite the number, should rest very lightly against the edge of the arm, K. This arm is fitted in a bracket, and its position can be altered by means of an adjusting-screw. This adjustment need only be performed once for all ordinary positions of the instrument when used in taking velocities.

If the electro-magnet and the bracket be removed to the upper part of the column, as shown in Fig. 285, it may be necessary to readjust the arm in order that the registrar may still hang vertically. The levelling of the registrar is verified in the same manner as in the case of the chronometer, viz., by ascertaining—1st. That when moved laterally it returns to its original position; 2d. That it falls freely without touching the tube, L.

1277. 2d. *Regulating the Electro-magnets.*—This is done (as with the Navez-Leurs instrument) by withdrawing the core of the magnets until they are only capable of just supporting the rods. It is always an advantage to work with weak magnets, as the variation in the time required to demagnetize them need not be taken into account; should, however, their power be insufficient, the operator will experience some difficulty in suspending the rods.

The following method has been adopted for making the electro-magnets of just sufficient power:

The chronometer, with its zinc tubes, is increased in weight by means of a brass tube, which is slipped over the upper zinc. It is then suspended to the magnet, and the core gradually withdrawn until the power is insufficient to support the weight, when it falls. The core must be turned slowly and gently, so as not to free the rod by any jar or vibration. The extra weight is then removed, and the chronometer can be suspended without difficulty.

The other magnet is regulated in the same manner, a smaller brass tube being supplied for increasing the weight of the registrar.

In order to suspend the chronometer to its electro-magnet without difficulty, the following method should be adopted: Hold it lightly in the left hand at the centre, the fingers open and towards the body; allow the bob to rest upon the second joint of the first finger of the right hand, the hand being half open, the palm vertical and turned towards the body, and the fingers together; the chronometer is thus held in a vertical position, the numbered face of the bob being turned towards the operator. Bring it in this position to the electro-magnet, by placing the exterior surfaces of the two cones in contact, and, as soon as attraction is perceived, let go with the left hand, still keeping the fingers near to catch the chronometer should it fall. Then slowly lower the right hand, so that the two cones, sliding over one another, remain with their points only in contact, and place the bob in its proper position by moving the first finger of the right hand, upon which it still rests. This done, withdraw the support of the right hand by lowering it vertically, when the chronometer will remain suspended in its proper position. If there should be any vibration it will soon cease from the friction against the rest.

The registrar is suspended in the same manner, but the *chronometer is always placed in position first.*

Difficulty is sometimes experienced by beginners in suspending the parts of the chronograph; minute details have therefore been given as to the best way of doing so.

The other operations are exceedingly simple.

To cock the disjunctor, so as to establish the currents, press the milled-headed screw, z (Fig. 288), with the centre finger of the right hand, until the spring is held by the catch, x.

To break the currents press the catch, x, with the forefinger of the right hand, the thumb being placed against the support, y.

In cocking the trigger care must be taken not to disturb the level of the instrument; consequently the left hand only is used, the fingers being placed against the support of the tube, L, and the spring drawn back with the thumb until it is held by the claw of the lever.

The trigger must always be cocked before attempting to suspend the chronometer.

1278. 3d. *Regulating the Disjunctor Reading.*—As we have said before, this reading should represent a time $= 0''.15$, and the mark should consequently be 110.37 mill. above the origin. This height is shown on the scale by a special mark called *disjunction.* To facilitate the operation, commence by tracing on the small zinc tube a circle at the required height. For this purpose fasten the vernier by means of the clamping-screw, with the index opposite the line marked "disjonction." Place the chronometer flat on a table with the numbered face next the body, and apply the rule to it by inserting the conical point of the hinge in the recess of the bob, allowing the index of the vernier to rest on the zinc. Support the end of the rule in the right hand, and with the left turn the tube, taking care to keep it pressed against the bob at the lower end of the chronometer. In this manner a fine line is traced on the tube, with which, when the instrument is well regulated, the disjunctor-marks ought to correspond.

The indent made by the knife is a notch, clearly cut in the metal, the base of which is in a plane perpendicular to the axis of the tube. It is the section of this plane with the tube which must be taken as the mark, and the index of the vernier must always be brought against it when reading the height of the indent.

The point of the vernier index is of the same form as the edge of the knife, and consequently fits accurately against the plane (or lower) side of the indent, so that there can be no uncertainty in the measurement.

The instrument having been prepared, a disjunctor-reading is taken; if the mark is exactly on the circle previously traced, no alteration is necessary, and the experiments can be proceeded with at once.

Should the mark, however, be above the circle, the space through which the registrar falls must be diminished by raising the disk of the trigger; if below, the disk must be lowered. In the former case it is turned in the contrary direction to the sun, and in the latter case with the sun.

The arrangement by which the amount of alteration in the height of the disk is regulated has already been pointed out when describing the trigger. When the height of the disk has been regulated for some previous experiments, the reading will not vary on another occasion more than a few tenths of a millimètre, and this can be (at once) corrected by turning the disk, in the proper direction, through the required number of divisions of the circle.

1279. Method of Taking Velocities.—The instrument is prepared for measuring velocities in the same manner as for taking the disjunctor-reading. First cock the disjunctor, then the trigger, and afterwards suspend the chronometer and registrar. Before suspending the rods, however, it is advisable, in order to prevent the possibility of errors in measuring the indents given by different rounds, to make ink-marks round the lower edge of the upper zinc tube, about one-twentieth of an inch apart, and to turn the tube after each round so as to bring these marks successively opposite the line on the centre ring. Equidistant lines are thus obtained, upon which the marks of successive rounds will be registered.

The same may be done with the lower (or disjunctor) tube; by this means each tube can be made to register about twenty indents at each end, and can be turned end for end when the circle at one extremity is completed.

An indent having been obtained on the upper tube by firing a projectile through the screens, the velocity may be ascertained in two ways: 1st, by measuring the height of the mark above the origin, and calculating the time and corresponding velocity from the tables; 2d, by measuring the velocity on the scale adapted for that purpose.

The former method is the more accurate, while the latter takes less time, and, for ordinary purposes, such as the proof of powder, indicates the velocity within sufficiently narrow limits.

1280. Method of Correcting Irregularities.—When the foregoing directions for adjusting and regulating the instrument are adhered to, not only do successive disjunctor-readings taken between the rounds agree within very narrow limits, but the readings generally remain constant from one round to another. It is therefore sufficient, when accustomed to the chronograph, in order to ensure its regularity, to take a reading of the disjunctor after every three or four rounds.

The operator must judge from the regularity of these readings whether he should repeat them, and whether it may be necessary to readjust the instrument.

The following directions will assist him. If the reading is too high or too low, repeat it; and if the difference remains constant, and is small, the height of the disk of the trigger need only be altered. Should, however, the error be considerable, indicating that there is a variation in the force of one of the magnets, this force must be regulated.

1281. Should the disjunctor-readings become irregular, the following points must be looked to, viz.:

1st. If one of the magnets has not become too strong.

2d. If the instrument is properly levelled; that is, if the rods hang vertically, and do not rest too heavily against the support.

3d. If there be not an imperfect connection in the circuits, including the battery and the screens.

Should the mark obtained be indistinct, the chronometer must be brought nearer to the knife (by means of the levelling-screws), care being taken that it still falls freely and without friction.

1282. If, during the experiments, one of the currents becomes broken without any apparent cause, try (after ascertaining that the screens are properly mended), whether there is contact between the plates, q q′, of the disjunctor (Fig. 288), and the pins, r r′, by removing the wire from the binding-screw at one extremity of the plate, and bringing it into contact with the screw at the other end. If the current is thus re-established, it shows that the break occurs at the point of contact of this plate with the screw, which should be cleaned by passing a piece of paper between them.

1283. The only parts of the instrument that require special attention are the points of contact between the rods and the electro-magnets.

These four points ought to be kept clean and polished, and it is as well never to touch them with the fingers, and to rub them frequently with a chamois-leather. The rest of the instrument may be covered with rust and dirt without affecting its working, whilst a single spot of rust on one of these points may cause irregularity in the disjunctor-readings. If by accident they should get rusty, very fine emery cloth must be used to clean them, care being taken to rub round the point so as not to alter its form.

1284. From the nature of the instrument itself nothing can affect the chronometer while falling, and the rate of falling being according to a well-known and invariable law, it is evident that there can be no *constant error* in the measurement of velocities, provided that the scale is correctly graduated, and the disjunctor in proper working order.

1285. The *accidental errors* which may be committed correspond to those which occur when a series of disjunctor-readings are taken, after the instrument has been properly regulated; and any one at all accustomed to using the instrument will see at once that the errors in determining velocities (including errors in reading the scale) do not exceed a few decimètres, and that the results are sufficiently accurate for ordinary experiments, the variations being far less than those due to other causes.

1286. If the two currents are not broken by the disjunctor identically at the same instant, there will be a *constant error* in the readings. The disjunctor is not liable to get out of order, but, if required, its accuracy can at any time be verified as follows:

Determine the height of the disjunctor-reading, and then invert the currents by removing the wires which were first at s and v to s′ and v′, and those at s′ and v′ to s and v (Fig. 288), so as to send the chronometer current through the side on which the registrar current first passed, and vice versa. Having done this, take several readings, and ascertain whether they agree with those previously taken, which will be the case if the disjunctor is correct.

If there should be any difference between the height of these two series, it represents *double the error* of the disjunctor, and from the relative position of the marks it can be seen on which side contact is first broken; *i. e.*, which plate is raised before the other. To correct this error, it is only necessary to elevate or lower one of the screws, v v′, until both plates are raised by the cross-piece of the spring exactly at the same moment.

1287. SCHULTZ CHRONOSCOPE.—This instrument, invented by Captain Schultz, of the French artillery, is designed for measuring very short intervals of time. By means of it, periods varying from thirty seconds to the $\frac{1}{5000}$ part of a second have been measured with very great approximation, and with great ease and accuracy. It was introduced into the United States by Colonel Laidley for the purpose of determining the initial velocity of projectiles in the proof of gunpowder.

A tuning-fork, making an ascertained number of vibrations per second, is arranged to trace on the blackened surface of a revolving cylinder a sinuous line, showing the beginning and end of each vibration. This sinuous trace will be an actual scale of time. If, then, the instant the projectile reaches each of the two given points in its trajectory be marked upon the cylinder, beside the sinuous line or scale of time, the number of vibrations comprehended between the two marks will be an exact measurement of the time required.

The important parts of the machine (Fig. 289) are the *Cylinder*, *Vibrating-fork*, *Electric Interrupter*, *Ruhmkorff*

Coil, *Pendulum*, and *Micrometer;* and, while experimenting, the *Galvanic Batteries* and *Targets*.

1288. *The Cylinder*, with its connections, forms the most

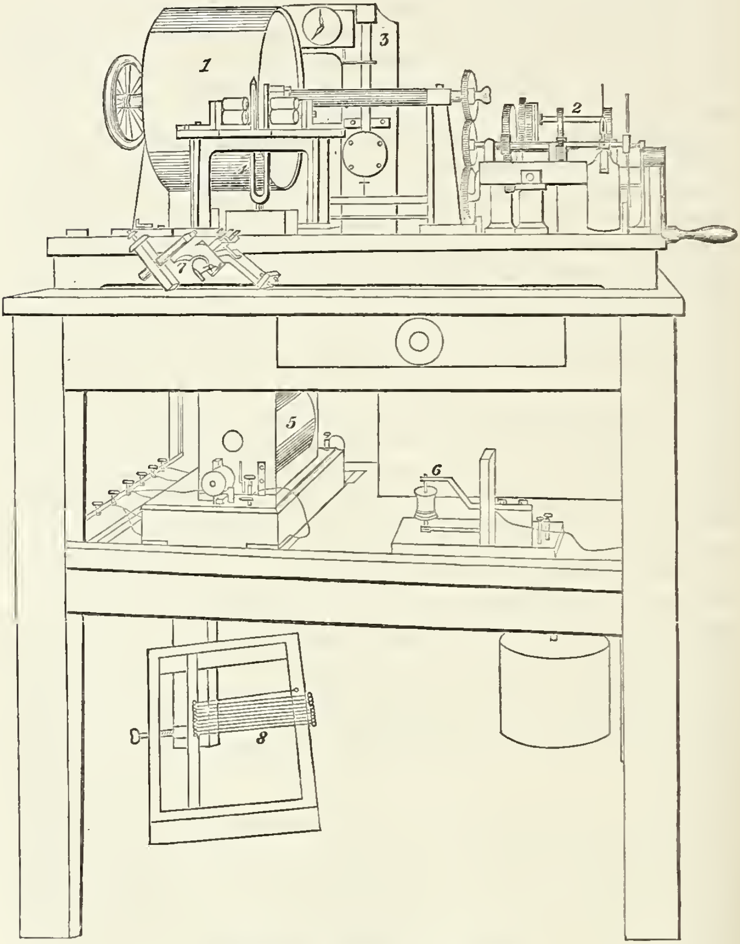


FIG. 289.—Schultz Chronoscope.

1. Cylinder. 2. Clock-work. 3. Pendulum. 4. Vibrating-fork. 5. Ruhmkorff Coil. 6. Interrupter. 7. Micrometer. 8. Target.

bulky of the working parts. A double motion of rotation and translation is given it by means of a cord and weight acting on a system of clockwork. These motions can also be given separately by hand, independent of the weights. The cylinder is detached from or connected with the clockwork by a thumb-screw that clamps one of the wheels; and the sliding motion is produced or stopped by closing or opening the nut in which the translating-screw works.

The silver face of the cylinder is covered with a thin coating of lamp-black, which is removed by the trace and spark, and the bright surface exposed in strong contrast to the blackened parts.

1289. *The Vibrating Fork* stands immediately in front of the cylinder. It is clamped tightly to the bed-plate of the machine, which is of iron, resting on a stout oak table. On each side of the fork, supported on a stand, are two small electro-magnets, meant to originate, sustain, and equalize its vibrations, and can be set at any required distance from it. The left branch of the fork is armed with a flexible quill point, which can be made to touch the cylinder at pleasure, and thus trace upon it both the middle line and the line of vibration, in the form of a helix; the former while the fork is at rest, and the latter while it is vibrating.

1290. *The Interrupter* is the point of termination of the poles of the battery which supplies the current for the small electro-magnets. It consists of a light beam one end of which is fixed, and the other end, extending beneath two electro-magnets and over a small cup containing mercury and alcohol, has a platinum blade attached which rises from or descends to the surface of the mercury as the beam is affected by the electro-magnets above it. One pole of the battery passes through a platinum wire into the mercury; the platinum blade at the end of the beam becomes the other pole, and each time it touches the surface of the mercury, completes the circuit and excites the electro-magnets on each side of the fork, as well as those which act on the beam itself. The magnets lift the blade out of the mercury by attracting the beam and thus rupture the current. This done the magnets lose their magnetic force, release the beam, and the blade descends to the mercury, completing the circuit, and so on. All the electro-magnets being in the same current, are subject to a change of condition with each motion of the beam, which must rise and fall as often as the fork vibrates, accommodating itself to and acting in unison with it, in order that the small electro-magnets shall always assist and never retard the vibration of the fork.

Small sliding weights are attached to the beam, which, when moved, change its time of rise and fall; the mercury-cup, when raised or lowered, has the same effect. Should the above means fail, recourse is had to the nuts that clamp the beam, and these are tightened or loosened until the proper movement is obtained. If the fork vibrates for twenty or thirty seconds without apparent change, the beam is supposed to be moving in unison with it, as there can be no permanent vibration of the fork unless this condition be fulfilled.

1291. *The Ruhmkorff Coil.*—The secondary currents obtained by magnetic induction possess a high degree of intensity, and if the circuit be broken at the moment the current is passing, a brilliant spark will be observed at the point at which the interruption is occasioned.

The secondary currents are rendered efficient by means of the Ruhmkorff coil. It consists of two concentric helices of copper wire; the primary or inner coil consisting of a stouter and shorter wire than the secondary or outer coil, which is made of a very thin wire, insulated by silk, and each layer of coils is carefully insulated from the adjacent layer; a bundle of soft iron wire is placed in the axis of the coils. The primary coil is not continuous through its length, but admits of being broken. So long as the current circulates uninterruptedly through it, the iron core becomes an artificial magnet. As soon as the current is broken, however, the iron core ceases to be a magnet, but a powerful secondary current is induced in the secondary coil, which will emit a spark at any point in its circuit where broken.

The power of the instrument, and the intensity and striking distance of the spark, may be much increased by connecting the primary wire with the modification of the Leyden jar, commonly called a *condenser.* This consists of a pile of alternate sheets of brown paper or oil-silk and tin-foil.

To use the Ruhmkorff coil, the primary wire is connected with a battery and the targets; the secondary wire with the instrument; one of the ends is brought through a glass tube close to the cylinder just over the fork, the other end is connected with the bed-plate and thence with the cylinder and other parts of the machine, except the support for the glass tube, which is carefully insulated. By this arrangement, when the primary current is broken by rupturing the target wire, a secondary current is induced and a spark is projected from the end in the glass tube to the face of the cylinder, which represents the other end, where a bright spot beside the trace indicates the exact instant the rupture took place.

1292. *The Pendulum* is used to determine the exact number of vibrations of the fork in a second of time, a matter of the greatest importance. It is connected with an ordinary clock-work, and should be regulated to beat half seconds with accuracy. Below it is an insulated upright spring, the movable end of which is in contact with a metallic stand. To determine the number of the fork's vibrations, the Ruhmkorff coil is put in connection, no longer with the targets, but with the pendulum, one pole of the primary current being attached to the spring, and the other pole to the metallic stand. A spring is fixed to the end of the pendulum itself, which, at every double beat, strikes the insulated spring from its place, thus breaking the current and giving a spark on the cylinder to mark each second of time. As the cylinder can run for thirty seconds, the *number* of vibrations sought can be obtained with close approximation, by dividing the entire number of vibrations registered on the cylinder by the number of seconds.

1293. *The Micrometer* serves to divide a vibration on the cylinder into very small parts for close reading. It magnifies the trace, and, by means of movable cross hairs, fixes the position of the spark. A double vibration of ordinary length may be divided into 2,000 parts, and as each of the former is about the $\frac{1}{250}$ portion of a second, the readings of the micrometer may approximate to the $\frac{1}{500000}$ portion of a second of time.

1294. *The Batteries.*—A Bunsen's battery of eight cups, the zinc cylinders of which are seven inches long and three inches in diameter, is connected with the interrupter and tuning-fork; and another battery of two, three, or four cups is connected with the Ruhmkorff coil. The number of cups used with the latter will depend on the size and distinctness of the spark required, and on the length of the wire used. The wire need not be more than .06 inch in thickness.

By using a solution of bi-chromate of potash instead of nitric acid in the porous cups, a saving in the cost of the liquid is effected and the injurious fumes of nitrous acid avoided, without loss of strength in the battery. The liquids in the cups should be renewed, and the parts of the battery cleaned, once a week.

1295. *The Targets.*—In working the instrument it is essential that the current pass only through one target at a time, there being but one coil and one battery, no matter how many targets may be used. After the first target is ruptured, the current must be transferred to the succeeding one before the projectile reaches it, and so on throughout the series. The targets must therefore be so made and arranged as that each shall transfer the current to the succeeding target the instant its wires are ruptured; and that the transfer shall be completed before the projectile reaches the latter.

To effect this, a wire from one pole of the battery connects both targets on one side. From the other pole a wire leads to the first target, and is attached to one of two brass rods that are on the top of the frame. A wire from the second brass rod leads to the second target. If the rods be connected by resting a piece of metal on both, the current will pass continuously through both targets; but if the rods be disconnected, the current, being interrupted by their separation, will pass through the first target only. A series of brass levers are placed on the top of the frame, extending directly over the two rods. From their lower ends a wire passes down and up to form the target; when the wire is tightened, the levers are raised from contact with the two rods. Now, the first target being broken, the levers are released by the slackening of the wire and are instantly pressed down upon the two rods by a series of steel springs, and the connection made with the second target.

In the experiments made at the Frankford Arsenal, with targets one foot apart, the current was transferred from one to the other by means of a simple brass spring, in less than $\frac{7}{10000}$ of a second of time.

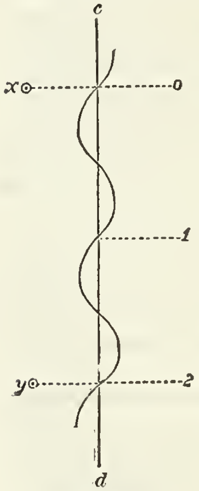


FIG. 290.

1296. *Principles of the Machine.*—From the above description of its parts, it will be understood that the *Fork*, when vibrating, traces a scale of time on the coated surface of the revolving cylinder, the unit of which is the duration of a double vibration. The value of the unit for this machine is $\frac{1}{249.055}$ of a second of time. The *Interrupter* originates, sustains, and equalizes the lateral extent of the vibrations of the fork; and the *Coil*, in connection with the targets, deposits a spark beside the traced scale of time, to indicate the instant the wire of a target is broken, thus marking the beginning and end of each interval to be measured. The *Pendulum* serves to determine the number of vibrations made by the fork in a second of time.

The measurement of time by this instrument, then, depends on the equality of duration of the vibrations made by the fork. These vibrations are known to be isochronal for the same fork, when their amplitude is constant, and are in no way affected by the motions of the other parts of the machine.

The vibrations made by the fork are recorded on the cylinder in the form of a sinuous line, as in Fig. 290, making the scale of time. The middle line, *c d*, traced by the fork when at rest, is of great importance, as it divides the sinuous line and gives the exact points of the origin and end of each vibration. Even when not in the middle, no error can occur when double vibrations are counted.

As expressed on the cylinder, each of the double vibrations is sufficiently large to admit of being divided into tenths by the eye; when greater accuracy is required, the micrometer must be used.

To determine the value of the interval between two sparks, the number of double vibrations are counted. Where both sparks fall immediately opposite the intersections of the two lines, the value will be summed up in entire double vibrations, as in Fig. 290, x and y being the sparks.

When one or both of the sparks do not fall opposite an intersection, the value of the interval is thus arrived at. In Fig. 291 the sparks are at x and y. From a to b are twenty-three double vibrations. By the eye or the micrometer, the distances $a\ x$ and $b\ y$ are found to be .8 and .25 of a double vibration. Therefore $x\ y = 23 + .8 + .25 = 24.05$ double vibrations $= \frac{24.05}{249.055} = .096565$ seconds of time.

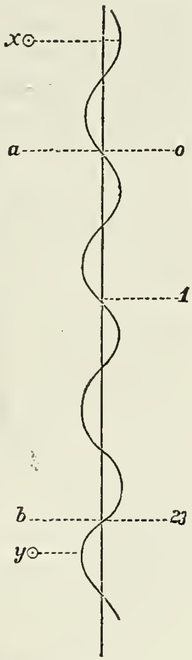


FIG. 291.

As the velocity $= \frac{\text{space}}{\text{time}}$, suppose the space between the targets to be one hundred feet, then the velocity of projectile will be equal to $\frac{100}{.096565} = 1035.5$ feet per second.

1297. *To Use the Chronoscope.*—The cylinder is coated by revolving it over the flame of an oil-lamp with a flat wick. This takes ten minutes, and twelve or fifteen rounds may be fired before the coating needs renewal. The operator, standing in front of the instrument, releases the translating-screw, pushes the cylinder to the right, clamps it to the wheel-work, and throws the translating-screw into gear again. He then sets the point of the quill, at the extremity of the fork, very lightly against the face of the cylinder, and releases the brake. While rotating, the cylinder will be removed toward the left by the

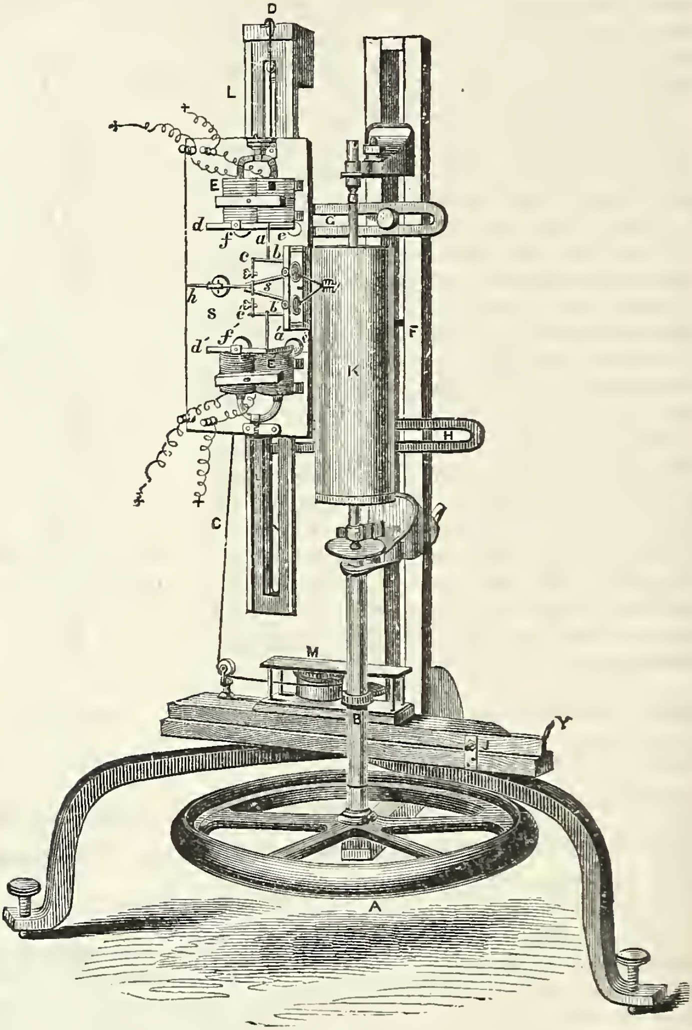


Fig. 292.

translating-screw, and receive the trace of the middle line in the form of a helix. This done, the quill is raised and the cylinder is pushed to the right as before. The quill is again set with its point exactly on the middle line, the translating-screw thrown into gear, the circuit of the battery and the interrupter closed, and the beam touched gently to start it vibrating. At this point the caution "Ready!" is given, the circuit of the battery and the Ruhmkorff coil promptly closed, and the cylinder started rotating when the command "Fire!" is given. As soon as the report is heard, the machine is stopped by the brake, both currents opened and interrupted, the quill point removed, and the cylinder detached from the wheel-work; when the operator counts the result, while the gun is being reloaded, and the targets mended preparatory to another round.

1298. The Bashforth Chronograph.—Profr. Bashforth, of the Artillery School, Woolwich, England, has made extensive experiments to determine the resistance of the air to the motion of rifle projectiles, with a chronograph of his own invention. Fig. 292 gives a general view of the instrument.

1299. *Description.*—The fly-wheel, A, is capable of revolving about a vertical axis, and carrying with it the cylinder, K, which is covered with prepared paper for the reception of the clock and screen records. The length of the cylinder is 12 or 14 inches, and the diameter 4 inches. B is a toothed wheel which gears with the wheel-work, M, so as to allow the spring, CD, to be slowly unwrapped from its drum. The other end of CD, being attached to the platform, S, allows it to descend slowly along the slide, L, about $\frac{1}{4}$ inch for each revolution of the cylinder. E E′ are electro-magnets; *d d′* are frames supporting the keepers; and *f f′* are the ends of the springs, which act against the attraction of the electro-magnets.

When the current is interrupted in one circuit, as E, the magnetism of the electro-magnet is destroyed, the spring, *f*, carries back the keeper, which, by means of the arm, *a*, gives a blow to the lever, *b*. Thus the marker, *m*, is made to depart from the uniform spiral it was describing. When the current is restored the keeper is attracted, and thus the marker, *m*, is brought back, which continues to trace its spiral as if nothing had happened. E′ is connected with the clock, and its marker, *m′*, records the seconds. E is connected with the screen, and records the passage of the projectile through the screens. By comparing the marks made by *m m′* the exact velocity of the projectile can be calculated at all points of its course.

The slide, L, is fixed paralled to F, and the cylinder, K, by the brackets, G H. Y is a screw for drawing back the wheel-work, M; and J, a stop to regulate the distance between M and B. The depression of the lever, *h*, raises the two springs, *s*, which act as levers, and bring the diamond points, *m m′*, down upon the paper.

When an experiment is to be made, care is taken to see that the two currents are complete. The fly-wheel, A, is set in motion by hand, so as to make about three revolutions in two seconds. The markers, *m m'*, are brought down upon the paper, and after four or five beats of the clock the signal to fire is given, so that in about ten seconds the experiment is completed and the instrument is ready for another. The pendulum of a half-seconds clock strikes once, each double-beat a very light spring, and so interrupts the galvanic current in E' once a second.

1300. *The Targets.*—Fig. 293 gives the details of the screen. It represents a piece of board 1 inch thick and 6 or 7 inches wide, and rather larger than the width of the screen to be formed. Transverse grooves are cut at equal distances, something less than the diameter of the projectile. Staples of hard brass spring-wire are fixed with their prongs in the continuation of the grooves. Pieces of sheet copper, *a c e*, are provided, having two elliptical holes the distance of whose centres equals the distance of the grooves. The pieces of copper are used to connect each wire staple, *b*, *d*, *f*, with its neighbor on each side. These copper connections hold down the wire springs, which, when free, are in contact with the tops of the holes; but when properly weighted, they rest on the lower edge of the holes. Thus the copper *c* forms a connection between the staples *b* and *d*; the copper *e* joins *d* and *f*, and so on.

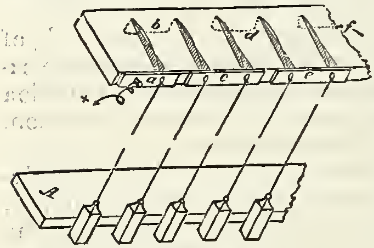


FIG. 293.

A galvanic stream will therefore take the following course, whether the springs be weighted or unweighted: copper *a*, brass *b*; copper *c*, brass *d*; copper *e*, brass *f*, etc. The current will only be interrupted when one or more threads have been cut and the corresponding spring is flying from the bottom to the top of its hole. About one-fiftieth of a second is required for the complete registration of such an interruption, the spring traversing about half an inch.

The shelf, A (Fig. 293), is placed for the weights to rest against, partly to prevent them from being carried forward by the projectile, but chiefly to prevent the untwisting of the threads which support the weights. The weights used are about 2 lbs. each, and the strength of the sewing-cotton for supporting them is equal to a stress of about 3 lbs., which is sufficient to withstand a tolerably strong wind. As the weights are equal the threads are kept equally stretched.

1301. *Arrangement of Screens* for an experiment is shown in Fig. 294. The wires for conveying the galvanic current are like the common telegraph-wires carried on posts. *a b c d e f g h* is a continuous piece of wire, and the current is made to circulate through the screens. The ends, *a h*, are connected with the instrument and battery. The projectile, being fired through the screens, in passing cuts one or more threads at each screen, so that corresponding to the instant at which the projectile passes each screen there is an interruption of the galvanic current and a simultaneous record on the paper.

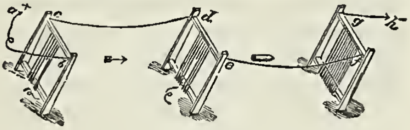


Fig. 294.

1302. The Noble Chronoscope.—The principle of action of this instrument consists in registering, by means of electric currents upon a recording surface, travelling at a uniform and very high speed, the precise instant at which a projectile passes certain defined points in the bore. (Fig. 295.)

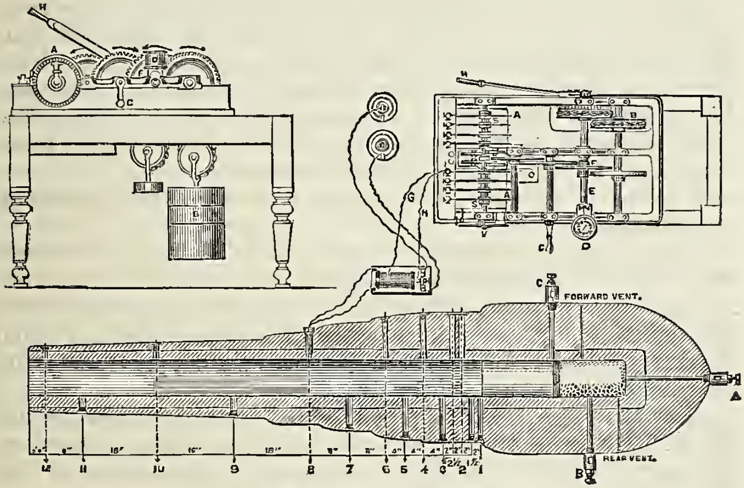


Fig. 295.—Chronoscope.

It consists of two portions: firstly, the *mechanical arrangement* for obtaining the necessary speed and keeping that speed uniform; secondly, the *electrical recording arrangement.* The first part of the instrument consists of a series of thin metal disks, A A, each 36 inches in circumference, fixed at intervals upon a horizontal shaft, S S, which is driven at a high speed by a heavy descending weight, B, throught a train of gearing multiplying 625 times. The driving-weight is, during the experiment, continually moved up by means of the handle, H. If the requisite speed of rotation were got up by the action of the falling-weight alone, a considerable waste of time would ensue; to obviate this inconvenience, the required velocity can be obtained with great rapidity by means of the handle, C.

1303. The precise rate of the disks is obtained by means of the stop-clock, D, which can at pleasure be connected or disconnected with the revolving shaft, E, and the time of making any number of revolutions of this shaft can be recorded with accuracy to the one-tenth part of a second. The speed usually attained in working this instrument is about 1,000 inches per second, linear velocity, at the circumference of the revolving disks, so that each inch travelled at that speed represents the one-thousanth part of a second; and, as the inch is subdivided by the vernier, V, into a thousand parts, a linear representation at the circumference is thus obtained of intervals of time as minute as the one-millionth part of a second.

1304. As a small variation in speed would affect the relation between the several records obtained, the uniformity of rotation is ascertained on each occasion of experiment by three observations: one immediately before, one during, and one immediately after the experiment, the mean of the three observations being taken for the average speed. With a little practice there is no difficulty in arranging the instrument so that the disks may rotate either uniformly or at a rate very slowly increasing or decreasing.

1305. The arrangements for obtaining the *electrical records* are as follows: the revolving disks are covered on the edge with a strip of white paper, and are connected with one of the secondary wires, G, of an induction-coil. The other secondary wire, H, carefully insulated, is brought to a discharger, I, opposite the edge of its corresponding disk, and is fixed so as to be just clear of the latter. When a spark passes from the discharger to the disk, a minute hole is perforated in the paper covering upon that part of the disk which was opposite the discharger at the instant of the passage of the spark; but as the situation of this hole in the paper would be very difficult to find, on account of its extreme minuteness, the paper is previously coated with lamp-black, and the position of the hole is thus readily seen; a distinct white spot is left on the blackened paper, the lamp-black at that point having been burnt away by the spark, so that the white paper is shown beneath. By means of the micrometer the distance between the sparks on the disks is read off.

1306. In order to connect the primary wires of the induction-coils with the bore of the gun, so that they may be cut by the projectile in its passage, the gun is tapped in a number of places for the reception of hollow steel plugs carrying at the end next the bore a cutter which projects slightly into the bore. This cutter is held in position by the primary wire, which is carefully insulated and passed down the plug, through the cutter, and back out of the plug, the ends being connected to the main wires leading to the induction-coils. When the projectile reaches the point where the plug is screwed in, it presses the cutter in flush with the bore, and, by so doing, cuts the primary circuit. As each plug is reached a spark is delivered, and thus the passage of the projectile along the bore is recorded at regular intervals.

Some idea may be conveyed of the minute intervals of time which can be measured by this means, from the fact that the distances between the parts of a X-inch gun at which the time records have been obtained are in some instances only 2.4 inches, while the total time the projectile takes to reach the muzzle of the gun—a distance of 100 inches—when fired with a full charge, is about the one-hundredth part of a second.

By this means the time may be recorded which the projectile occupies, from the commencement of motion, in reaching different parts of the bore, and from these time records may be deduced the velocity with which the projectile is passing through the different parts of the bore, and the pressures in the gun which correspond to these velocities.

1307. The Electric Clepsydra*.—Generally, with chronometric instruments, the time is deduced from the space passed over during the interval to be measured, by a body which moves according to a determined law. This moving body, which we call "chronometer," is the important part of the apparatus; the other fittings are but accessories serving to put the chronometer in operation; that is to say, to render it capable of marking the commencement and the end of the time to be measured.

The choice of chronometer, then, is of first importance. A weight falling freely constitutes, incontestably, the most simple and most exact chronometer; regulated by an immutable law of nature, its motion is accomplished without the aid of any

* Naval Ordnance Papers, No. 4. Translated by Lieutenant-Commander J. D. Marvin, U. S. Navy.

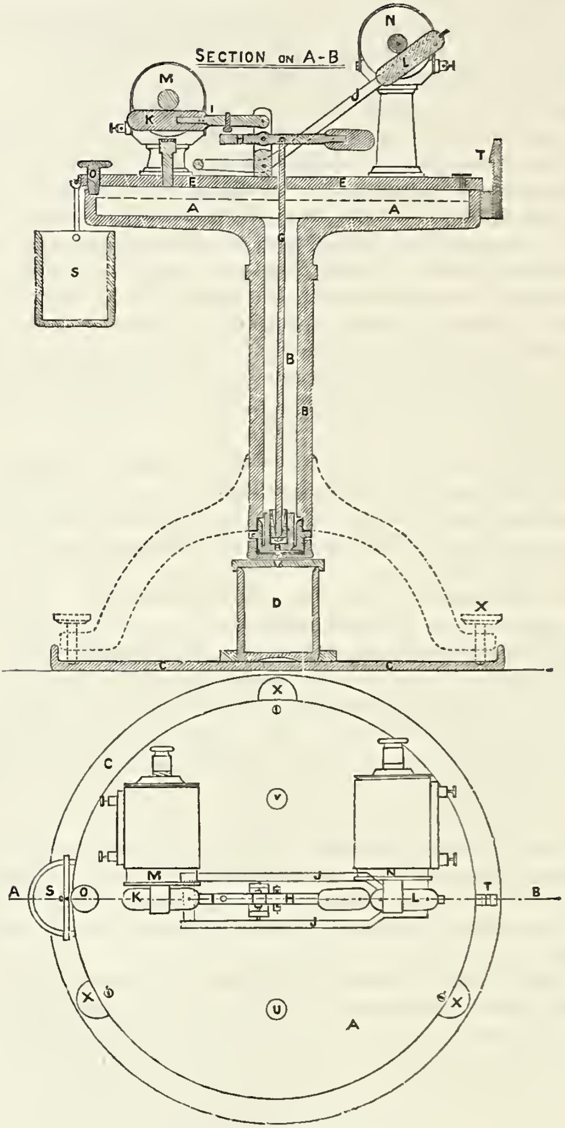


Fig. 296.—Electric Clepsydra.

intermediary force; neither use nor time can alter its rate; it is absolutely invariable.

Unfortunately, this chronometer is only applicable to the measure of times relatively short, for the extent of fall increases with the time in very rapid proportions.

One can, it is true, transform the vertical fall into a movement of rotation, whether continuous, such as that of revolving cylinders, or alternate, such as that of pendulums; but in both cases the great advantage of a constant chronometric movement is lost; account must then be taken of friction, and this may be varied by causes which escape the observation, and certainty and reliability in the result no longer exist. In order to avoid this inherent inconvenience in the employment of such a mechanical instrument, we may employ as a chronometer the flow of a liquid, and determine the time by means of the weight run out during the interval to be measured. For this purpose mercury presents itself naturally to the mind; this metal, very fluid and homogeneous, has great specific weight; its evaporation is insensible, and, not moistening the inclosing surfaces, its use is extremely clean and convenient.

This has been done by Major La Boulengé of the Belgian Artillery, in an instrument to which he has given the name of *Electric Clepsydra.*

1308. *Description of the Instrument.*—It is composed (Fig. 296) of a circular reservoir, A, of $0^m.20$ diameter by $0^m.03$ high, containing mercury, and supported by a hollow central column, B, of $0^m.20$ height, terminating in a tripod fitted with levelling-screws X. This vessel, of cast-iron, rests on a circular plate, C, of the same metal, which is fitted with a rim to catch the mercury which may through inadvertence flow out of the receiver, D. A disk of cast-iron, E, covers the reservoir and bears the electrical fittings of the apparatus. The hollow column, which makes a part of the receiver, terminates at the lower end in a fine orifice, above which is fitted a conical valve, which prevents the mercury from running out. The face of the orifice, the body of the valve, R, and its seat, F, are of steel.

A rigid stem, G, connected by a swivel-joint to the body of the valve, rises, following the axis of the receiver, traverses a central opening in the upper disk, and then connects above this latter to a horizontal lever, H, which is called the valve-lever. If the arm of this lever opposite to the connection of the stem be pressed down, the valve is opened and flow is produced. If the effort be discontinued, the valve falls back upon its seat, and the flow is arrested instantaneously.

1309. The opening and closing of the valve are performed by the action of two levers, I and J, which fall successively, and of which the heavier extremities, fitted with armatures of soft iron, K and L, are held in the state of "ready" (shown in the figure) by electro-magnets, M and N. The lever for closing is formed of two parallel arms, united at one end by the armature, at the other by a cross-piece used to raise the lever, K; this disposition permits it to move without touching the valve-lever.

If the current which actuates the electro-magnet M be broken, the opening lever falls upon the end of the valve-lever, opens the valve permanently, and the mercury flows into the receiver, D, placed immediately under the orifice. We call the lever K, opening-lever; its magnet current and circuit will be called by the name of electro-magnet current and circuit of opening, to distinguish them from similar fittings which operate the closing. If the second current be broken, the closing-lever falls in turn, raises the opening-lever to its original position; then the lever of the valve being freed, this latter falls back into its seat, and the flow is arrested.

A catch, T, prevents vibration of the closing-lever after its fall. This simple combination of three levers fulfils perfectly the mechanical conditions imposed, for the valve opens suddenly by a shock, while it closes freely by its own action.

In actual practice the two currents are broken successively by the projectile, a weight, P′, of mercury flows into the receiver, and it is required to deduce from it the period which has separated the two ruptures.

1310. Let us suppose for a moment that the apparatus furnishes a constant flow, and let P be the flow of the orifice, that is, the weight of mercury which flows per second; by dividing P′ by P, the time is obtained which has elapsed between the instant of opening and that of closing the valve.

The relation $\frac{P}{P'}$ will also give the time which has elapsed between the rupture of two currents, if the valve has opened and closed at the precise instant of the rupture of the corresponding current. But this is not the case; when the first current is broken, a certain time is necessary in order that the magnet may arrive at such a state of demagnetization as to release the armature, then a certain time for the fall of the lever, and finally an additional time for the complete raising of the valve. Analogous periods transpire between the rupture of the closing current and the arrest of the flow. The determination of these short periods is obviated by applying to the instrument the method of simultaneous disjunction, the important feature of which has been devised by Major Navez. To this end the fall of the levers is regulated in such a way that the opening-lever occupies less time than the other, from the commencement of its fall to its action on the valve. Thus, when by means of a disjunctor both currents are cut at the same time, the first lever opens the valve a certain time before the second closes it; the weight, P, of mercury run out in this way, is the precise quantity to be deducted from P′, in order to obtain from the expression $\frac{P'-p}{P}$, the time which has elapsed between the rupture of the two currents.

This method of procedure takes into account both the time lost in the working of the mechanism and that of demagnetization, which varies with the respective force of the two currents.

1311. The disjunctor is the same as that which has been adopted for Le Boulengé's chronograph. It is composed (Fig. 297) of a bent spring, *t*, the free end of which is caught by a catch, *x*, when it is pressed down by bearing on the button, *z*. In this position it permits two thin plates of steel, *q* and *q′*, to bear upon the conducting-pins, *r* and *r′*, and closes by this contact the two circuits. If the catch be released, the spring rises suddenly; its cross-piece, *u*, covered with an insulating-plate of ivory, raises the two plates, *q* and *q′*, and breaks the currents. The two pins, *r* and *r′*, are fitted with a screw thread, and thus provide for the adjustment of the height of the two plates, so that they may be raised at the same time by the spring. The head of the screw, *p*, limits the play of the spring; the bottom surface of the disjunctor is covered with a sheet of India-rubber, for the purpose of deadening the vibrations, which permits it to be set up on the same table as the instrument.

Experience has proved that this disjunctor is without fault; once regulated, it is not liable to be deranged; its regularity is perfect, for with the chronograph it gives identical disjunctions, and as to its exactitude it can be verified whenever desired, by establishing that inversion of the currents does not produce any change in the disjunction.

1312. *Basis of the Calculation of the Times.*—We will now explain how the time is deduced from the weight of mercury run out.

We have supposed the flow constant; but it is not so in reality, for in proportion as the liquid runs out the height of the level diminishes, and with it the discharge. In order that the flow may always commence under the same conditions, before each trial the mercury is brought to a fixed level, which is done by a very simple operation. For this purpose, the instrument being levelled by means of an air-bubble level, which is laid in two directions at right angles to each other on the upper disk, a fresh quantity of mercury is added to that in the receiver; then an overflow is opened (called *level-escape*) formed by a simple screw, *o*. The orifice being opened, the excess runs out into a little bucket, *s*, hung under the level-escape.

The level thus obtained, which we will call the original level, is always of the same height; for the determining experiments show that in the first unit of time the same volume always runs out. But the weight of this volume will vary with the temperature; consequently, to reduce all experiments to the same terms, each weighing must be brought to a uniform temperature. They are reduced to 0° by the formula $P_0 = P(1 + \alpha t)$, α being the coefficient of the expansion of mercury, $0^m.00018$, and t the temperature of the receiver. This temperature is indicated by a thermometer, which forms a part of the apparatus, the bulb of which is immersed in the mercury-reservoir by passing it through an opening, U, in the upper disk.

The rapidity of flow will vary at each instant by reason of the lowering of the level, but on account of the great surface of the receiver as compared with that of the orifice, this lowering during the interval of a second is very small (about one-tenth of a millimètre,) and the time may be calculated without errors in the results by supposing—

1. That the flow is constant during the interval of one second.

2. That in passing from one second to another, the amount of flow decreases by a constant quantity.

1313. We will support this method of calculation by an example, the data for which are given by the instrument itself.

Let H be the height of the original level above the orifice, and P the weight run out during the first second. At the end of this time the level will have been lowered by a quanity, h, which will be the altitude of a cylinder having for a base the surface of the upper reservoir, and for volume $\frac{P}{\delta}$, δ being the density of mercury, 13.598.

We shall have then $h = \frac{P}{\pi R^2 \delta}$, R being the radius of the reservoir.

At the beginning of the second second the height of the level will be $H' = H - h$.

Let us call A the surface of the orifice, and m the coefficient of the contraction of the stream, we will have, by the laws of hydraulics—

$$P = m A \sqrt{2 g H}.$$

Since from second to second the level falls only by an almost inappreciable fraction, the coefficient, m, will not change, and

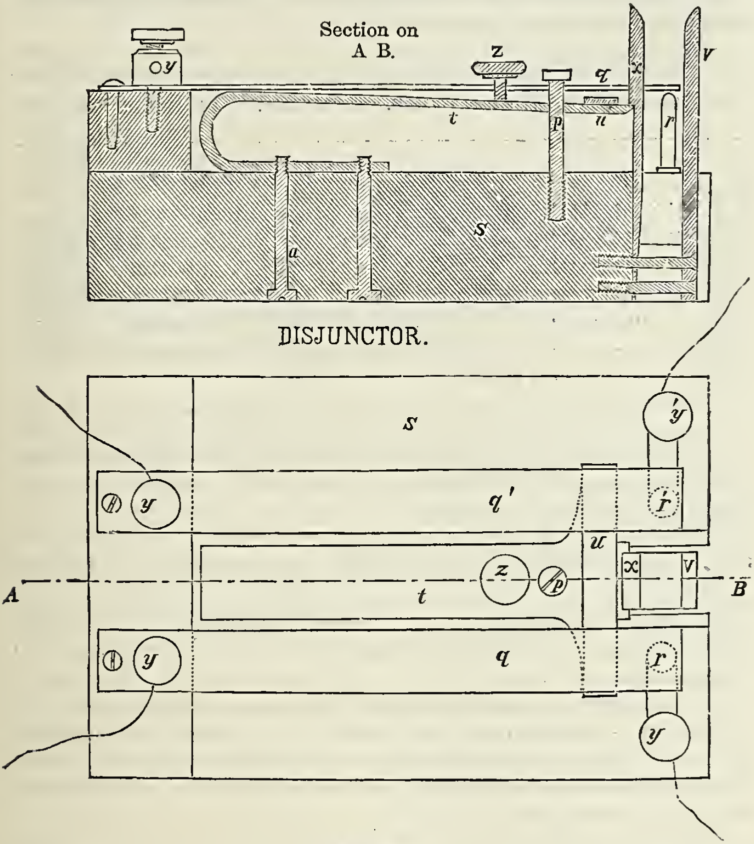


Fig. 297.

we shall have also the weight run out during the second second,

$$P' = m A \sqrt{2 g H'}.$$

Consequently
$$P' = P \sqrt{\frac{H'}{H}}$$

is the formula which enables us to calculate the weight of the second second; that of the first, the height of the original level, and the radius of the reservoir being known.

Having calculated P′, we may deduce from it in the same way P″ P‴, etc., the weights run out during the third, fourth, and following seconds.

The data given by the instrument are $H = 0^m.20$, $R = 0^m.10$, and $P = 6200$ centigrammes.*

1314. Applying these values to the preceding calculation, we have the following results:

SECONDS.	Height of Level.	Discharge.	1st. Dif.	2d. Dif.
	Millimètres.	*Centigrammes.*	*Centgr.*	*Centgr.*
First...............	0. 200000000000	6200. 000000	2 .250042	
Second......	0. 199854862517	6197. 749958	2. 250032	0. 000011
Third..............	0. 199709777705	6195. 499927	2. 250020	0. 000011
Fourth.............	0. 199564745545	6193. 249907	2. 250008	0. 000012
Fifth	0. 199419766096	6190. 999899	2. 249995	0. 000013
Sixth	0. 199274839298	6188. 749904	2. 249982	0. 000013
Seventh...........	0. 199129965171	6186. 499922		

The figures of this table prove that it is permissible to consider the difference of weights run out from one second to another as absolutely constant.

The column of second differences shows, in effect, that they are so, to nearly the ten-millionth of a gramme, or in time $\frac{1}{620000000}$ or $0''.000000002$, a quantity ten thousand times smaller than the fraction of time which we can hope to measure in practice.

In the second place, the difference between the weights run out in two consecutive seconds being but $2^c.25$, which represents in time $0''.0003$, no appreciable error is committed in calculating the time as though the flow were constant during the interval of one second.

1315. In order to compute the table of times of the clepsydra according to the principles indicated, it will be seen that we must know the height of the original level. Owing to the convex curve formed by the mercury, it is very difficult to measure this height exactly, but fortunately this exact measure is unnecessary, as will be shown. The weight of the first second being $6,200^c.00$, we have, by supposing $H = 0\ .200$, found

* In the use of the instrument the centigramme is adopted as the unit of weight.

for the second, 6,197^{c}.75. Suppose that in the measurement of H a mistake of a millimètre is made, and that in reality $H = 0^{m}.201$, the weight of the second second, calculated with this new value, would be 6197.76 ;

for $H = 0^{m}.202$ it would be........... 6197.77
for $H = 0.203$ it would be.... .... 6197.78
for $H = 0.204$ it would be............ 6197.79

That is to say, an error of a millimètre in the measurement of H brings into the calculation of the second second only an error of $0''.000002$, a quantity which can clearly be neglected in practice.

1316. *Experimental Determination of the Table of Times.*—In order to determine experimentally the weight of mercury which runs out in the first second, the two currents of the apparatus must be broken at intervals, separated by exactly one second. A first method would consist in passing the current through a plate *rheotome*, which we will describe farther on, and by bearing on the plates in following the beats of a seconds pendulum. From the weight obtained we would subtract the weight of disjunction, and thus have the weight of the first second. But by this method even a very experienced operator could never obtain in his observations the precision of which the instrument is susceptible; for this reason, a more exact method has been sought out, which consists in causing the currents to be broken by the pendulum itself, which divests the process of all personal skill. A system of two small metallic circuit-closers, *a b c* and *d e f* (Fig. 299), are fastened to the lower part of the case of a seconds-beating regulator, and in the vertical plane of the pendulum. Each of these closers is movable around an axis, *b* and *e*, perpendicular to the plane of oscillation. The pendulum terminates in a cutter, O, which, meeting in its course the points of the closers, causes them to fall alternately to the right and to the left of their respective vertical positions. Let *t s* be the opening circuit, and let a point, *r*, of this circuit be united by a conductor to the connection *k*, and a point, *q*, to the connection *l*.

1317. The base, *p p*, which supports the whole system is insulated, but the connection *k* communicates through metal with the axis *b*, and the connection *l* with the screw *g* ; consequently, when the pendulum is at *m m*, that is to say, at the end of its beat to the left, the closer *a b c* being in contact with the screw *g*, the diverted circuit, *r k l q*, is complete. If in this state of things the circuit be cut in the part *q r*, the opening current will not be destroyed; it will pass entirely by the diversion *r k l q*, but the pendulum continuing its course will destroy the continuity of the diversion, and consequently the opening current, at the instant when, arrived at *z z*, it touches the arm *c*. It must be remarked that so long as the circuit between *q* and *r* is not interrupted, the movement of the pendulum cannot break the current. Let an analogous diversion, *x i j v*, be established by means of the closer *d e f*, in the closing circuit *u y*. The pendulum, having arrived at *m′ m′*, will have met the arm *f*, pressed down the *closer d e f* upon its screw of con-

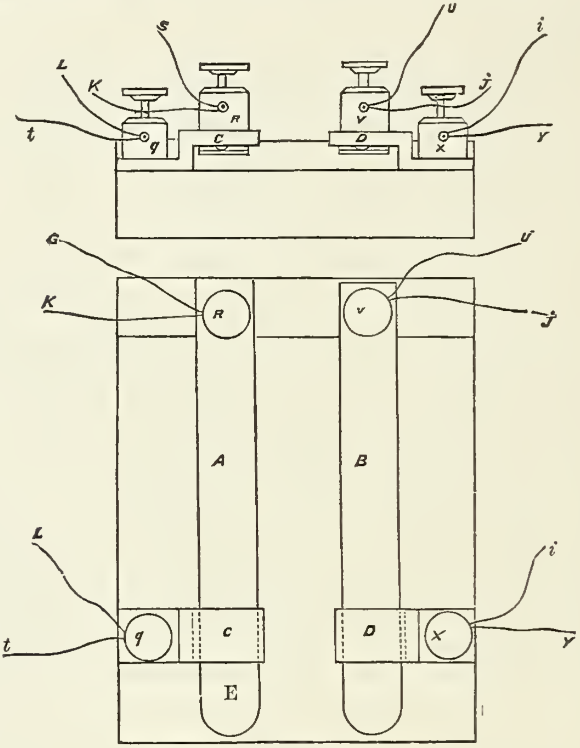


FIG. 298.

tact, *h*, and closed the diversion of the closing current. If at this instant a rupture be made between *v* and *x*, the closing circuit will not be broken; but this rupture will take place when the pendulum, arriving at *z′ z′*, touches the arm *d*.

1318. It is apparent, then, that the operator can break the opening current by means of the pendulum, when it, in passing to the left, arrives on the line $z\ z$, and in the same way he can break the closing current at the moment when the pendulum coming to the right, arrives on the line $z'\ z'$. To accomplish the breaking of the circuits $q\ r$ and $v\ x$, a *rheotome* (Fig. 298) is used having two plates, A and B, which close the circuits by their contact with C and D. These contacts established, the opening current passes at the same time through the general circuit $t\ q$ A $r\ s$, and through the diversion $q\ l\ k\ r$, which includes the contact of the closer. If the finger be pressed on the extremity, E, of the plate A, the general circuit is interrupted between q and r, and the closing current passes as a whole through the diversion. The same effect is produced in the closing circuit by means of the plate B. The circuits being established in the manner which has just been explained, and the clepsydra being in readiness, that is to say, the mercury at the level-mark and the two levers raised, the operator follows with the eye the movement of the pendulum. When he has taken up the cadence accurately, he places the forefinger on E when the pendulum is nearly in the position $m\ m$; then the pendulum, arriving at $z\ z$, breaks the opening current, and the running out commences. Toward the end $m'\ m'$ of the same oscillation, the operator presses down the second plate, B, and the pendulum, repassing to $z'\ z'$, breaks the closing current, and the flow is arrested. Let us call α the weight of mercury obtained by this operation, and β that which would have been obtained if the two currents had been broken at exactly the same instant; then $\alpha - \beta$ will be the weight run out while the pendulum is passing over the angular space $z\ m' + m'\ z'$. This space will correspond exactly to one second, if the two oblique lines $z\ z$ and $z'\ z'$ are equidistant from the vertical; but this condition is realized with difficulty in practice, and if we were to bind ourselves to its acceptance, the process would be subject to serious errors; therefore we have made the process independent of it, by proceeding in the following way:

1319. After having obtained the weight α, as has just been explained, the mercury is again raised to the level-mark, and the instrument put in readiness; then the operation is recommenced, but a longer time is measured. After having broken the first current, the second is not ruptured at the end of the oscillation; on the contrary, the pendulum is allowed to return, and it is not until its arrival for the second time at $m'\ m'$ that the second plate, B, is pressed down. Let γ be the weight obtained in this second operation; $\gamma - \beta$ will be the weight which runs out while the pendulum is passing over $z\ m' + m'$

$z' + z'\ m + m\ m' + m'\ z'$. If from the time $(\gamma - \beta)$ we subtract the time $(\alpha - \beta)$ which is required by the pendulum to pass over $z\ m' + m'\ z'$, there will remain $\gamma - \alpha$, which will be the time employed by the pendulum to pass over the space $(z\ m' + m'\ z' + z'\ m + m\ m' + m'\ z') - (z\ m' + m'\ z')$ or $z'\ m + m\ m' + m'\ z' = 2\ m\ m'$, that is to say, two complete oscillations, and $\frac{\gamma - \alpha}{2}$ will be the weight run out in one second.

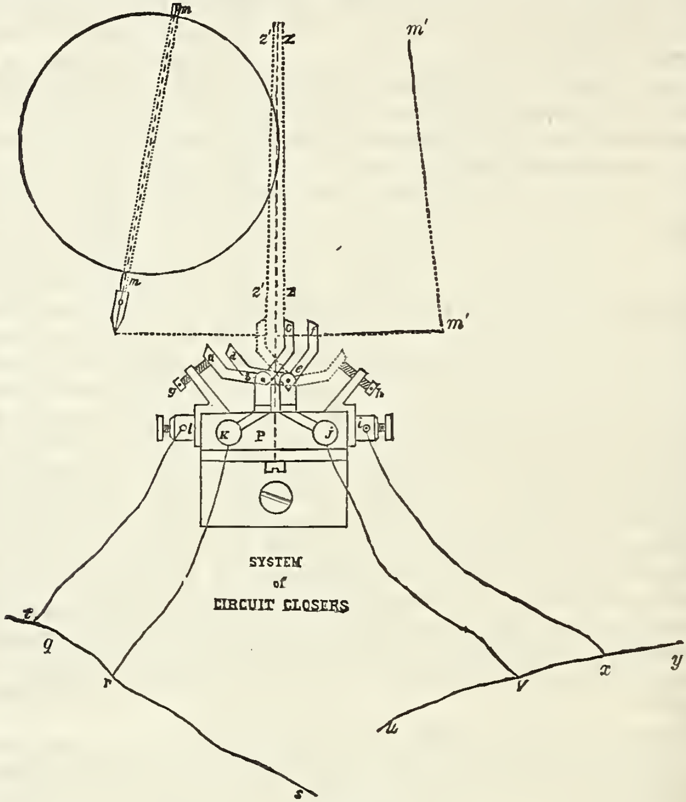


Fig. 299.

By this method we obviate the determination of the weight β, corresponding to a simultaneous disjunction. The electrical conditions not varying from one trial to another, this weight will remain the same, and since it is included in each of the above partial operations, it is eliminated by the subtraction.

1320. Knowing the weight, $\frac{\gamma - \alpha}{2}$, of one second, we can calculate the weight of the following by the process which has been explained, and we will discover in consequence the constant difference ω, from one second to another. These two quantities suffice for calculating the weights P_1, P_2, P_3, P_4, P_n, corresponding to the 1^{st}, 2^d, 3^d, 4^{th}, n^{th} second. Let it be remarked, first, that the system of *closers* being established as far as possible in the vertical plane of the pendulum, the weight $\gamma - \beta$ will be very nearly that which runs out during the first three seconds.

$\alpha - \beta$ will in the same way be the weight of the first second; consequently the weight $\gamma - \alpha$ will be that which flows during the second and third seconds.

We will have then—

$$P_2 \times P_3 = (\gamma - \alpha),$$

and

$$P_2 - P_3 = \omega;$$

whence

$$P_2 = \frac{(\gamma - \alpha) + \omega}{2},$$

$$P_3 = \frac{(\gamma - \alpha) - \omega}{2}.$$

The first second will be $P_2 + \omega$, the fourth $P_3 - \omega$; and the n^{th} $P_{(n-1)} - \omega$.

Before giving the results furnished by this process, a remark in relation to its use remains to be made. The contact between the *closer* and the bearing-screw not being very close, this point presents a great resistance to the passage of the current, and it often happens that when the direct circuit is cut by the *rheotome*, the current does not retain sufficient force to hold the armature of the magnet; it is for this reason that one should, in this experiment, give to the magnets a great force of attraction, in order that they may preserve a sufficiency when the current passes through the diversion alone.

1321. *Use of the Instrument in Experimental Firing.*—The clepsydra is set up in a place in close proximity to the firing-ground, and on the same table are placed the disjunctor, B, and the balance, C (Fig. 300). The batteries are on the floor or elsewhere near by. They are formed of Bunsen's elements, arranged in the ordinary way, that is, with nitric acid in the porous cup, and a mixture of sulphuric acid and water in the glass. Two or three cells generally suffice for the opening current, the number necessary for the closing current varying with the extent and resistance of the circuit. In certain special cases Bunsen cells, such as are used for telegraphy, have been employed. In these cells the carbon is replaced by a plate of copper, riveted to the zinc cylinder; the glass contains only water, and the porous cup a mixture of water and sulphuric acid. This system has the advantage of being serviceable for two months without its being necessary to touch it, but the electro-motive force which it develops is very rapidly exhausted. When the current is allowed to circulate during any time, the battery is very sensibly weakened; if the circuit be interrupted, it stores up a fresh force, and the current returns to its original intensity. These batteries are very irregular, and much inferior in this respect to the ordinary Bunsen batteries, the action of which can be considered constant during the same series of experiments.

1322. The opening-circuit, *a b c d e f g* (Fig. 300), includes the first target, the disjunctor, and the opening electro-magnet; it passes in front of the muzzle of the gun, whether on an ordinary target-frame placed at 10^m from the muzzle, or in a simple wire stretched across the face of the muzzle. In this latter case it must be ascertained whether the wire used is strong enough to resist the blast of gas which precedes the projectile.

1323. The second circuit, *h i j k l m n o p q r s*, includes the second target, the disjunctor, and the closing electro-magnet. In the trials at the Naval Experimental Battery, Annapolis, Md., there is used in forming this circuit a telegraphic line parallel to the line of fire. The current is brought to the second target, *k l*, by a conductor, *i k*, united to the line at the top of the target. After its passage through the target the current reaches the earth through a plate, *m*, thrust into the ground near by, the circuit being continued by a second plate, *n*, planted near the location of the instrument; the current returns from this plate to the battery by passing through the instrument. By this arrangement, when the range is changed, it suffices to simply move the second target and its earth-plate. These plates, which are formed of a simple plate of copper or of zinc of a few decimeters long, or of a coil of wire, ought to be placed either in water or in a damp stratum of soil. If by the nature of the ground this kind of soil is difficult to reach, the current should be returned to the battery by a second metallic conductor.

1324. All these dispositions being made, it is ascertained whether the currents pass, and whether they have sufficient force to hold the levers of the clepsydra in position.

The magnets are then regulated by running the movable core more or less inside the coil. The force of attraction is regulated so that the levers will be held with the least power necessary to prevent their being subject to accidental release. The operator then fills to level by pouring a cup of mercury into a glass funnel placed in the orifice, V, and then opening the overflow. It is to be remarked that by this operation the mercury, which forms the surface of the bath, is drawn from the receiver, and this is the only portion which can contain impurities. This mercury is poured into a flannel strainer, from which it comes out freed from oxide and dust. This process is necessary, for experience has proved that the mercury employed ought to be perfectly clean; it must then be improved in quality by use in the instrument, owing to these successive filtrations.

1325. To make ready the instrument, the currents are first made to circulate, by pressing on the button of the disjunctor

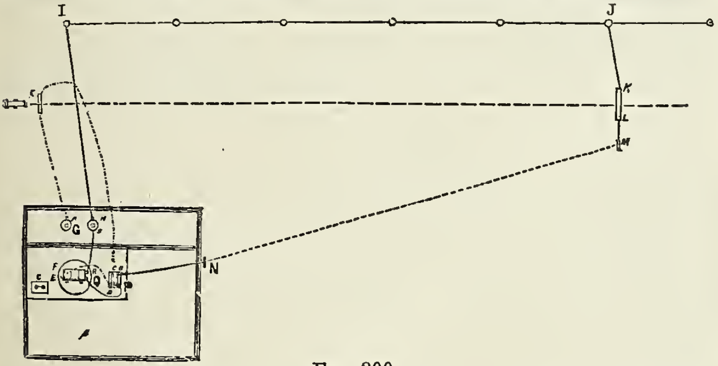


Fig. 300.

until the spring is caught in the catch; then with the forefinger the catch, T, is disengaged, while the closing-lever is brought in contact with its magnet by using the thumb. As to the opening-lever, it is self-acting, for it is raised against its magnet each time the mechanism operates.

1326. To cause disjunction, the spring of the disjunctor is released by bearing with the forefinger on the trigger, x, and with the thumb on the guard, v. These operations, as will be seen, are extremely simple and rapid; the principle has therefore been adopted of making three disjunctions before each fire, which requires hardly a half minute. The mercury being received each time in the same vessel, the total weight, divided by three, will be that of the disjunction obtained by a mean of three trials. After having made the disjunctions, the original level is not restored preparatory to the firing, for the quantity of mercury run off is too small to alter, in a sensible degree, the height of the liquid in the reservoir. At the instant of firing, the levers I and J fall successively, but if the magnets be regulated too "fine," it will follow that the shock produced by the fall of the first lever will cause that of the second. This effect is avoided in the following way: If the time to be measured exceeds one second, which is generally the case, before giving the order "fire," the closing-lever is held against its magnet by the finger until the opening-lever has fallen. Operating in this way in the measure of a time less than a second, there would not be time to remove the finger before the rupture of the second target; therefore, in this case, sufficient force is given to the magnet to prevent its releasing its hold when the first lever falls.

1327. The weights are taken by means of a balance forming a part of the apparatus, which is constructed with a view to this special use. For convenience of transport, it can be dismounted and placed in the instrument-case. This balance not being sensitive beyond a half centigram, the weights are easily taken. This degree of precision is quite sufficient, for the half centigram represents a time less than the twelve-thousandth of a second. Immediately after firing, the disjunction is weighed; then the discharge during the passage of the shot, and the mercury poured back into the instrument, restores the original level. In this way the operation of levelling need be done but once at the commencement of the practice; if, however, the temperature changes sensibly, it ought to be done over.

As the two-fold weighing is quite a long operation, a mongrel process is used which possesses very nearly the same exactness. In the experiments the weight which will be obtained is always approximately known, and this weight, varying but very little from fire to fire, a counter-balance is used which balances this approximate weight placed in one of the scale-pans with the vase in which the mercury is to be weighed. At each trial it is only necessary to replace the approximate weight by the mercury obtained, and to balance the scale with small weights, which are the amount to be added or subtracted in order to get the weight sought. In order to simplify this operation, the counter-balance is adjusted for the minimum which can be obtained, and in this way the difference is always to be added. A counter-balance is also used in weighing the disjunctions. Experience has shown that, with a little practice at the balance, the operation of weighing is easily done within the time required for repairing the targets and the serving of the piece.

1328. Force of Gravity.—In the use of nearly all electro-ballistic machines, the force of gravity enters as a necessary element in the calculation. The following formula* may be employed to calculate the most probable value of the apparent force of gravity—being the resultant of true gravitation and centrifugal force—in any locality where no pendulum observations of sufficient accuracy have been made.

This formula with the two coefficients which it involves, corrected according to modern pendulum observations, is as follows:

Let G be the apparent force of gravity on a unit mass at the equator, and g that in any latitude λ: then

$$g = G\,(1 + .00513\ \mathrm{Sin}^2\,\lambda).$$

The value of G in terms of the absolute unit is 32.088.

When the point of observation is materially above the sea level, the true gravity may be derived with sufficient accuracy for all practical purposes from

$$g = g^1\left(1 + \frac{5\,h}{4\,r}\right),$$

in which g' represents the force of gravity at the height, h, above the sea, and r, the radius of the earth. (*Army Ordnance Manual*, p. 469.)

The formulæ given by different standard authorities will give somewhat varying results for the same station. That used at the Naval Experimental Battery, Annapolis, and deduced from what are considered the most reliable data, is $g = 32.1533$.

1329. STRAIN UPON THE GUN.—The resistance opposed to the motion of a projectile in the bore of a gun, and which tends to increase the explosive force of the powder, depends upon the form and weight of the projectile, upon the circumstance of the piece being smooth-bored or rifled, and upon the system of rifling adopted.

The projectile will commence to move when the force of the gas has become equal to the resistance offered to motion.

The time necessary for the conversion into gas of the quantity of powder required to move the projectile, will depend upon the nature of the gunpowder used, the form of the cartridge, and the point of ignition of the latter.

* *Elements of Natural Philosophy*, by Professor Sir W. Thompson and P. G. Tait. Oxford: 1873.

The maximum strain upon the metal of the gun will mainly depend upon the rapidity of the conversion of the powder into gas.

1330. The initial velocity of the projectile may not, however, be in proportion to the maximum strain, but it varies as the work done on the projectile, or as the pressures into the spaces through which they act, or:

$$PS = \frac{WV^2}{2\,g},$$

where P=pressure of gas,
S=space through which P acts,
W=weight of projectile,
V=velocity of projectile,
g=force of gravity.

And if S be a very small interval, a fair approximation to the mean strain exerted through it in the bore of a smooth-bored gun may be calculated by this formula.

1331. Pressure-gauges.—These are instruments used for determining, by the method of *indentation*, the pressure exerted within the bore of the gun by the ignition of the powder.

1332. Rodman's Pressure-gauge is shown in Fig. 301, and in using it, a hole is drilled through the gun at any point or points in the bore where it is desired to ascertain the pressure exerted by the exploding charge. Into this hole the tube, A, is screwed, its lower end, which is open, being flush with the bore.

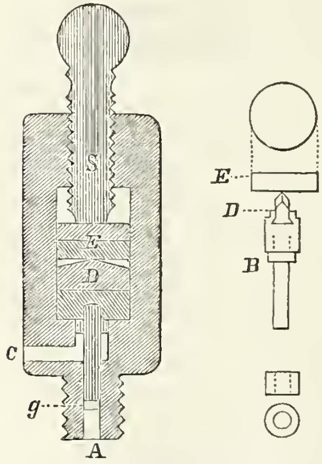


Fig. 301.—Capt. Rodman's pressure piston. (Section.)

The other end is closed with the piston, or indenting-tool, B, the joint being rendered tight by means of the gas-check, *g*. The piston carries a knife, D. (Art. 424), and upon the knife rests a piece of copper, E, which is held tightly against it by the screw, S.

The hole in the tube shown at C, and the recess around the stem of the indenting-tool, are made for the purpose of letting out any gas that might pass the piston, and thus prevent its acting against the shoulder of the indenting-tool.

1333. Use.—In using this apparatus the shank or piston of the indenting-tool and the hole in the tube into which it is inserted for use are well cleaned and oiled, and the indenting-tool inserted into the tube, which is then screwed into the gun, and a disk of soft copper placed on the point of the indenting-tool, the disk being held in position by the screw, S, acting either upon a second copper disk or upon a piece of iron having a plain surface next the disk to be indented.

The pressure on the inner end of the indenting-piston forces the point of the indenting-tool into the copper disk when the gun is fired.

This disk is then removed to the testing-machine, and the pressure required to produce an equal indentation with the same tool in the same disk, or one from the same bar of copper, is accurately weighed; then, knowing the area of a cross-section of the indenting-piston, the pressure per square inch is calculated. For the purpose of getting greater accuracy of results the indenting-point is very broad and thin so as to make a very long cut as compared with its breadth and depth.

1334. Internal Pressure-gauge.—This apparatus is placed wholly within the bore of the gun, being inserted in the bottom of the cartridge-bag, and having the charge filled in over it so that no powder will get under it and come between it and the bottom of the bore when rammed home in the gun.

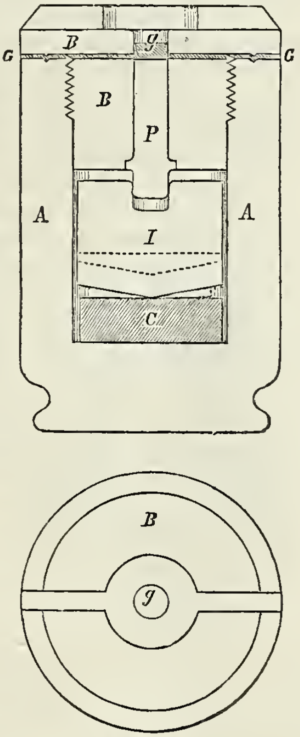


Fig. 302.

Fig. 302 shows the construction of this instrument.

A, outer cylinder; B, screw-plug for closing mouth of outer cylinder; G, copper gasket to form gas-tight joint; C, specimen of copper to be indented; I, indenting-tool; P, indenting piston; *g*, gas-check.

1335. Use.—All its parts except the exterior of the outer cylinder are carefully cleaned before each fire, and the threads of the screw-plug and the indenting-piston carefully oiled; the copper specimen is then placed in the bottom of the cylinder, the indenting-piston inserted into the screw-plug, and with the outer cylinder horizontal, the plug is screwed home; being afterwards tightly set in with a wrench while the cylinder is held in a vice. The cylinder is then carefully set down upon the closed end, and the indenting-piston gently pushed down till the point of the indenting-tool rests upon the copper specimen; a small gas-check is then inserted, mouth outwards, till it rests upon the end of the indenting-piston.

1336. At the Naval Experimental Battery, a gauge called the "double plug," from its giving two indications, has been designed for use with disks of pure silver, and the records of pressure obtained are very reliable.

The instrument is inserted into the gun with the screw-plug towards the muzzle, and is generally found in the bore of the gun or near the piece after its discharge, when the screw-plug is withdrawn, and the specimen removed, having an indentation in its surface, due to the pressure that has been exerted upon the outer end of the indenting-piston.

1337. The indications of pressure by this instrument are generally found to be something less, for equal charges of powder, than those by the external gauge.

One reason for this is probably owing to the fact that in the external gauge the gas has a considerable space to travel through between the powder-chamber and the indicating parts, so that before reaching the piston the gases have attained a high *vis-viva*, especially with quick-burning powders.

To enable those who have not the means of determining the pressure corresponding to a given length of indentation to obtain approximate results from the pressure-gauge, tables are constructed by accurately measuring the length of cut due to each 100 lbs. of pressure.

1338. MARVIN'S ESTIMATOR * is an instrument for measuring and verifying indentations in the disks used with the pressure-gauge.

Description.—Fig. 303 is a profile, and Fig. 304 a midship vertical section of the Estimator. The instrument consists (Fig. 304) of a *cutter-stem*, A B C, cylindrical as far as B, and from B to C rectangular, as per cross-section. This stem carries two nuts, E and F, and one disk, D; E, working on a left-handed *screw* of 12 *to the inch pitch;* F, on a right-handed thread cut *accurately to* $\frac{1}{20}$ *inch pitch.*

The lower end of the cutter-stem is grooved to receive the

* Designed by Comdr. J. D. Marvin, U. S. Navy.

feather of a knife, *m*, about $1\frac{7}{10}$ inches long. G is cylindrical from *a* to *b*, but square from *b* to *c*, and has through it a slot in which the lower end of the cutter-stem, A B C, fits accurately. H is a square plate having in its centre a circular recess to contain the disk, I. J is the saucer which centres the plate, H, and guide-block, G; *e e* (Fig. 304) are holes in which to place a punch, to drive out the disk or plate in case they jam. K (Fig. 303) is a pointer with a bob on its end, pivoted at *d*, in a slot cut in G; it is horizontal when the nut, F, rests on G, but drops down by its own weight when they are separated.

The nut, F, is of precisely 3.183 inches diameter on the out-

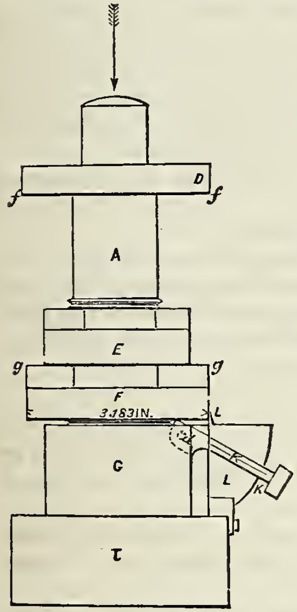
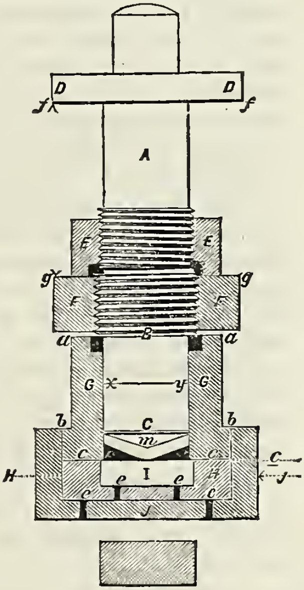


Fig. 303.



Cross section on *x y*.

Fig. 304.

side, the circumference being 10 inches; this has a scale of inches marked upon it, and is graduated to .02 inches. The cutter has a trifle over 0.2 inch vertical play, which exceeds the depth of an ordinary cut.

When the point of the cutter is tangent to the disk, I, the zero of the scale on F should be opposite the point L; F resting firmly on G, and the pointer, K, horizontal.

The length of cut corresponding to any given projection of the cutter beyond the lower face of G may be determined either mathematically or by experiment.

The pitch of the screw on which F works being $\frac{1}{20}$ inch, and the diameter of F being 3.183 inches graduated to fiftieths of an inch on the circumference, it follows that the extension of the cutter can be read by the index, L, to $\frac{1}{10000}$ of an inch. By applying inside calipers between D and F at *f* and *g*, a check can always be had on the setting of the cutter.

1339. Use.—Place the disk in the recess of the plate, H, and place H in the saucer, J. Adjust the guide-block, G, on the top of H, slack up the locking-nut, E, and revolve F the number of times necessary to give the play between F and G needed to make the required cut. Run down the locking-nut firmly, to relieve the thread of F of as much strain as possible. Insert the cutter-stem in the slot, G, and the instrument will now be ready to place in the testing-machine, where weights are applied, until the pointer, K, comes horizontal as shown by a mark on the index, L. As soon as the pointer is up, reverse the crank and relieve the pressure. The pressure comes upon the point indicated by the arrow.

A graduated scale of lengths of cut corresponding to readings on the circular scale F, is used with the estimator. The reading corresponding to the length of the cut to be duplicated is brought opposite to the point L. The cutter actually used in the pressure gauge, is used in the estimator, on a fresh uncut disk. The power required to force the knife down to duplicate the cut is the measure of the pressure.

1340. The Crusher-gauge.—This is a term applied to the English pressure-gauge. (Fig. 305.) It consists of a tube or cylinder of steel which admits of the insertion of a small cylinder of copper, B, which is retained in the centre of the chamber, *c d e f*, by a small watch-spring. One end of this cylinder rests against an anvil, A, and the other is acted upon by a movable piston, C, which is kept tight against the cylinder by the spring, *i*. A gas-check, D, is inserted against the lower extremity of the piston, and should any gas get past this, there are passages by which it can escape into the open air. In this apparatus the method of *compression* is used for ascertaining the pressures.

The crusher-gauge is used in exactly the same way as the Rodman-gauge. Upon the explosion of the charge the gas acts upon the area of the piston and crushes the copper cylinder against the anvil. The amount of compression the copper thus sustains becomes an indication of the pressure exerted upon the piston.

1341. In order to obtain data whereon to base the calculations of the pressures, a series of experiments is made by means of a testing-instrument to determine the pressure required to produce a definite amount of compression on copper cylinders similar to those used in the instrument. The results of these experiments are tabulated, and they furnish a means of comparison whereby the amount of compression produced in the crusher becomes a direct indication of the pressure exerted by the gases at that part of the bore where the gauge is placed.

1342. The results of experiments show that the copper disks cannot be depended upon to give uniform results, but latterly disks of pure silver have been employed, and the margin of error has been much reduced.

1343. One great obstacle to the attainment of correct pressure indications is the difficulty of obtaining perfect uniformity in the quality of the metal upon which the pressures are recorded. To this possible defect as well as the probable imperfect action of the piston may be attributed the very wide differences between the results sometimes obtained with equal charges of the same kind of powder.

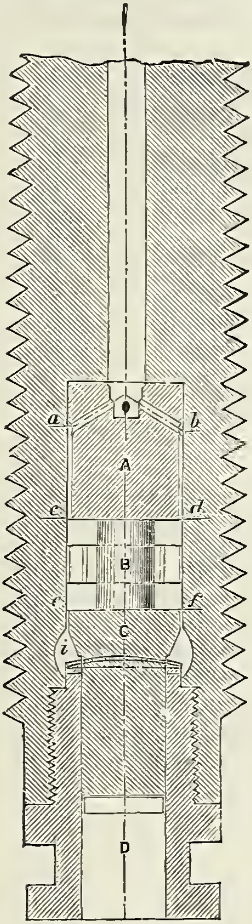


Fig. 305.—Sectional elevation of Crushing-instrument.

1344. Pressure-curves.—Having obtained the pressures and velocities as they actually occur in the bore, we may make a graphic representation of them by constructing a curve which would have for abscissas the times, and for ordinates the pressures, of the gases. We would find it somewhat similar to Fig. 306. That is, the tension increases with great rapidity in the first moments of combustion; it attains promptly the maximum, and then decreases with less rapidity. It is to this circumstance that are due the bursting properties of the powder and the destructive effects which it sometimes exerts upon the bore of the piece.

But with equality of charge the curve is found to vary very much with different powders; therefore it is desirable to produce such a powder that the curve O M B may be replaced by a curve such as O M′ B′, in which the maximum may be less elevated, but whose total area may be equal or even superior.

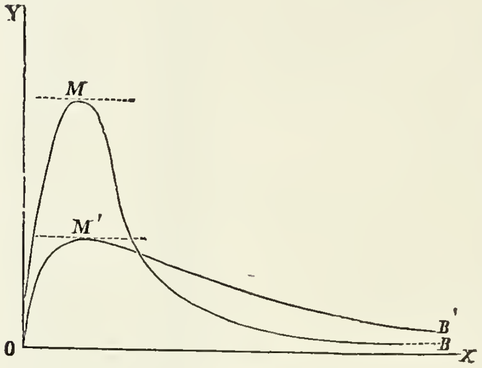


FIG. 306.

Thus we should endeavor to take away from the powder its bursting properties and preserve to the projectile the same velocity in leaving the bore, or even impress upon it a greater velocity. In order to accomplish this it is necessary to consider what has been said under the head of *Explosive Force of Gunpowder* (Art. 1198).

1345. HYGROMETRIC QUALITIES.—If the powder be made of pure materials and have the required density, its hygrometric quality follows as a matter of course. It may be determined by exposing the powder to air saturated with moisture. For this purpose, samples of about 1,500 grains weight may be placed in a shallow tin pan, nine inches by six inches, set in a tub the bottom of which is covered with water. The pan of powder should be placed about one inch above the surface of the water, and the tub covered over. In this manner any sample of powder may be compared with another of known good quality. Good powder, made of pure materials, will not absorb more than two and a half per cent. of moisture in twenty-four hours.

1346. ANALYSIS.—Whatever may be the mode of proof adopted, it is essential, in judging of the qualities of gunpowder, to know the mode of fabrication, and the proportions and degree of purity of the ingredients. The latter point may be ascertained by analysis.

The following plan is recommended by *Fresenius:*

Determination of the Moisture.—Weigh two or three grams of the substance (not reduced to dust or pulverized) between two well-fitting watch-crystals, and dry in the desiccator, over concentrated sulphuric acid, or at a gentle heat, not exceeding 60° centigrade, till the weight remains constant.

Determination of the Saltpetre.—Place an accurately weighed quantity (about five grams) on a filter and moisten with water; then saturate with water, and after some time, repeatedly pour small quantities of hot water upon it, until the nitrate of potassium is completely extracted. Receive the first filtrate in a small weighed platinum dish, and the washings in a beaker. Evaporate the contents of the platinum dish cautiously, adding the washings from time to time; heat the residue cautiously to incipient fusion, and weigh it.

Determination of the Sulphur.—Oxydize two or three grams of the powder with pure concentrated nitric acid and chlorate of potassium, the latter being added in small portions, while the fluid is maintained in gentle ebullition. If the operation is continued long enough, it usually happens that both the charcoal and sulphur are fully oxydized, and a clear solution is finally obtained. Evaporate with excess of pure hydro chloric acid in a water-bath to dryness; filter, if undissolved charcoal should render it necessary, and then precipitate the sulphuric acid by barium chloride with the usual precautions.

Determination of the Charcoal.—Digest a weighed portion of the powder repeatedly with sulphide of ammonium, till all the sulphur is dissolved; collect the charcoal on a filter (previously dried at 100° and weighed), wash it first with water containing sulphide of ammonium, then with pure water; dry at 100° and weigh.

The charcoal so obtained must, under all circumstances, be tested for sulphur by the method given above, and, if occasion require, the sulphur must be determined in an aliquot part.

These operations can only be performed with accuracy, in a properly appointed chemical laboratory, by one somewhat experienced in quantitative analysis.

1347. INSPECTION REPORT.—The report of inspection should show the *place* and *date* of fabrication and of proof; the *kind* of powder and its general qualities, as the number of grains in 100 grs.; whether hard or soft, round or angular; of uniform or irregular size; whether free from dust or not; the initial velocities obtained in each fire; the amount of pressure for each charge; the amount of moisture absorbed; and, finally, the height of the barometer and hygrometer at the time of the proof.

1348. MARKS ON THE BARRELS.—Barrels must be marked on the head (Fig. 307) with maker's name, date of manufacture, initial velocity when manufactured, density, pressure, kind of powder, lot, class, last initial velocity and pressure obtained.

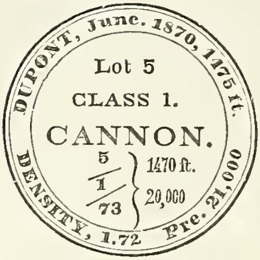


FIG. 307.

1349. RESTORING UNSERVICEABLE POWDER.—When powder has been damaged by being stored in damp places, it loses its strength. If the quantity of moisture absorbed does not exceed seven per cent., it is sufficient to dry it, to restore it for service. This is done by exposing it to the sun.

1350. CONDEMNED POWDER.—When powder has absorbed more than seven per cent. of water, it is condemned, and sent to the powder-mills to be worked over.

When it has been damaged with salt water or become mixed with foreign matter which cannot be separated by sifting, the nitre is dissolved out from the other materials and collected by evaporation.

When powder is condemned by survey, it should be turned into store; as the nitre contained, which forms three-fourths of the powder, is still perfectly good, and can be made serviceable in making new powder. (Art. 1066.)

1351. PURCHASING POWDER ABROAD.—In case of necessity, powder for saluting may be purchased abroad in order to preserve a supply of our own proof-powder for battle.

Should it become necessary to use powder for service charges which has not been regularly inspected and proved in the manner required by regulations, such tests of it must be made as circumstances will admit. The ranges given by it may be compared with those of service powder of good quality under the same circumstances. If deficient in strength, the quantity of the charges should be increased, until the ranges are equalized, in order that the sight-bar may still indicate the proper elevations for each charge and distance.

Section IV.—Preservation and Storage of Gunpowder.

1352. PRESERVATION AND STORAGE.—In the stowage of powder, both ashore and afloat, especial pains should be taken to secure it from the dangers of explosion and the effects of moisture; and to this end great care is observed in the construction and locality of magazines and shell-rooms, particularly on board ship, where many details have to be considered, and every possible precaution taken to accommodate the full allowance of powder completely, to guard it to the utmost against injury and accidental explosion, and to deliver it from the magazine as required, with facility and certainty.

1353. Magazines on Shore for the storage of gunpowder are generally built of brick or stone in a very substantial manner, and in places free from moisture, and should be remote from danger. The magazine should be fire-proof and dry, and protected by lightning-rods, which are attached to masts or poles planted from six to ten feet from the walls of the building; the mast should be of such height that the point of the stem may be about fifteen feet above the building. Magazines should never be opened while there is thunder and lightning.

For the preservation of the powder, and of the floors and lining of the magazine, it is of the greatest importance to preserve unobstructed the circulation of air under the flooring as well as above. The windows should have inside shutters of copper wire-cloth. The ventilators must be kept free. No shrubbery or trees should be allowed to grow so near as to protect the building from the sun. The magazine-yard should be paved and well drained, and kept scrupulously clean.

1354. Storage.—Powder barrels in magazines on shore, when there are no racks, should be stowed on their sides, with their marked ends towards the alleys, three tiers high, or four tiers if necessary, with small skids on the floor and between the several tiers of barrels, using chocks at intervals on the lower skids to prevent the barrels from rolling. If it is necessary to pile the barrels more than four tiers high, the upper tiers should be supported by a frame resting on the floor; or the barrels may be placed on their heads with boards between the tiers.

Whenever practicable, the barrels should be arranged in double rows, with a passage-way between the rows, so that the marks on each barrel may be seen at a glance, and any barrel easily reached.

Barrels must be carefully examined before putting them into the magazines, to see that they are perfectly tight; that the hoops are not fastened with iron nails; that there is no iron or anything objectionable about the barrel.

1355. The powder should be separated according to its kind, the place and date of fabrication, and the proof-range.

Each parcel of powder should be inscribed on a ticket and attached to the pile, showing the entries and the issues.

Powder, when stored in magazines on shore, must be kept *only* in barrels, and arranged in lots, being classed as follows:

Class 1. New powder.

Class 2. Powder returned from ships and other sources which has been found after proof to be up to the required standard for service.

Class 3. Returned powder, fit only for filling projectiles. (Powder taken from projectiles shall be used again only for filling projectiles.)

Class 4. Returned powder fit only for saluting.

Class 5. Powder unfit for use.

There should be an unencumbered space of six or eight feet square at the door or doors of the magazine.

1356. Preservation.—Powder-houses or magazines on shore are to be inspected by the ordnance officer at least once in every week, and every precaution taken to guard them against explosion, and to preserve the powder dry and in good condition.

Magazines should be opened and aired in clear, dry weather, when the temperature of the air outside is lower than that inside the magazine. The moisture of a magazine may be absorbed by chloride of lime or charcoal, suspended in an open box under the arch of the door, and renewed from time to time.

The use of quicklime is dangerous and forbidden.

The powder in barrels should be turned from time to time, at least as often as every three months, and being arranged as mentioned before, the oldest powder will always be accessible for first delivery, without disturbing that of more recent manufacture.

1357. Service of the Magazine.—When powder is handled in powder-houses or magazines on shore, either for the purpose of inspection or preparation for delivery to ships, the baize-cloth is to be spread, and the people before entering the magazine must divest themselves of every metal implement, empty their pockets,—that nothing likely to produce fire may escape detection,—and put on the magazine-dresses and slippers. Neither loose powder nor open barrels will be permitted to remain in a magazine, nor shall barrels on any account be opened in a magazine. Should a barrel-head start, the barrel must be immediately removed to the *shifting-house*, and the powder shifted into a serviceable barrel. The barrels must be opened only on the floor-cloth in the shifting-house, and no metallic setter used in driving either copper or wooden hoops. Powder-barrels should never be opened except when required for use, as grains of powder falling between the staves would prevent their being tightened. Samples must always be taken from the bungs.

Magazine-dresses.—They are to be of worsted, like a simple shirt, to reach to the knees; no metal buttons to be worn.

Magazine-slippers.—They must be made wholly of cotton, cloth or buckskin. In hot or warm climates the naked feet are generally preferred. India-rubber and woolen-slippers are prohibited.

1358. *Fixed Ammunition* should not be put in the same magazine with powder in barrels.

Fireworks should never be stored in a powder-magazine.

1359. *The Magazine Ledger* should show at all times the quantity of powder on hand, the number of barrels, the marks on each barrel, and, in fact, a complete history of all the powder in the magazine.

1360. *Issuing Powder.*—When powder is to be issued for use to any vessel, it shall be selected as far as practicable from deliveries made by the same manufacturer, at the same time or date. The powder is measured in copper measures and put into cartridge-bags, and the cartridges stowed in powder-tanks. A correct history of all powder issued must accompany it. When powder is shifted from one barrel or tank to another, care must be taken to remove all old marks, and to mark the barrel correctly for its contents.

Great irregularities having been discovered in the weight of cartridges supplied from the different magazines, it is ordered that at least ten measures shall be weighed at each filling, and allowance made for different densities, by using a small compensating measure to supply the deficiency or to remove the excess.

1361. Ships' Magazines.—All powder, whether public or private, must be safely stowed in the magazine.

Form.—In view of the fact that all the powder for use on board of ships is now put up in cartridge-bags and stowed in cubical copper tanks made water-tight, the form of magazines should be as nearly rectangular as the shape of the vessel will admit.

Strength.—They should be built strong enough to resist sufficiently the effect of the working of the vessel in heavy weather, and also the pressure of water they will have to sustain in case of being flooded.

Situation.—When there is only one magazine, it is always in the after part of the vessel; but when two, one aft, the other forward; and they are to be as nearly equal in regard to capacity as the shape of the vessel and other circumstances will admit.

1362. CONSTRUCTION.—The magazine consists of three parts: (Fig. 308.)

The room where the charges are stowed; a small delivery-

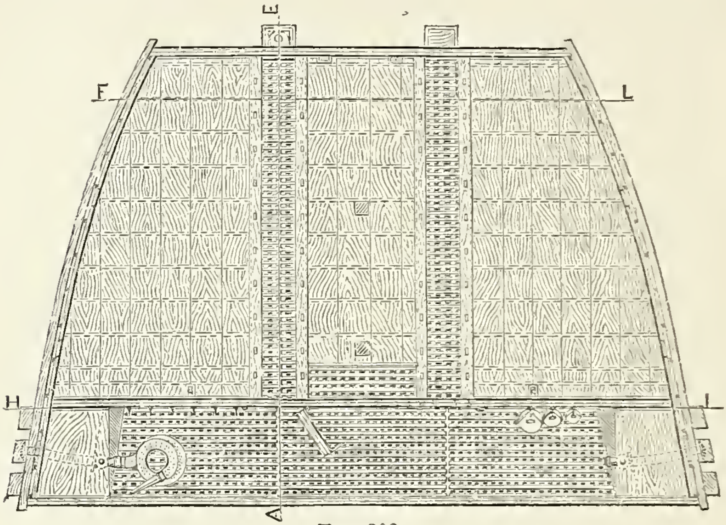


FIG. 308.

room or passage, usually athwartship, immediately outside of this, into which the charges are passed before going on deck; and the light-rooms, or boxes.

The magazine and its passage, considered as one, must be made perfectly water-tight, by caulking the bottom and sides, and then lining them internally, first with white-pine boards, tongued and grooved, and again with sheets of lead of extra thickness, soldered together over these boards. Both these linings are to extend entirely over the bottom, or floor, and all the way up to the crown on all sides.

When the magazine reaches the ceiling of the ship it must be battened off two inches; the lining of the floor must be battened up one inch, and also the magazine-deck, so that water leaking through the sides of the vessel may run by and under, and not into, the magazine.

An external lining of sheet-iron must be resorted to as a protection against fire, and to prevent the intrusion of rats.

When it is impossible to avoid extending the sides of the magazine so far out towards the skin of the ship as to leave only an air-passage on either side, the crown should be at least six feet below the deep load-line.

In all cases where this crown is less than six feet below that line, the sides should be made susceptible of protection by allowing a space to interpose materials, such as sand, coal, or water in tanks, between them and the interior planking of the ship. An average space of six feet or more on both sides will be sufficient.

Under no circumstances, however well the side be guarded, should the crown of the magazine, if it can be avoided, be less than four feet below the load-line.

Their floors may rest on the kelson, but should not come below it.

1363. Their height should be equal only to an exact number of times the height of a powder-tank when lying on its side, in addition to the thickness of the shelving; an additional inch should be allowed for play or spring.

The whole height in the clear should be limited by the condition that a man standing on the floor may reach the upper tier of tanks with ease.

Four tiers of 200-pound tanks, three of them resting on shelves two inches thick, and the other on inch-battens on the magazine-floor, with an allowance of one and a half inch for play, will require a height, in the clear, of six feet two inches. Both safety and convenience would suggest this as the maximum limit in height, even for the largest magazine.

If, however, in a ship of great draft of water, it should be found practicable to have height enough for five tiers of tanks, then the lower tier may be laid so as to occupy the whole of the magazine-floor; and on the top of this tier, in the alley-way, a light false bottom is to be placed for the men to stand upon to enable them to reach the upper tier, which is the one that should be exhausted first. This false bottom should be made of gratings, and in sections convenient for speedy removal.

A magazine *aft* in a ship is to have its passage for delivering powder adjoining its *forward part*; and one *forward* in a ship is to have this passage adjoining its *after part*, in order that it may never be necessary to pass powder over the light-box scuttle.

1364. As many doors, D (Fig. 309), are to be cut in the bulk-head, I H (Fig. 308), separating this passage from the magazine-room, as there are alleys to be left in the latter, between the racks or shelves on which the tanks are stowed; and these doors must correspond with those alleys. They are not only to afford a means of entrance to the magazines, but also for passing the tanks in and out.

Section on H I, Fig. 308.

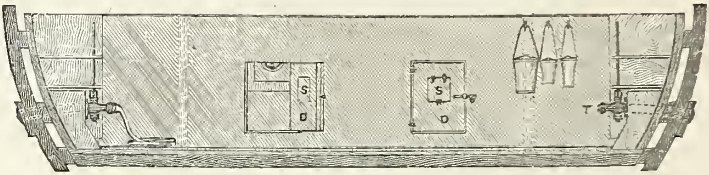


Fig. 309.

Through the upper part of each door a small scuttle, S, is to be cut,—two, if necessary,—for the purpose of passing the cartridges out of the magazine-room with the door itself closed: and is to have a lid so arranged as to open outwards only, and to close of itself when the scuttle is not actually in use.

Frigates should have two alleys for each magazine. In screw-vessels of large size, where the shaft will interfere with this arrangement, two alleys for the forward magazine. In smaller vessels one alley will suffice. In all cases the alley is not to be less than two feet and ten inches in breadth, and it ought to be more, if practicable, to prevent confusion and delay. Each alley (A E, Fig. 308) is to be illuminated by a separate light.

If there be room in the magazine, there should be space left at one end for a man to pass from one alley to the other without going into the passage.

All the metallic fixtures about a magazine, delivering-passage, and light-room must be of copper.

In order to increase security against the effects of lightning, a magazine should be placed, if practicable, so as not to include a part of a mast.

1365. Flooding the Magazine.—Each magazine as a whole, that is, including the delivery-passage, being made as stated before, water-tight, is to be provided with an independent cock, T, for filling it rapidly with water; a waste-pipe leading from the upper tier of tanks to carry off the superfluous water, and a cock just at the floor to empty the magazines after having been flooded. Both the cocks must be turned from the decks above, each having a lever attached to its spindle for the purpose, distinctly marked with engraved letters what it is and how it is to be used, and kept secured by a proper lock, the key of which is to be kept among those of the magazine. A perforated disk or strainer is to be secured inside of the hole, at the upper part of the magazine, for the waste-pipe; the delivery-pipes are trapped to prevent vermin or vapor entering.

Section on A-E, Fig. 308.

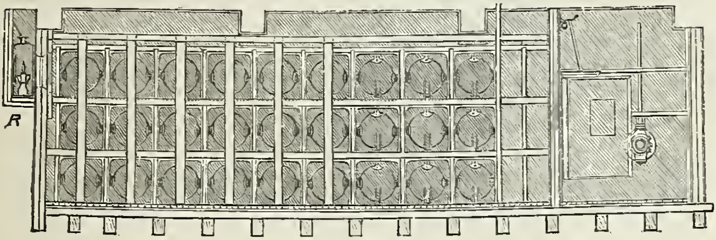


FIG. 310.

1366. LIGHTING THE MAGAZINE.—The magazine is to be lighted by means of one regulation lantern, to correspond with each alley of the magazine-room, placed in a box arranged for the purpose, R (Fig. 310).

The lantern is fitted to hold a regulation candle of large diameter. The box, of which a portion of the magazine bulkhead forms a part, is lined internally with soldered sheets of copper. The entrance to it is at the top, through a scuttle in the deck large enough to admit the lantern. For single-decked vessels this scuttle may be surrounded by a composition covering pierced with holes one-fourth of an inch in diameter, on the forward and after sides, near the top. The cover must be so arranged that, when placed on in one position, all the holes will be closed; by turning it half round, they are all open, thus supplying air to the lantern and carrying off the smoke. A small dome or reversed funnel of copper, when it can be conveniently done, is to be placed above the lantern and fitted with a pipe of the same metal to convey the smoke off. This pipe may pass up through the covering of the light-box, which is to have a plug-hole lined with brass for the purpose, and then led farther, if necessary, taking care, however, to consult perfect safety throughout.

The admission of air to the light-box may be from the division of the hold in which it is placed, by small holes near its top, through its side or back, protected with copper-wire gauze, inside and outside of the box.

In the portion of the magazine bulkhead before alluded to, and so as to throw as much light as possible into the magazine-room, an opening with great bevelling is cut, which is covered by two plain glasses of suitable thickness, somewhat separated from each other, one of which, W (Fig. 311), that next to the lantern, must be permanently fixed; and the other, that next to the magazine, X, is to be let into a wooden frame so that it may be easily removed, and thus both glasses cleaned with convenience and safety. These glasses are held in place by brass screws, after being closely fitted, having their edges made perfectly tight.

1367. STOWING THE MAGAZINE.—Ledges on the shelves,

Section on F L, Fig. 308.

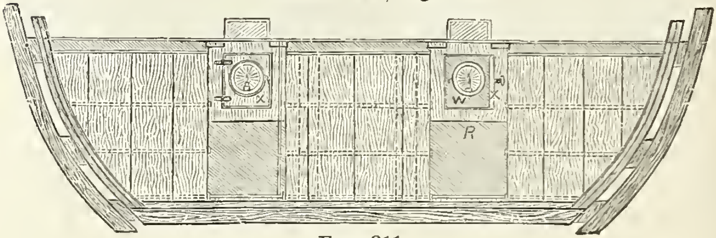


FIG. 311.

or a bar of wood (Fig. 310), to ship and unship with facility, will be provided for each tier of tanks on both sides of the alleys, to secure them from getting out of place when the ship rolls.

The powder-tanks containing charges for each class of guns are stored on their sides with the lids next to the alleys and hinges down, near the magazine-scuttles through which these charges are delivered. When tanks are emptied they are stowed on the upper shelves in order that the powder may be kept as much as possible below the water-line.

Before the tanks are filled they must be thoroughly cleaned, and before stowing them in the magazine the exteriors are carefully cleaned and the lids examined.

1368. POWDER TANKS.—The powder-tanks, for the reception, and safe storage of the powder on board ship, are rectangular metallic cases, the sides and bottom being of sheet-copper, zinc-coated, and the top of composition. They have a circular hole or opening in the top, which is closed by a composition lid on hinges, *c* (Fig. 312), and made water-tight by means of a rubber-gasket inserted in an annular groove on the lower side of the lid, shutting down upon a knife-edge around the opening, and when closed is retained in place by a screw-bolt fitted in the lid opposite the hinges. There is also a circular copper disk, or cover, A, fitting over the charges, inside the composition lid. On the same end are two handles for transporting the tank.

All tanks before issue should be thoroughly tested, to see that they are water-tight. This is done by immersing them in water six feet in depth, for twenty-four hours.

They are made of four sizes and are denominated as 200 lb., 150 lb., 100 lb., and 50 lb. tanks respectively, this being their capacity for powder in grain; but the 200-pound tank is considered the standard size for service, the others being used only in exceptional cases, and to fill up small vacant spaces.

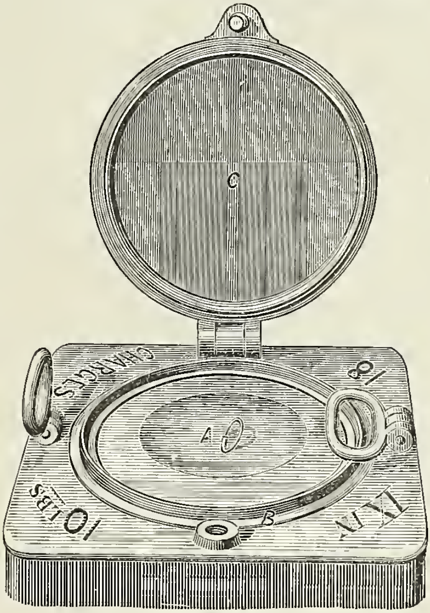


Fig. 312.

1369. The System of Marking Powder-tanks is as follows: The lid end is painted white, and is marked with the weight of cartridge, number of cartridges, and calibre of gun for which they are intended, thus: the lower part of the lid end, as the tank lies in the rack (Art. 1367), is marked with the number of charges contained (Fig. 313). The upper right-hand corner is marked with the number of pounds in each charge. The upper left-hand corner of tanks for supplying the battery, is marked with the calibre of the gun for which the contents is intended, and the calibre is also marked in red on the lid, in large Roman numerals, for all smooth-bore guns.

They are marked on their upper sides, next the lid end, with the name of the manufacturer, kind of powder, initial velocity, density, pressure, and date of manufacture.

And in order to distinguish more readily those tanks containing "Service," "Saluting," "Torpedo," or other charges from each other, the following plan of painting the lids has been adopted: Tanks containing saluting-charges have one-half of the lid painted red, and "Saluting" is marked on the other half.

Tanks containing shell-charges have a red circle painted on the lid, and inside the circle is marked "Shell."

Tanks containing powder for torpedoes are marked on the upper left-hand corner of the lid end "Torpedo," and on the

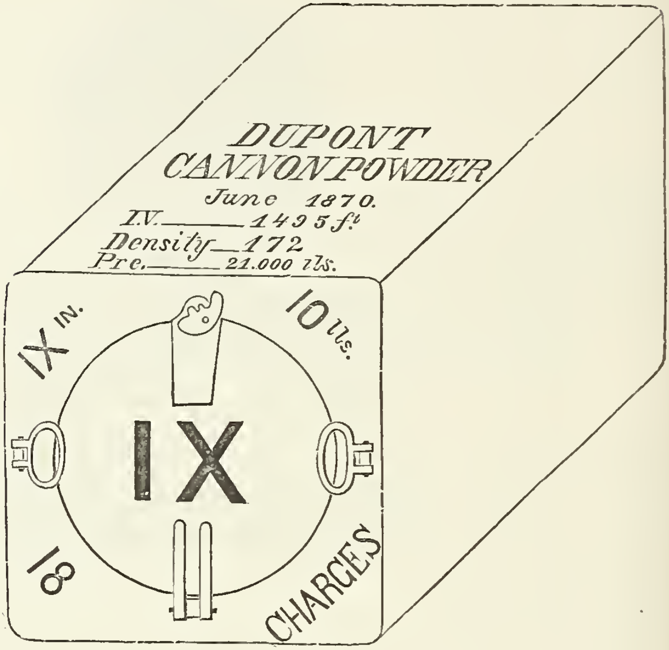


Fig. 313.

lid is marked in red a large letter T. Powder for torpedoes is put in cartridge-bags properly stencilled.

Tanks containing howitzer charges are marked on the upper left-hand corner of the lid end "Howitzer," and on the lid is painted in red a large letter H.

Tanks containing *shell-powder* have a large letter S painted in red on the lid. This kind of powder is put up in any convenient size of bag which will make the best storage, the bags being properly stencilled.

Tanks containing rifle-charges, beside having the calibre marked on the upper left-hand corner of the lid end, have also on the lid a large letter R painted in red.

A history of the powder contained in each is to be pasted or stencilled on the inside of the tank-lid.

No loose powder is ever to be taken or carried on board ship.

1370. Service of the Magazine.—Whenever the magazines are opened, every precaution is to be taken to guard against accident by fire; to examine that all the men stationed in any way, in or about the magazine, embracing all stationed within the magazine-screen, put on the magazine-dress and shoes, and on no account have anything metallic about them, and that no improper articles are introduced; and to see that all the articles required for sweeping and removing loose powder are at hand, and that these operations are performed before the magazine is closed.

The tanks are never to be opened unless by special order, or when powder is actually required for service, and then no more of the lids are to be unscrewed than the immediate supply necessitates. The strictest attention to this is required, as experience has proved that the preservation of the powder in good condition depends upon the entire exclusion of damp air.

No coopering is ever to be done in the magazines of ships. Should powder be received on board in barrels, the hoops and heads must be started on the orlop, or berth-deck, before entering the magazine.

1371. Dampness of Magazine.—Sponge dipped in a solution of salt water, dried and weighed, is a means of ascertaining if dampness exists in these places. If it becomes heavier the magazine is damp.

Ventilation.—Provision must be made by means of grating-hatches for sufficient ventilation in action, to supply the men with fresh air, and allow the dampness caused by perspiration to pass off; and fan-blowers are to be fitted to increase the supply of fresh air, and to assist the ventilation. The magazine should be opened and aired at least once a fortnight, for a few hours, on bright, clear days.

1372. Magazine Screens.—They are made of thick fearnaught or double-baize, with holes through which to pass the powder; these holes to be covered with flaps of the same material. One screen is to be hung abaft, and another forward of the magazine passing-hatch, and scuttles in sloops-of-war; in frigates, one is usually hung abaft the fore, and one forward of the after magazine-scuttle; but as ships are differently arranged, two to each magazine are allowed, if they are necessary.

1373. Transportation of Powder.—Barrels of powder should not be rolled for transportation; they should be carried in hand-barrows, or slings made of rope or leather. In moving powder in the magazine a cloth or carpet should be spread;

all the implements used there should be of wood or copper, and the barrels should never be repaired in the magazine.

When it is necessary to roll the powder for its better preservation, and to prevent its caking, it should be done with a small quantity at a time, on boards in the magazine yard.

In wagons, barrels of powder must be packed in straw, secured in such a manner as not to rub against each other, and the load covered with thick canvas. In transportation by railroad, each barrel should be carefully boxed, and packed so as to avoid all friction. The barrels should have a thick tarpaulin under them. The cars should have springs similar to those of passenger-cars.

1374. Vessels-of-war always receive their powder and loaded shell in the stream.

When receiving powder the red flag is always to be hoisted at the fore, and all proper precaution taken to guard against accidents from fires and lights. The tanks should be passed through the ports most convenient to the magazines, and landed on mats to prevent injury.

The red flag is always to be hoisted at the powder-houses when they are open, and kept flying until they are closed.

The wharf or landing-place must be spread with old canvas, so that the barrels or tanks may not come in contact with, and convey, sand or gravel to the magazines.

When avoidable, gunpowder is not to be sent from vessels to powder-houses, nor from powder-houses to vessels, in wet weather, nor when there is a probability of wetting the barrels or tanks; and the packages must be conveyed in covered boats or wagons showing a red flag.

The powder-boat, before being used, must be swept thoroughly clean, and the bottom covered with mats.

Before shipping powder by a vessel, the hold must be examined to see that all iron bolt-heads, etc., are covered with sheet lead, leather, or old canvas; that the hold is clean swept and free from grit or dust.

A cushion (stuffed with oakum) covered with leather is to be used for landing all powder barrels or tanks upon, whether in the hold of a vessel, or on a wharf, when loading or discharging powder.

Section V.—Explosive Compounds.

1375. General Considerations.—Numerous as have been the attempts to apply other explosive agents as substitutes for gunpowder in fire-arms, no rival of the latter has established any good claims to success as a propelling agent, except for sporting purposes.

The various fulminating substances known to chemists are unfit for use in fire-arms, owing to a variety of circumstances; one of which is the extreme rapidity of their explosion, the whole mass appearing to be converted into gas at once. The action of fulminates is also too local; if a portion of any of the more violently explosive substances be fired on a piece of metal, the latter will be perforated or depressed exactly at the spot occupied by the substance; and if it be attempted to use it to charge fire-arms, they will be destroyed, yet in all probability the ball not projected; moreover, these substances are not serviceable for charging shells, because the latter, instead of being blown into pieces of moderate size capable of inflicting great damage, become converted into fragments so small as to be far less destructive.

But, although gunpowder is still the only propelling agent susceptible of general application, it no longer enjoys a monopoly in connection with some equally important applications to naval, military, and industrial purposes, such as blasting, demolition of walls, buildings, or wrecks, and destruction of vessels by torpedoes.

1376. GUN-COTTON.*—This is obtained by the action of concentrated nitric acid on cotton. Cotton is nearly pure cellulose, which is the principal part of the ligneous fibre or woody matter of plants. Cotton, linen, and hemp fabrics and unsized white-paper are nearly pure cellulose.

When cellulose, cotton wool for instance, is acted upon by a strong mixture of nitric and sulphuric acids, its external appearance remains unchanged, but its chemical composition is very much altered, *pyroxyline* being formed. This is a nitro-substitution product. A certain number of equivalents of hydrogen being abstracted from the cellulose, and their place supplied by an equal number of equivalents of nitryl.

There are a number of these substitution products in which the substitution is more or less complete, and they differ more or less in their properties.

The pyroxyline used to make collodion is a mixture of several of the lower ones. The lower products decompose more readily than the higher ones, and at a lower temperature they are more prone to spontaneous decomposition and more inflammable, and will explode, but with less violence than the higher ones.

* Hill.

The term *Gun-cotton* should be restricted to the highest one of the products; and in making it, the substitution must be carried as far as possible, so that none of the lower and less stable compounds may be obtained mixed with the higher ones. The cotton used must be perfectly dry, and free from grease or other impurities. Only the very strongest nitric acid must be used, and the treatment must be prolonged until the conversion has become complete. The gun-cotton must be finally freed from every particle of acid.

1377. MANUFACTURE.—The various details connected with the manufacture of gun-cotton are frequently changing, and, therefore, only a general description of the mode of preparation will be given.

1378. PURIFICATION OF THE COTTON.—Long-staple raw cotton of the finest quality is the best to use. It is first cleaned and then washed in an alkaline solution to get rid of all oily matters, which would otherwise prevent the complete saturation of the cotton by the acids used in its preparation. After being purified, it must be again thoroughly washed and then dried before going through the subsequent operations.

1379. TREATMENT WITH ACID.—The perfectly dry cotton is converted into gun-cotton by immersion in a mixture of strong nitric and sulphuric acids, in the proportion by weight of one part of nitric to three parts of sulphuric acid.

The sulphuric acid does not act at all in forming the gun-cotton, but only takes up the water that is formed during the process, thus preserving the strength of the nitric acid. The nitric acid is of the strength not less than spec. grav. 1.50. The sulphuric acid is the ordinary oil of vitriol, spec. grav. 1.83.

The cotton is first dipped in this mixture, and exposed to its action for a few moments. It is then taken out, and as much as possible of the acid that has been taken up removed by pressure. It is then put in fresh acid, where it remains 48 hours. The vessels are kept cool during this time by a stream of cold water. In the first acid the cotton is nearly all converted, but it is a matter of the greatest importance that the conversion should be complete. It is therefore necessary that the second and prolonged operation should be made.

1380. TO REMOVE THE ACID.—To remove all the acid from the gun-cotton thus made, it is placed in a centrifugal drying machine, and then thoroughly steeped for a considerable time in running water, and subsequently dried.

It is finally treated with an alkaline solution, as carbonate of soda, and again washed, thoroughly dried, and packed.

1381. ABEL'S METHOD.—In the manufacture of gun-cotton, there is great difficulty in thoroughly washing the cotton, because the long, hollow fibres get twisted and bent, so that it is very hard to free them from the acid. Abel has instituted the pulping process, by which the cotton is so torn as to be easily washed; and instead of raw cotton of high quality and long staple, any description of cotton can be employed; and the waste cuttings from spinning-machines, such as are used for cleaning machinery, are more suitable than cotton in any other form. The pure, fine pulp is pressed into compact masses while wet.

1382. *Pulping.*—The cotton, after being washed and strained, is carried to a long tub, or *beater*, filled with water, in which a wheel revolves, armed on its periphery with steel cutters. From the bottom of the tub under the wheel extend similar projections of steel, and as the motion of the wheel carries the cotton around, all parts are driven through the contracted space between the cutters, thus reducing the whole to a pulp. From the beater the entire contents is run into a *poacher*, or large tub in which a paddle-wheel revolves. The object being to continue the washing of the cotton, after being reduced to pulp, so as to secure the perfect cleansing of the material. All parts of the pulp are carried over and over by the wheel, and this operation is continued several hours. The operations of the preparation of the cotton are now complete, and it only remains to drain off the water and press the pulp into the required shape.

1383. *Compressing.*—In order to drain off the water, the first operation is to draw off the pulp and water from the poacher to a large iron cylinder, or *stuff-chest*, where it is agitated by paddle-wheels. From the bottom of the stuff-chest there runs a pipe to lead the pulp to the press for forming the cakes.

This press is a circular machine consisting of a shelf having thirty-six circular perforations about two and a half inches in diameter, which have cylindrical continuations extending about one foot below. Beneath these hollow cylinders are a corresponding number of solid cylinders fitted so as to enter them, which are attached to a plate that is actuated from below by a hydraulic force. The solid cylinders being entered into their corresponding hollow ones, the pulp is allowed to run in through a movable trough, and fill the recesses. The upper orifices are now covered with a weight, the solid cylinders forced up, and the pulp compressed, the water being allowed to escape through strainers or perforations in the pressing cylinders.

The cylinders of gun-cotton thus formed are removed to a second press having only four cylindrical recesses, in each of which are placed three of the cylinders, separated from one another by disks of iron having scored edges to allow the escape of water. The operation is repeated, the pressure being six tons to the square inch. This press produces cylinders about three inches in length by two and one-half inches in diameter, and weighing one-half pound; about six per cent. of moisture being still retained.

1384. General Properties.—Gun-cotton is entirely insoluable and unaffected by water, so it may remain in it any length of time without injury. Its permanency has been a matter of doubt, and for this reason the more extended use of gun-cotton has been greatly hindered. Of course if it is liable to spontaneous decomposition, it cannot be used with any degree of confidence, but the late improvements in its manufacture seem to give a very stable and safe product. If so regarded, it possesses many advantages over gunpowder, as follows: less danger in making; unaffected by moisture, or even immersion in water; easier transportation; it leaves no residue and makes no smoke.

1385. Forms in which Gun-cotton is Used.—It can be worked into many forms for different uses. The process of manufacture when not pulped leaves it in the loose state, resembling ordinary cotton. It can then be run into threads and ropes, and the threads into webs or hollow cylinders. For ordnance purposes it is made into disks from the pulp, or the yarn is wound on a hollow tube or core. Besides this, the compact masses pressed from pulp can, while still moist, be cut, sawed, or drilled into any shape, granulated or mixed with other bodies.

Potassium nitrate or chlorate, is usually mixed with the pulped article. Abel has proposed a mixture called *Glyoxiline* composed of compressed nitrated gun-cotton saturated with nitro-glycerine.

1386. Uses of Gun-cotton.—It is much used for mining purposes and submarine explosions, since it is more readily handled than gunpowder, is not injured by water, and less is required to do the same work. Compressed gun-cotton is much used for torpedoes and large engineering operations, for which it presents very great advantages. It is very effective when great destructive effects are to be produced very quickly, as blowing up bridges and military works. For instance, to destroy a bridge it is only necessary to place upon it a charge of gun-cotton and fire it with a detonating fuze. In the same way large quantities of rock may be broken up and guns may be disabled.

1387. Mode of Firing.—Dry gun-cotton when unconfined flashes off without explosion; when ignited, therefore, to obtain its force it must be confined in strong vessels so that the gases first generated will be driven through the whole mass enveloping every particle with flame before the case is ruptured. Under these circumstances great explosive effects may be obtained. The explosion is very much influenced by the manner in which it is effected. It can be readily detonated, and then it is unnecessary to have it strongly confined. The more powerfully it is compressed the more readily it can be detonated, since the particles are less able to move on one another, and therefore offer a greater resistance, causing more rapid evolution of heat.

Compressed gun-cotton can be fired while moist, or even when saturated with water, by exploding in it a disk of the dry, by means of a fulminate fuze. When dry and unconfined, if ignited by a flame, it burns steadily and quietly until consumed; but if fired by a detonator, it explodes violently.

1388. NITRO-GLYCERINE.—This is a nitro-substitution product of glycerine; it is a violently explosive substance produced by the action of nitric-acid on *glycerine.*

Its formation resembles that of gun-cotton, three equivalents of hydrogen being removed from the glycerine by the nitric acid, and three equivalents of nitre introduced in their place.

1389. Glycerine is the sweet principle of oils and fats. It is a sweet, viscid, colorless liquid, soluble in water and alcohol in all proportions. In this country it is principally derived from the fats of hogs. That of commerce contains more or less water, and is slightly colored. Sometimes it also contains small quantities of fatty acids. This is a very dangerous impurity, if it is to be used in making nitro-glycerine, and must be guarded against.

1390. Method of Manufacture.—It is produced by the action of strong nitric-acid on glycerine at a low temperature.

As in making gun-cotton, the nitric-acid is mixed with a large proportion of strong sulphuric acid,—one part of the former to two parts of the latter, by weight,—which acts in taking up the water that results from the reaction, and so keeps the nitric acid at its full strength.

Glycerine is mixed slowly with the acid mixture, which is constantly agitated during the operation, and great pains is taken to keep down the temperature. When all the glycerine has been added, the mixture composed of nitro-glycerine and the remaining acid is poured in a thin stream into a large volume of water, where the nitro-glycerine is precipitated as a white, opaque, heavy oil. When it has subsided the water may be poured off. It must be thoroughly washed, as too much stress cannot be laid upon the importance of a complete removal of the acid from the nitro-glycerine.

After some time, depending on the temperature, the white, opaque, thick fluid changes to a clear, pale amber, somewhat thinner liquid, and then should be entirely free from acid. If so, it will remain unaltered, not becoming acid again.

Converting glycerine into nitro-glycerine must be carefully and properly conducted, if good results are to be obtained. It must be carried on at as low a temperature as possible, and a great rise of temperature must be prevented during the operation. The glycerine must be free from dangerous impurities.

The strongest nitric acid must be used; if weak acid is used, the quality of the product may greatly vary.

1391. General Properties.—Nitro-glycerine is more violent in its explosive effects than gun-cotton, more nearly resembling the fulminates, though not so easily exploded. When not pure, it undergoes spontaneous decomposition with evolution of nitrous fumes, frequently causing explosions; but when well purified, it may be kept for a long time without alteration.

It is unaffected by, and does not mix with, water, so that it can be exploded when in direct contact with it. It is a light yellow, oily liquid, has a faint, peculiar smell, and a sweet, pungent aromatic taste. A drop of it is said to cause very violent headache, and in large doses it appears to be decidedly poisonous.

1392. Mode of Firing.—To explode nitro-glycerine it is necessary to use what is technically called a *strong exploder*, that is, one that in itself gives a strong blow or shock. Therefore, fulminate of mercury is generally employed for that purpose. Nitro-glycerine explodes only locally by percussion. If placed upon an anvil and struck with a hammer, the particles receiving the blow detonate, not exploding, but scattering the rest of it. It is not exploded by friction or concussion in the ordinary sense of the words, that is, by an ordinary or reasonable friction or concussion. Simple application of flame will not fire it, though, of course, it may be heated to explosion; but it is not sensitive, that is, not easily exploded by slight causes, therefore an ordinary fuze or slow match is useless.

However exploded, it seems always to be instantaneous through the whole mass. When fulminate is used, this is evidently by direct detonation. In other cases, probably by initial detonation of a small particle. It is more easily detonated than any other body, and less fulminate is required. It can readily be fired by this means, when unconfined; but as is always the case, greater effects are obtained if it is confined, however slightly. It is with the greatest difficulty that it is fired when frozen; therefore it is used in the liquid state.

1393. Transportation.—It is usually kept in cans and frozen for transportation or preservation, and must be melted before it is used. It solidifies at 40° Fahr., which can readily be accomplished by keeping it in melting ice a sufficient time. It freezes to a nearly pure white crystalline mass. When frozen, it can be melted by means of hot water not above 90° or 100° Fahr.

1394. Stability or Permanence.—The history of nitro-glycerine closely resembles that of gun-cotton. The manufacture has been carried on before it had been properly studied or its characteristics known. As to its stability, the little exact knowledge obtained of it has caused the opinion to be formed that it is very unstable. Even yet we have very little precise knowledge of it, but it is believed that its permanency depends upon its purity, and that if pure and well made it is sufficiently stable, provided proper care is taken of it. As an explosive it is so valuable that it would still be used even were it much more dangerous.

1395. Uses of Nitro-glycerine.—It has generally been used for submarine and other blasting. For heavy work it surpasses any other agent, being so much more powerful than gunpowder; less is required and less drilling is necessary. It is a powerful shattering agent, and breaks up the rocks finely. It leaves no residue and gives no smoke. It is well adapted to many kinds of submarine work; good results are obtained by placing it on the surface of rocks under water, the latter acting as a *tamping*.

1396. COMPOUNDS OF NITRO-GLYCERINE.—The successful application of the remarkable explosive liquid, *nitro-glycerine*, has been developed chiefly in the last few years, and the existence of several most serious obstacles to its use in the pure liquid condition has been practically demonstrated; in several instances, indeed, by most disastrous accidents; therefore, many attempts have been made to devise some method of promoting safety, and also certainty of action in its employment.

These ends have been attained to a great extent by mixing nitro-glycerine with some solid substance of perfectly inert nature, and of absorbent character, through the medium of which the liquid is susceptible of employment in a condition assimilating to that of other explosive agents in practical use.

1397. Dynamite.—This is the name given to a compound of nitro-glycerine formed by absorbing it in a light silicious earth, which may be mixed with about three times its weight of nitro glycerine without becoming more than moist to the touch, and is therefore readily susceptible of manipulation as a solid material. This mixture is as readily susceptible of explosion through the initiative agency of a detonating fuze as nitro-glycerine itself, and though it obviously cannot be so powerful an explosive agent as that substance when successfully applied in its undiluted state, its destructive powers are still greatly in excess of those of gunpowder.

Dynamite is applicable to all the uses for which nitro-glycerine is employed. When properly applied it does not need confinement for the development of its explosive forces, and it is especially applicable for military purposes.

It is by far the best of the nitro-glycerine mixtures, and is probably the best form for its use in torpedoes.

Certain defects are inherent in the material, such as its losing its susceptibility to detonation by the ordinary means at a low temperature,* and the tendency of the nitro-glycerine to partial separation from the silicious earth during transport and storage; but in balancing its advantages against those of other explosive agents, the special defects of these have also to be taken into account, so that, provided the uniform stability of the material becomes established, and the apprehensions as to its comparatively dangerous character, to which certain accidents have given rise, are allayed by further experience in its storage and use, and, possibly, by improvements in its manufacture, a high position may be assigned to dynamite among the most useful explosive agents of the present time. It is the best of all the nitro-glycerine preparations.

1398. Lithofracteur.—Several other methods of applying nitro-glycerine as a destructive agent have been brought forward. Among these is the substance to which the inventor has given the name, *lithofracteur*, and which contains, in addition to nitro-glycerine and an absorbing medium of the description used in dynamite, some proportion of other explosive materials, such, for example, as the constituents of gunpowder. This substance is of a plastic and almost pasty nature, and is employed in the form of rolls made up in paper.

Lithofracteur may be considered a dynamite to which has been added about twenty per cent. of bad gunpowder containing an enormous excess of carbon. The addition of the constituents of gunpowder lowers its firing-point, which is of

* If finely divided, it may be exploded when frozen; but this fact is practically of little value.

doubtful advantage and makes it more liable to be injured by moisture. Its force must be less than dynamite, for it depends on the amount of nitro-glycerine in it; no additional force being derived from the other ingredients.

1399. Dualine.—Sawdust and similar absorbent materials have also been used as vehicles for the application of nitro-glycerine, under the name of *dualine.*

This mixture also contains about twenty per cent. of saltpetre. It, however, owes its explosive qualities to the nitro-glycerine, and the only thing in its favor is that it is not liquid. In other respects there are serious objections to it. The slight absorbent power of the sawdust makes the amount of nitro-glycerine taken up comparatively small, while holding feebly what is absorbed. The mixture of nitre and wood makes dualine more sensitive to flame or blows, and lowers the firing-point. It contains less nitro-glycerine than dynamite, and hence is weaker. It is much lighter than dynamite, and for equal volumes has much less force. It has an excess of carbon from the wood, so that great amounts of that deleterious gas, carbonic-oxide, are formed, diminishing the force of the reaction.

1400. FULMINATES.—Fulminate is the general name for a class of explosive bodies which are compounds of fulminic acid with a base. They are all more or less explosive by the action of heat or friction; of these the fulminates of mercury and silver are the most important.

1401. Fulminate of Mercury is prepared by dissolving one part of the mercury in twelve of nitric acid, sp. gr. 1.42, aided by a gentle heat. As soon as the mercury is dissolved add eleven parts of alcohol sp. gr. 0.87. A brisk action will ensue and the solution will become turbid from the separation of crystals of the fulminate. Dense, white clouds are also evolved at the same time. When the action has subsided the vessel may be filled with water and the fulminate allowed to settle, after which it is collected on a filter, washed, and dried by exposure to the air. When dry, it must be handled cautiously, as it explodes by friction or percussion, especially when in contact with particles of sand or glass. It is also exploded by heating to about 300°, by the electric spark and by contact with concentrated nitric acid or sulphuric acid.

When wet it will not explode. Its explosive force is not much greater than that of gunpowder, but it is much more sudden in its action.

The readiness with which it is fired makes it an excellent agent for exploding other substances, and this gives it its value. It is used in percussion-caps, primers, and fuzes—not pure, but mixed with nitre, mealed-powder, and other substances, because it is necessary to moderate its explosive property, since it is otherwise too rapid and violent for the purpose. It is sometimes mixed with chlorate or nitrate of potash, and ground glass is often added to increase the sensibility of the mixture to explosion by percussion.

1402. Fulminate of Silver is prepared by a process similar to that for fulminate of mercury, but as its explosive qualities are far more violent it is advisable to prepare it only in minute quantities. When dry, it must be handled with the greatest caution. Nothing harder than paper should be used in manipulating it, or for wrappers. It is exploded in the same way as fulminate of mercury, but is of no practical value on account of its sensitiveness.

1403. Picric Acid and Picrates.—Picric Powder.—Picric, or tri-nitrophenic acid, is another nitro-substitution compound. It is formed by the action of nitric acid upon phenol, or phenylic alcohol, better known as carbolic acid. It is used as a dye-stuff. It has but feeble explosive properties, yet many of its salts are highly explosive.

Potassium picrate is so very sensitive to friction or percussion as to be practically useless.

Abel's picric-powder is a mixture of ammonium picrate with saltpetre. It is very little affected by blows or friction, possesses considerably more explosive force than gunpowder, and can be worked in a moist state like ordinary powder. It is said to be useful for torpedoes.

CHAPTER IX.

PYROTECHNY.

*Section I.—Materials.**

1404. Definition.—Pyrotechny is the art of preparing ammunition and fireworks for military and ornamental purposes.

Buildings.—To conduct the operations of the laboratory with safety and convenience, the following rooms are necessary, viz.:

1st. *Furnace-room*, for operations requiring the use of fire.

2d. *Cartridge-room*, for making all kinds of cartridges.

3d. *Filling-room*, for filling cartridges with powder.

4th. *Composition-room*, for mixing compositions.

5th. *Driving-room*, for driving rockets, fuzes, etc.

6th. *Packing-room*, for putting up articles for transportation.

7th. *Carpenter's and Tinner's-shop.*

8th. *Magazine*, for storing powder and ammunition.

A laboratory, like a powder-mill, should be situated apart from inhabited buildings; and for convenience of communication, the rooms, with the exception of the furnace-room, carpenter's-shop, and magazine, should be situated under one roof.

1405. Furnaces.—A furnace is composed of a cast-iron kettle 2 feet in diameter set in a fireplace of brick. In the field, sods may replace the brick, if the latter cannot be obtained.

Two kinds of furnaces are employed in a laboratory; in the first, the flame circulates around both bottom and sides of the kettle; in the second, it only comes in contact with the bottom; the latter is used for compositions, in which gunpowder forms a part.

1406. Precautions.—To prevent accidents in the operations of a laboratory, avoid as much as possible the use of iron in the construction of the buildings, fixtures, etc.; sink the heads of iron-nails, if used, and cover them with putty; cover the floor with oil-cloth or carpets, and have it frequently swept. Let the

* *Benton's Ordnance and Gunnery.*

workmen in the powder-room wear socks, and take them off when they go out. Keep no more than the requisite amount of powder in the laboratory, and have the ammunition and finished work taken to the magazine. Let powder-barrels be carried in hand-barrows made with leather, or with slings of rope or canvas, and the ammunition in boxes. Let everything that is to be moved be lifted, not dragged or rolled on the floor. Never drive rockets, port-fires, etc., in a room where there is any powder or composition except that used at the time. Never enter the laboratory at night, unless it is indispensable, and then use a close lantern, or wax or oil light well trimmed. Allow no tobacco to be smokod, nor friction-matches to be carried in or around the laboratory.

1407. MATERIALS.—Laboratory materials may be divided into four classes, viz.:

1st. Those for producing light, heat, and explosion.

2d. Those for coloring flames and producing brilliant sparks.

3d. Those used in preparing compositions.

4th. Those used in making cartridge bags, cases, etc.

1408. 1ST CLASS.—*Nitre.*—For laboratory use, nitre must be reduced to a fine powder or very minute crystals. It is best pulverized in rolling-barrels at the powder-mills, but it may be pulverized by hand, in the laboratory, with a rolling-barrel, or by pounding in a brass mortar, or by stirring a crystallizing solution.

1409. *Chlorate of Potassa.*—Chlorate of potassa is formed by passing a current of chlorine, in excess, through lime-water, and then treating the mixture with the chloride of potassium, or by the carbonate or sulphate of potassa. The chlorate of potassa and chloride of calcium are formed; the former crystallizes, the latter remains in solution. It is soluble in water, but not sensibly so in alcohol. As before stated, it is a more powerful oxydizing agent than nitre; and when mixed with a combustible body, easily explodes by shock or friction. It is inflamed by simple contact with sulphuric acid, and thus affords a simple means of exploding mines.

A convenient form of apparatus for this purpose is a glass vessel with two compartments; one containing sulphuric acid, and the other chlorate of potassa and gunpowder. It is placed near the surface of the ground, and when broken under the feet of the enemy, the two substances are brought in contact, producing fire, which explodes the mine.

1410. *Charcoal.*—For laboratory use, charcoal may be made by charring wood in an iron kettle buried in the ground. It may be pulverized by rolling in a barrel with bronze balls, or by beating in a leather bag with a maul. It should be kept in close barrels in a dry place.

1411. *Sulphur.*—When melted sulphur is to be used, care must be taken that it does not become thick, which occurs at about 400°. It may be pulverized in a rolling-barrel, or by being pounded in a mortar and sifted. Roll brimstone is better for melting than flowers of sulphur. When flowers of sulphur are to be mixed with chlorate of potassa, it should be washed to remove the free sulphuric acid. Sulphur hastens the combustion of compositions to which it is added.

1412. *Antimony*—Antimony, or *regulus of antimony*, is a grayish-white metal, easily reduced to a powder, and by its combustion with sulphur produces strong light and heat; the color of the flame is a faint blue.

1413. *Sulphuret of Antimony.*—Sulphuret of antimony is mixed with inflammable substances to render them more easily ignited by flame or friction.

1414. *Gunpowder.*—For compositions, gunpowder is pulverized, or *mealed*, by the rolling-barrel, or by grinding with a muller on a *mealing-table*, or by beating in a leather bag. The simple incorporation of the ingredients of gunpowder does not answer the desired purpose.

1415. *Lampblack.*—Lampblack is the result of the incomplete combustion of resinous substances. It is composed of about 80 parts of carbon and 20 of impurities. It is employed to quicken the combustion of certain mixtures; but before it is used, it should be washed with a strong alkaline solution, to remove all traces of empyreumatic oil.

1416. 2d Class.—Coloring Materials.—A flame is colored by introducing into the composition which produces it a substance the particles of which, on being interspersed through the flame, and heated to the incandescent state, give it the required color. Coloring substances do not generally take part in the combustion, and their presence more or less retards it; it is for this reason that chlorate of potassa, a more powerful oxydizing agent than nitre, is used in lieu of it, in compositions for colored fires.

1417. *Colors.*—There are a great variety of substances which give color to flames, the principal of which are *nitrate* and *sulphate of strontium*, and *chloride of strontium*, for red; the *nitrate of barium*, for green; the *bicarbonate of soda*, for yellow; the *sulphate*, *carbonate*, and *acetate* of copper, for blue *Lampblack* is employed to give a train of rose-colored fire in the air; *powdered flint-glass*, for white flames; and *oxide of zinc*, for blue flames.

1418. *Sparks.*—Brilliant sparks are produced by introducing into the composition filings or thin chips of either wrought-iron, cast-iron, steel, or copper, or by fragments of charcoal; the effect depends upon the size of the particles introduced. The particles should be freshly prepared, or should have been well preserved from rust.

1419. 3D CLASS. PREPARING COMPOSITIONS.—*Turpentine* is the substance which exudes from the freshly cut surface of a pine-tree in warm weather. The first year's running is called *virgin*, or *white, turpentine;* after this it becomes more hard and yellow.

1420. *Spirits of Turpentine.*—This is the *essential oil* obtained by distilling native turpentine.

1421. *Rosin.*—This substance is sometimes called *colophony*, and is the residuum of the distillation of turpentine.

1422. *Tar.*—Tar is a semi-fluid substance, obtained from the heart of the pine-tree by a smothered combustion, as in charcoal-pits.

1423. *Pitch.*—Pitch is obtained by boiling down tar to the requisite consistency, either by itself or combined with a portion of rosin; it becomes solid on cooling, but is softened by the heat of the hand.

1424. *Venice Turpentine.*—Venice turpentine is obtained from the larch; but what is commonly known by that name is a compound of melted rosin and spirits of turpentine. The foregoing substances are chiefly employed in the preparation of compositions for producing light.

1425. *Alcohol, etc.*—*Alcohol* (spirits of wine), *brandy*, *whiskey*, or *vinegar*, is used for mixing compositions in which nitre enters, because this salt is but slightly soluble in these liquids.

1426. *Gum-Arabic.*—Gum-arabic in solution is employed to give body to certain compositions. It retards combustion; and as the solution is liable to spontaneous decomposition, it should only be prepared as wanted.

1427. *Beeswax* and *Mutton-tallow* are employed chiefly in mixing compositions intended to produce heat and light.

1428. 4TH CLASS.—PREPARING CARTRIDGES, ETC.—The material of which cartridge-bags are made is woven expressly for the purpose. The color is white, and the calibre of the gun and the weight of the charge must be stencilled on the bag in figures two and a half inches long. When procured of necessity elsewhere, the stuff should be chosen of wool entirely free from any mixture of thread or cotton, and of sufficiently close texture to prevent the finer powder from sifting through. Wild-boar, satinet, merino, and bombazette are named as proper materials for cartridge-bags; of these the thinnest stuff, not twilled, but having the requisite strength and closeness of texture, is the best. Fabrics of cotton and flax are not used, because the powder sifts through them, and they are more apt to leave fire in the gun than woollen stuffs.

1429. Compositions.—The term *composition* is applied to all mechanical mixtures which by combustion produce the effects sought to be attained in pyrotechny. If these compositions be examined, it will be found that many of them are derived from gunpowder, by an admixture of sulphur and nitre, in proportions to suit the required end.

1430. *Preparation.*—Compositions are prepared in a dry or liquid form; in either case it is necessary that the ingredients should be pure and thoroughly mixed.

1431. *For dry compositions*, the ingredients are pulverized separately, on a *mealing-table*, with a wooden *muller*; they are then weighed and mixed with the hands, and afterwards passed three times through a wire sieve of a certain fineness. When a highly oxydizing substance, as the chlorate of potassa, is present, great care must be observed in mixing to avoid friction or blows which might lead to an explosion. When coarse charcoal or metals in grains are used, they should be added after the other ingredients have been mixed and sifted.

1432. *For the liquid form.*—When it becomes necessary to use fire to melt the ingredients, the greatest precaution is necessary to prevent accident, especially when gunpowder enters. The dry parts of the composition may be generally mixed together first, and put by degrees into the kettle, when the other ingredients are fluid, stirring well all the time. When the dry ingredients are very inflammable, the kettle must not only be taken from the fire, but the bottom must be dipped in water, to prevent the possibility of accidents.

1433. Form.—To give a portable form to compositions, they are inclosed in cases, cast in moulds, or attached to cotton-yarn, rope, etc.

1434. Cases.—Cases are generally paper tubes, made by covering one side of a sheet of paper with paste, or gum-arabic, wrapping it around a *former*, and rolling it under a flat surface until all the layers adhere to each other. The quality of the paper and the thickness of the sides of the case should depend upon the pressure of the gases evolved in the burning. (Fig. 314).

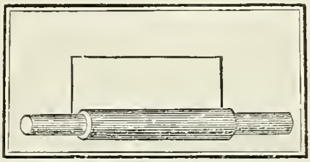


Fig. 314.

1435. *Filling.*—To fill a case, it is first cut to the proper length and placed in a mould; the composition is then poured in, a ladleful at a time, and each ladleful is packed by striking a certain number of blows on a drift with a mallet of a given weight. The height of each ladleful of composition should be about equal to a single diameter of the bore of the case.

1436. *Drifts, etc.*—Small drifts receiving heavy blows should be made of steel, and tipped with bronze (Fig. 315); large drifts may be made of wood or bronze, depending on the force of the blow. In driving highly inflammable compositions, as that of the rocket, care should be taken to settle the drift so as to exclude the air before striking with the mallet, as the heat generated by the sudden condensation of air might be sufficient to ignite the composition.

FIG. 315.

Preliminary tests of all new materials should be made by burning one or more specimens of the composition, and the proportions of the ingredients corrected, if necessary.

1437. *Vent.*—The length of the flame from a given composition depends on the size of the vent and the extent of the burning-surface. The vent is made small by *choking* the end of the case with stout twine; and the burning-surface is increased by driving the composition around a spindle which, on being withdrawn, leaves a conical-shaped cavity. A vent may be also formed by driving in moist plaster of Paris or clay, and boring a hole in it with a gimlet. If the end of the case is to be closed up entirely, the boring is omitted.

Section II.—Means of Firing Cannon.

1438. PRIMERS.—One of the most important subjects to be considered in connection with the efficiency of the ship's battery, is that of providing a simple and efficient means of discharging the guns instantaneously and with certainty; to this end numerous contrivances and inventions have been suggested and tried.

Percussion and friction primers are now used in the service, although electric primers, tubes, port-fire, and slow-match are manufactured, and may be used in special cases.

1439. PERCUSSION-PRIMERS.—The percussion-primer has a wafer or flat-head attached to a quill-barrel. The process usually observed in selecting the material and manufacturing the primers is as follows:

Each quill must be clarified and furnish a barrel at least two and a half inches long. The barrel is to be round, free from flaws, pith, and brittleness occasioned by clarifying, or any other defect which may render it unfit for the purpose required. (Flatness of the quill-barrel will subject it to be rejected at the discretion of the Inspecting Officer.) It must not exceed in diameter nineteen-hundredths of an inch at any part, nor be less than seventeen-hundreths of an inch, within one and one-half inches of the end that is cut from the quill. The small end must not be broken or bruised.

1440. *Fabrication.*—Cut the barrels of the quills close from the feather, and insert them into the socket of a wooden block made two inches deep and two tenths of an inch in diameter.

A punch, having ten cutters radiating from the stem, is entered into each quill-barrel, and driven down with a smart tap, so as to slit the upper end of the barrel into ten prongs, and as far as the upper surface of the block permits. (Fig. 316.) Turn back the prongs, so that they will lie on the surface of the block; a circular punch is applied to each, and made by a blow to cut off the prongs to its own diameter (0.52 inch).

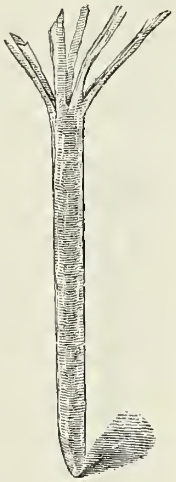


FIG. 316.

1441. Very stout paper, previously prepared by two coats of shellac varnish (gum-lac dissolved in alcohol), is punched with holes 0.17 inch in diameter, and so arranged as to correspond with the sockets of the wooden block. The quill-barrels are freed from pith, the punched paper laid on the block, the holes corresponding and the varnished side up, the quill-barrels put through the paper into the sockets of the block, filled with grained powder, seven grains Troy, and pressed firmly down with their prongs flat on the varnished side of the sheet of stout paper.

1442. Brush the shellac-varnish over the spaces of paper between the heads of the quill-barrels, and spread a sheet of good writing-paper, slightly moistened with water, over the entire surface of the stout sheet and the prongs of the quills. Put the block and the sheets thus stuck together, with the quill prongs between them, into a press, apply a force of about thirty tons, and keep them long enough to set the prongs and make the sheets of paper adhere firmly.

1443. Each quill is separated from the card by means of a circular punch, which cuts out a disk 0.62 inch in diameter, and of course includes the prongs enclosed between them. A stellated disk to cover the head of the primer is punched out of linen-made paper of the finest and closest fabric. This disk has twelve points—diameter from exterior points, 1.25 inches, from interior 0.700 inch. Metal plates are at hand with superficial recesses about 0.65 inches in diameter. On each of these a stellated cover is placed, and four grains of fulminate deposited on it. This is composed of five parts of fulminating mercury and one of mealed-powder, both dry. Place the head of the primer on the charge of fulminate, holding it by the quill-barrel and pressing it down firmly; brush good wheat paste on the points of the cover and on the interior surface of the head, turn the points over, and unite them neatly and closely on the paper head.

1444. The primer is now made and only requires to be protected from moisture. For this purpose, shellac is dissolved in alcohol, so as to be thin enough to be laid on with a brush. This is of a brownish yellow; a portion is prepared with lamp-black. Coat over the quill-barrel with shellac, then the under side of the wafer with the black shellac-varnish. Then shellac the upper surface of the wafer. Tip the end of the quill-barrel with black varnish, and apply a second coat of uncolored shellac thickly about the primer. (Fig. 317.)

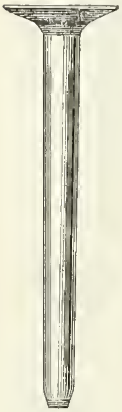


Fig. 317.

1445. The primers, being put in tin boxes made to hold fifty of them, are ready for inspection. After which the lids are coated with shellac to exclude moisture, until wanted for immediate use. These boxes are intended to fit in and form a lining to the primer-boxes which slip on the waist-belts worn by the Gun Captains.

1446. When primers have been returned from cruising ships, or have remained in store for one or more years, they must be tested by firing five per cent. of the number, and not issued again without special orders.

The date of manufacture or re-inspection, with the initials of inspecting officer, are to be legibly written and pasted within the cover of the laboratory cases, and, when issued for service, the date and station to which sent is to be added.

1447 Friction-primers.—The friction-primer for cannon is a small brass tube $1\frac{1}{2}$ inches in length, and 0.19 inch in diameter, filled with fine-grained powder, which is ignited by drawing a rough wire briskly through friction composition contained in a smaller tube inserted into the first near the top, and soldered at right-angles to it.

The short tube is 0.44 inch long, and 0.15 inch in diameter. The wire is 3.4 inches long, of brass, annealed, the end in the small tube flattened, and fitted with dentated edges, *a*; while the other end is doubled on itself and twisted, leaving a loop 0.2 inch in diameter, and then bent alongside the long tube for packing. (Fig. 318.)

1448. *Friction Composition.*—This is made of two parts of the sulphuret of antimony and one part of the chlorate of potassa moistened with gummed water, 50 grains of gum-arabic in two ounces of water to one pound of composition. The materials are first pulverized separately, mixed together dry, moistened with gum-water, and ground in an iron mill such as is used for grinding paint.

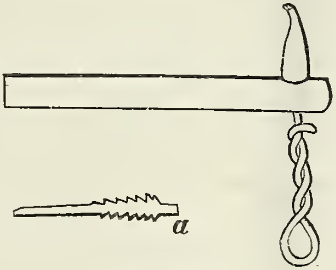


Fig. 318.

Friction-primers are packed in tin boxes in the same manner as percussion-primers.

1449. In case either lock or percussion-primer should entirely fail, recourse will be had to the friction-primer. In using them, the Gun Captain, after taking the primer from the box, will raise the twisted wire loop until it is on a line with the spur; place the tube in the vent with the spur towards the muzzle of the gun, then hook the lanyard into the raised loop, and pull it, when otherwise ready to fire the gun, as though it were a lock-string, using, however, a less degree of force. The lanyard may be hooked to the loop before the tube is put into the vent.

1450. Storage of Primers.—Percussion and friction primers and all other articles containing fulminating matter are kept in boxes prepared for the purpose, and the boxes are stored, separately from other articles, in a dry, secure, and safe place, under lock and key, and are on no account to be put in the magazines—being distributed in two or three places, and a portion kept constantly at hand.

1451. Allowance of Primers.—The allowance of percussion-primers to ships fitting for sea is three hundred for each one hundred rounds, and fifty per cent. additional for practice in pulling the lock-string.

The allowance of friction-primers is fifty to each gun on board ship.

1452. Spur-tubes.—These are quill priming-tubes (Fig. 319) filled with inflammable composition, and ignited by applying the match.

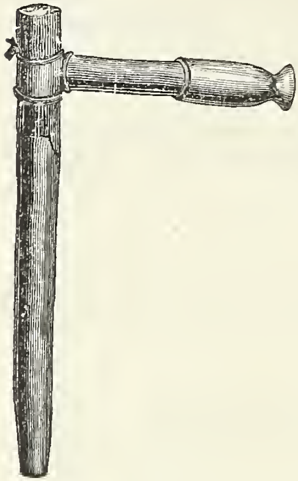


Fig. 319.

The body of the tube is filled with a composition of mealed-powder moistened with camphorated alcohol until a thick paste is formed; the composition is introduced into the quill by pressing its lower end into the paste, thus taking up a portion of it, and repeating the operation until the quill is filled.

A small wire is then run through the axis of the tube, and allowed to remain there until the paste is dry; when it is withdrawn, leaving the composition perforated throughout its entire length. The object of piercing the composition is to expose more surface to the action of the flame; the ignition of the whole contents of the quill is thus rendered instantaneous.

1453. The head of the tube, or *spur*, is formed by inserting a strand of quick-match, about an inch long, into the composition, through a hole near the head of the quill. This is protected by a small tube of stiff paper lashed at right angles to the quill.

The end of the quick-match is covered with a paper cap.

The whole is shellaced over to protect it from moisture.

Spur-tubes are packed in tin boxes in the same manner as percussion-primers.

When spur-tubes are used the Gun Captain exposes the priming, and the 2d Captain applies the match.

1454. Slow-match is used to preserve fire. It may be made of hemp, flax, or cotton rope. The rope is saturated with the acetate of lead or the lye of wood ashes; if it is made of cotton it is only necessary that the strand be well twisted. It burns from four to five inches in an hour, forming a hard-pointed coal, which readily communicates fire to any inflammable material with which it comes in contact.

For the Navy, loosely laid, one-inch flax-rope is used. It is placed in a solution of one pound of acetate of lead to five gallons of water, for twenty-four hours; then taken out, rove through blocks and well stretched. It is left on a stretch for eight or ten hours, and rubbed down smooth with rags; when it is cut in lengths of about two fathoms each, and packed in boxes ready for issue. For service a piece of this rope two or three feet long is wound around a *match-staff*, having a slit in one end and a point of iron on the other, which can be stuck in a match-tub.

1455. Quick-match is used to communicate fire. It is made of cotton-yarn (lamp-wick) saturated in alcohol and then put into a composition formed of mealed-powder and gummed spirits; after saturation the yarn is wound on a reel or hung up until perfectly dry.

The burning of quick-match is very irregular, varying with the condition of the match and the quantity of powder over its surface. One yard in thirteen seconds is about the mean rate of burning of new match when not confined. The rate of burning may be much increased or rendered almost instantaneous by enclosing it in a tube of any description.

The ignition of any combustible which it is not safe to approach may be readily effected by enclosing quick-match in a paper case or leader of the required length.

1456. Port-fire.—Port-fire is a cylindrical paper case containing a composition which burns with an intense flame. It is used for firing guns in the absence of other means, and also employed, as its name implies, to *carry fire* whenever required. In order to stop the combustion in a port-fire it is best to cut it off as near as possible to the flame. Port-fire is used for *life-buoy lights*, because of its ability to resist water. The power of a burning composition to resist the penetration of water to the mass is in direct proportion to the volume of gas evolved and to the rapidity of its escape, and consequently to the rapidity with which it burns. Port-fire cut up into small pieces and placed in a shell forms a very good incendiary material.

1457. In an emergency when port-fire cannot be procured, a substitute may be made by impregnating paper with a solution of 12 oz. of saltpetre to 1 gallon of water. When dried, the paper is rolled up into a solid cylinder about the size of the ordinary port-fire. It burns slowly, or rather smoulders.

The finished port-fires are 18 inches long and $\frac{7}{8}$ inch in diameter.

The composition is composed of: nitre, 4 lbs.; sulphur, 1 lb. 10 oz.; mealed-powder, 12 oz.; and burns at the rate of about one inch in a minute.

The bottom of the case is filled with clay and the top with mealed-powder. The case is painted black and the top tipped with red, to show which end to light.

When dry, the port-fires are packed in laboratory boxes, 50 or 100 in a box.

1458. Firing Cannon by Electricity.—Many methods have been proposed with this object in view. Such, for example, as if in the percussion-primer (Art. 1439) there was substituted for the flat-head an arrangement for electrical ignition constructed in the manner described under the head of Electric Fuzes (Art. 1509). Several contrivances on this principle have been brought forward, but experiment has not decided upon the best. A satisfactory mode of discharging cannon by electricity would be very serviceable in simultaneous and concentrated firing. Firing salutes by electricity may be very simply and easily performed by placing an electric fuze in each cartridge and leading the wires out of the muzzle of the gun to their appropriate connections.

1459. Electric Primer.—The electric primer chiefly used consists of a quill tube filled with fine-grained powder or pierced composition, to the top of which is secured a small hard-wood plug, in which is placed a small quantity of priming composition, and the copper wires so arranged as to ignite the composition upon the passage of the electrical current, by which means the powder in the tube is fired.

The head of the primer is arranged with proper connections for attaching the ends of the circuit-wires leading from the battery or electrical machine.

These primers are useful in firing time-guns, and also those subject to extreme proof.

Section III.—Fuzes.

1460. Fuzes are the means used to ignite the bursting-charges of hollow projectiles at any desired moment of their flight.

There are a great many varieties of fuzes. They may be classed according to their mode of operation, as *percussion, concussion*, and *time fuzes*.

1461. *The Time-fuze* consists of a column of inflammable composition which, being ignited by the charge in the gun, burns for a certain space of time, at the end of which it communicates its flame to the bursting-charge in the shell. In the Navy, all spherical shells except those for howitzers and for shrapnel are fitted with the *Navy Time-fuze.*

1462. *Requirements.*—The conditions required to constitute a good time-fuze are, that it should ignite with certainty; that it should burn regularly, and that when ignited it should not be liable to extinction.

Time-fuzes have the advantage of being independent of the object, and of furnishing a core of dispersion whose apex is above the target.

But they are entirely dependent upon the exactness of their adjustment, and even when properly adjusted they sometimes give premature or tardy explosions without assigned reasons; besides, they afford no means of estimating at sight the distance at which the projectiles burst, and consequently no criterion for correcting them, which is a great disadvantage.

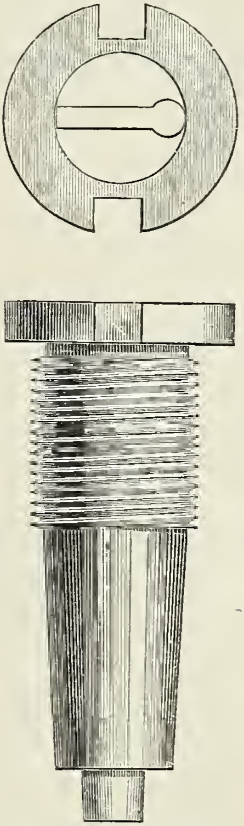


Fig. 320.—Navy Time-fuze.

1463. The Navy Time-fuze (Fig. 320).—This fuze is composed of a *composition* driven in a *paper case* and then inserted in a *metal stock*, which screws into the fuze-hole; so that one end of the composition lies even with the exterior surface of the shell, and is exposed to the flame of the charge in the gun, the other end being within, amidst the charge of the shell. The composition is covered with a *safety-cap*, which protects it from moisture and accidental ignition; also with a *water-cap* of peculiar construction, intended to protect the flame from being extinguished on ricochet.

1464. A *Safety-plug* at the lower extremity prevents the communication of fire to the powder in the shell, in the event of the accidental ignition of the fuze after being uncapped.

1465. *Composition.*—The ingredients of all time-fuze compositions are the same as for gunpowder, but the proportions are varied to suit the required rate of burning. Pure mealed-powder gives the quickest composition, and the others are derived from it by the addition of nitre and sulphur in certain quantities. The rate of burning of a fuze composition depends on the purity and thorough incorporation of the materials, and on its density.

These qualities are best secured by procuring the materials from the powder-mills ready mixed and granulated like powder, in which form it is not more liable to deteriorate than gunpowder, and can be preserved for a long time without the possibility of alteration.

The three compositions used are manufactured at Dupont's Powder-mills, and are known by the letters *L*, *M*, and *N*.

These compositions have the appearance of ordinary unglazed cannon-powder, but the proportions of the ingredients differ from those composing cannon-powder. By combining these compositions in different proportions and adding small quantities of mealed-powder, driving a few fuzes and burning them for trial, the several compositions for driving the various fuzes are found.

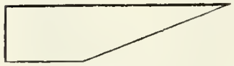


Fig. 321.

1466. *The Paper Fuze-case.*—The case into which composition is driven is made of strong white paper, which is cut into slips leaving one end square, the other tapered to a point (Fig. 321).

These pieces of paper are placed on a smooth board and covered with a refined glue, used rather thin and kept warm in a suitable vessel. They are then rolled on a steel cylindrical *former*, beginning with the square end, the gradual diminution of the other end of the paper producing the required taper on the exterior of the case. If one of these cases is cut in any part, the several layers of paper are not perceptible, but appear as if resolved into a perfectly firm and homogeneous material.

The finished case (Fig. 323) is put in a gauge to see that it is of the proper dimensions and both of its ends cut off even with the faces of the gauge.

1467. *The Safety-plugs* are made of the softest lead wire. This wire is cut into short lengths and put through molds to bring them to the proper diameter. They are then put into the plug-making machine, which cuts and forms the lead wire into the proper shape and length for safety-plugs.

1468. Before the composition is driven into the case, the safety-plug, P (Fig. 322), is inserted with its cavity end in the smaller end of the paper case, and the solid portion of it projecting below the tapering end of the case. A steel punch with a conical-shaped end, being introduced into the case and entering the cavity of the safety-plug, is struck a smart blow with a mallet, which forces the soft lead out, pressing it hard against the sides of the paper case.

1469. The jar of concussion consequent upon the explosion of the charge in the bore is so great as to detach the plug from

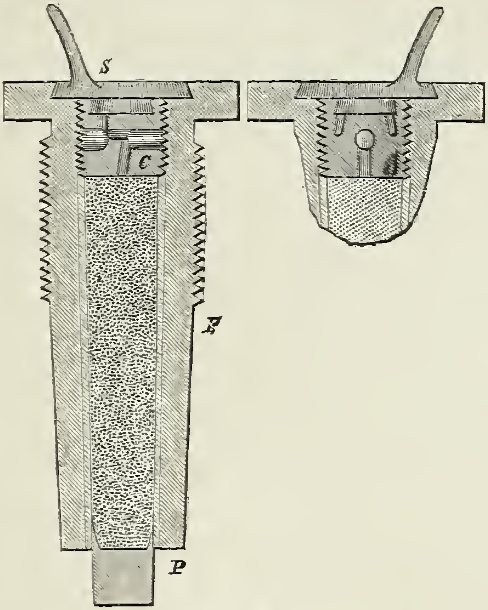


FIG. 322.

the case, so that from the moment the shell leaves the gun the communication is open between the burning composition in the fuze and the bursting-charge in the shell, and as soon as the composition is consumed the shell will explode.

FIG. 323.

1470. *Fuze-driving Machine.*—This is done by a machine. It is a screw-press requiring two persons to work it. The driving-shaft moves vertically through a metal tube on the exterior of which is a strong square thread. A nut works upon this by means of a large disk attached to it, of sufficient diameter to create the requisite power, and upon the upper side of this disk are established two levers, attached to the head of the shaft. By adjusting the weights upon the levers a bell is rung, when a pressure of 2,000 pounds is obtained with the screw.

1471. The paper case is secured in a steel mold or socket, which is made to adjust so closely to the exterior of the case as to sustain it and also protect the safety-plug against the pressure applied in condensing the composition. Two or more of these molds are placed around the edge of the circular plate carried upon the lower part of the frame, and revolving so as to bring the molds in turn to the shaft.

1472. *Driving the Composition.*—The composition, being first pulverized to a fine powder, is put into the case by a small scoop which holds eight or ten grains. Each charge is driven by a steel *drift* which fits snugly into the case, the workman moving around the lower plate so as to bring the drift under the driving-shaft of the machine, the positions being determined by a spring and catch working into a notch in the edge of the plate. The disk is now given a quick whirl by means of the handles on its periphery, and the driving-shaft descends on the drift; the movement is sustained and the pressure increased until the sound of the bell indicates that the lever has risen and the action of the machine has ceased.

1473. The motion of the disk is now reversed and the shaft sufficiently raised to allow the workman to revolve the lower plate and bring in place another mold, which has meanwhile been charged. The operation proceeds until the column of condensed composition is rather larger than required.

In this way the composition is solidified until its density is doubled and it becomes as hard as stone. The paper cases are removed from the driving-mold and placed in another of the exact length required; the projecting portion is then cut off evenly with a sharp knife.

1474. *The Water-cap* is made of copper, and is cylindrical in shape (C, Fig. 322). The upper end has a recess .10 inch deep, in which there are three holes, one going down to the centre of the cap and connecting with the side-holes; the other two are made to hold a small piece of quick-match. There are two holes in the sides of the cap opposite to each other and connecting, but leading at different angles; and one hole leading from the bottom of the cap to those through the sides. Thus the water-cap is perforated with a channel, which is filled with mealed powder. This communicates fire to the composition in the paper case, and the angles of the channel prevent the entrance of any matter, such as sand or water, over which the shell may ricochet.

The recess on top has two small pieces of quick-match, each secured in its own hole, and a small quantity of powder poured into the recess and pressed down, so that the outer surface is primed with mealed-powder and strands of quick-match, which are ignited by the scorching flame that rushes over the projectile at the firing of the charge in the gun.

1475. *The Safety-cap* is a circular leaden patch with a lip or lug attached (S, Fig. 322), cut out of soft sheet-lead that is about .06 inch thick. It is punched out with a cutter of the proper shape and dimensions.

This patch, with a thin piece of parchment of the same shape and size under it, is put on over the top of the water-cap and driven down into the recess in the head of the fuze-stock with a punch made for the purpose, having the length of the fuze in raised letters on the end, so as to leave this mark on the leaden patch.

1476. *The Fuze-stock* is made of tough bronze, with a stout shoulder or flange at the outer end (F, Fig. 322). Its length over all is 2.44 inches. The filled paper case, or fuze proper, is placed in the metal stock, safety-plug-end first, and then pressed down until the end of the paper case is nearly even with the lower end of the stock, the safety-plug projecting below the stock. The water-cap is screwed in on top of the fuze and covered with the safety-patch. A circular label is pasted on over the patch showing the length of the fuze, the date of fabrication, and the initials of the inspector.

A little shellac is brushed around the safety-plug and lower end of fuze-stock; also around the leaden patch and top of stock. A pasteboard cap is put on over the safety-plug-end of the fuze-stock to prevent the plug from being broken off, and the fuzes thus prepared are stowed in boxes.

1477. Time of Burning.—The *Navy Time-fuzes* are of 3½, 5, 7, 10, 15, and 20 seconds time of burning; which times are supposed to offer a sufficient variety for most of the exigencies of the service, and a certain proportion of each are supplied to each ship.

There are also supplied for special purposes paper-case fuzes of greater length, which when used are always to be inserted in metal stocks.

General Working-fuze.—All loaded spherical shell supplied are fitted with the five-seconds fuze, which is to be regarded as the general working-fuze. This fuze may be drawn and any of the others substituted. The XV-inch shell are fitted with three fuzes, each 3½, 5, and 7 seconds.

One-half of the shell allowed for rifled guns are fitted with time-fuzes, and the remainder with percussion-fuzes.

1478. To Shorten Fuzes.—For special firing any time-fuzes may be shortened. To do this, unscrew the water-cap and back the paper case out from the lower end with a drift and mallet, cut off from the lower end with a fine saw, or sharp knife struck with a mallet, the proportional part required, and insert the upper part in the stock, forcing it down with a few gentle blows with the drift; screw in the water-cap.

It is preferable, however, when circumstances will admit, to take up such distance as will correspond with the time of flight of one of the regulation lengths. In shortening the fuzes there is danger of disturbing the column of composition.

1479. Testing Fuzes.—Fuzes are tested by securing them in some convenient place, lighting them, and noting the time of burning. In testing the Navy time-fuze, the safety-plug must be removed. Being intended for use under a water-cap, they burn a longer time in the open air. Under the water-cap the gases are so confined that the combustion is augmented.

1480. Time-fuzes for Rifle-projectiles.—Time-fuzes are very unreliable in rifle-guns in consequence of the flame being cut off from the fuze; with the Parrott shell, however, the Navy time-fuze is the most certain of ignition and regular in its time of burning.

For rifle-projectiles, where the flame of the charge is entirely cut off from the fuze, the time-fuzes are fitted with a detonating arrangement at the top. This consists of a small hollow cylinder of metal, termed the *detonator*, containing a small quantity of detonating composition, and having a fire-hole communicating with the fuze-composition. A *plunger* is suspended in the detonator by means of a wire, and when the gun is fired the suspending-wire is broken, and the plunger coming in contact with the detonating composition explodes it, thus firing the fuze-composition.

1481. Imperfection of Time-fuzes.—It is impossible that any species of fuze should be absolutely perfect. When suitable opportunities for observation occur, it is noticed that in firing a number of shells many do not explode. The failure of the composition to ignite is probably generally due to the absorption of moisture; and therefore all fuzes taken from shell or returned from ships, which have been more than one year in service, are to be returned to the Laboratory in the Ordnance Yard at Washington, where all fuzes are prepared. Fuzes of over two years' date of manufacture are not to be issued for service.

Sometimes the fuze is extinguished after having been ignited. This may occur when the shell ricochets on soil or water. Water is not so detrimental as sand, and the fuze is rarely extinguished by several ricochets upon it.

Generally the gases evolved by the combustion of the composition will repel with great energy any obtrusive matter which would extinguish the fuze if once in contact with the ignited surface.

1482. Premature Explosion.—This may be caused by the increase of the ignited surface of the composition resulting from cracks in the case or composition itself, or by interstices between the case and composition; and in proportion to the extent of this cause so will be the increased celerity of the combustion. Crevices may occur in the composition from some defect in the tools or in the mode of using them, or they may be created by bending the case.

It may also happen that the displacement of the shell by the charge of the gun will force in the column of composition or the case with it. This would of course cause the shell to explode very quickly.

The shell may be defective in thickness or quality of metal, and be crushed by the force of the discharge, when the explosion will take place in or near the gun.

The bursting of shell near the muzzle of the gun is sometimes attributed to the detonating qualities of the powder in the shell. It is manifest that the premature explosion of shells is far more detrimental to their efficiency than the failure to explode at all.

1483. Commanders of vessels are required to observe carefully the action and result of all fuzes, and report in detail to the Bureau of Ordnance whenever opportunities may occur, particularly specifying the number and kind fired, elevation of gun, failure to explode, and satisfactory action; also whether the fire was ricochet or direct.

1484. The question of a good fuze for all conditions of service is still to be determined. For ordinary firing with smooth-bore projectiles, the service time-fuze, as made for many years past, continues to give good results, but the greatly increased range and time of flight at present obtainable with heavy guns render it desirable to adopt a principle of shell-explosions independent of the time of flight and of the preservation in good order of a long column of composition.

1485. The Bormann Fuze was invented by Captain Bormann of the Belgian army.

The case is a metallic disk about 1.6 inches in diameter and half an inch thick (Fig. 324), made of lead, hardened sufficiently for the purpose by the infusion of some tin. It is cast without the thread by which it is to be screwed into the fuze-hole, and this is afterwards cut in an ordinary slide-lathe.

The metallic fuze is screwed in flush with the shell, and well luted around the edge on the exterior surface.

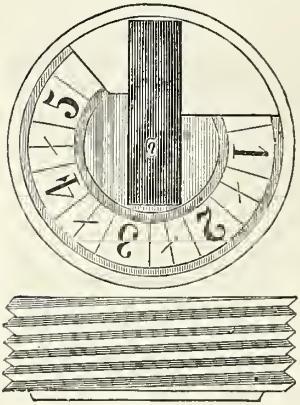


Fig 324.

The composition is firmly condensed into an interior canal, or horseshoe-shaped indentation, cast in the disk around its periphery and as near to it as possible, opening below, a strand of quick-match being first placed in the bottom of the channel. The canal is closed, after the composition is driven, by a piece of the same metal, corresponding in shape (Fig. 325), the cross-section of it being wedge-shaped. This is pressed down upon the composition by a machine sealing it hermetically.

1486. The upper surface of the disk above the composition is very thin, so as to yield readily to the cutting-tool employed to open it, its whole external corresponding of course with the composition below. It is graduated into seconds and fourths of seconds. The end of the composition where the enumeration begins communicates with a small magazine at the centre of the disk, which is charged with grained powder, and closed on the inner side with a very thin disk of sheet-lead so as to yield in that direction to the explosion. A pin-hole is sometimes punched in this disk to insure the escape of the flame into the shell.

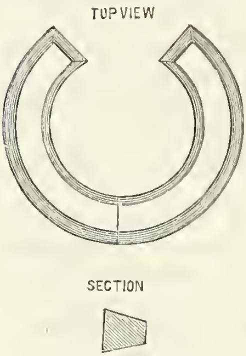


Fig. 325.

1487. *The Operation of the Fuze* occurs thus:

The thin covering of metal above the composition is cut so as to lay bare the upper surface of the composition, and to afford the flame access to it at the part desired. The cut should be made with the fuze-cutter close to the right of the mark in the index-plate; and it is best made in two or three efforts instead of trying to effect the cut at once.

Under fire, the Bormann fuze, though perfectly simple, is very liable not to be cut to the desired time; it is often done incorrectly, and sometimes not at all.

Shell fitted with this fuze should be placed in the gun with the cut of the fuze up, because in this position it is more certain of being touched by the flame of the charge as it rushes over the top of the shell.

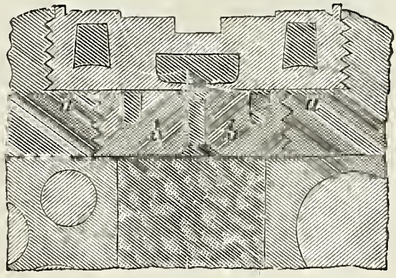


Fig. 326.

The combustion occupies the assigned time in passing from the incision towards the origin of the graduation, when it traverses the orifice leading into the magazine, the contents of which explodes smartly towards the interior, and then encounters instantly the charge in the shell.

1488. The metal of this fuze being soft and its diameter great, there is danger of its screw-thread being stripped, and its being driven in by the shock of firing, or of its being driven out on the ignition of the bursting-charge, thus affording a means of escape for the gas evolved, without bursting the shell. To prevent the former, a broad shoulder, *aa* (Fig. 326), is left when the fuze-hole is tapped. To avoid the possibility of the latter, and at the same time to increase the effect of a small bursting-charge, the fuze-hole below the shoulder is closed by screwing in a composition disk, *b*, with a small hole in its centre through which the fire from the fuze is communicated to the charge.

1489. *Advantages.*—The peculiar excellence of this fuze consists in the driving of the whole mass of the composition by a single pressure, and its disposition in such wise that the combustion occurs not with the stratification of the mass, but transversely to it, while in the ordinary fuzes the solidification and the process of combustion are just the reverse; that is, the column is composed of a number of layers solidified successively by an equal pressure; but as the inferior layers have, besides the pressure applied to them, to bear that of the superincumbent layers, it follows that the mass is not homogeneous, but increases in density with the inferior position of the layers.

The whole error of fabrication, whatever it may be, in the *Bormann fuze*, is only experienced when the fuze is opened at its extreme duration. At all inferior times it is reduced proportionally. The regularity of this fuze burning is very great. The Bormann fuze is fitted to all shrapnel and howitzer ammunition.

1490. Percussion and Concussion Fuzes.—A percussion or concussion fuze is one which is independent of the element of time of flight, and which depends wholly upon *impact* for its ultimate action.

The distinction between percussion and concussion fuzes has been somewhat arbitrary, and the application of the terms has depended upon the sense in which the inventor of any particular fuze chose to apply them.

1491. Concussion-fuze.—A concussion-fuze is one which is put in action by the discharge, but the effect of that action is restrained until it strikes the object.

1492. *Requirements.*—Such a fuze, in order to be serviceable, must not only produce explosion on striking, but it must not produce it on the shock of the explosion of the gun-charge, nor of that produced by the ricochets of the projectile in or out of the gun. These fuzes have usually consisted of some combination of the highly explosive fulminates, but the extreme danger of using them has been a great obstacle to their adoption. There is no fuze of this kind in use in the Navy.

1493. The Splingard Fuze is both a concussion and time fuze; the appearance of the paper case is similar to that of the Navy time-fuze, but the internal arrangement is different. The case is filled with fuze-composition, and a long cavity is formed in the lower part of the composition by driving it around a spindle as in a rocket; this cavity is filled with moist plaster-of-Paris, and a long needle is inserted in it, nearly to the bottom of the plaster, forming a tube enclosed in and supported by the composition. (Fig. 327.)

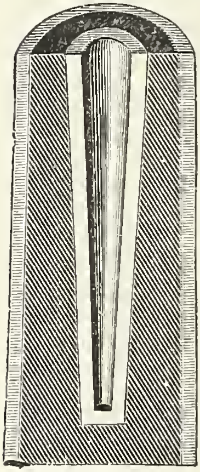


Fig. 327.

The composition is ignited in the usual way at the top, and as it burns away, leaves a portion of the plaster tube unsupported. When the shell strikes its object, the stock breaks off the unsupported part of the tube, and the flame of the composition immediately communicates with the bursting-charge; if the tube does not break the composition burns up, and the bursting-charge is ignited as in an ordinary time-fuze.

1494. The Bacon and McIntyre Fuze is very similar to this, except that the internal tube is differently formed. In this fuze a thin copper tube, E (Fig. 328), extends through the centre of the fuze-composition, and has a solid copper head, F, secured in its upper end by a little soft solder. The copper tube is enveloped with paper, C, and between the paper and the tube is a thin layer of plaster-of-Paris, D.

Fig. 328.—A, outside paper case. B, powder composition. C, inside paper case. D. coating of plaster of Paris. E, conical tube. F, ball on tube.

The fuze being ignited by the flame from the gun, the upper part of the composition burns away in the first second or two of time, melting the solder and leaving the head of the tube free to be displaced by the shock of impact.

Under ordinary circumstances this fuze acts like the time-fuze, the stopper, F, being kept in place by the plaster-of-Paris; but upon impact, the plaster breaks, the ball falls, and the flame passing through the tube at once ignites the bursting-charge.

1495.—Percussion-fuze.—A percussion-fuze is one which is prepared for action by the discharge, and put in action by the shock on striking the object. Like the concussion-fuzes, they have usually been dangerous from the fulminate employed, or from their complicated and delicate construction.

The embarrassments that beset the efforts to realize an efficient percussion-shell of the ordinary spherical form arise from the impossibility of having the projectile present a given point to the impact, and no reliable fuze of this nature has yet been arranged for spherical shells. In elongated rifle-projectiles this is more easily accomplished, and there are on trial for the rifled-cannon the percussion-fuzes of Schenkle, Parrott, and others.

Perhaps the case most completely illustrating the advantages that may accompany the use of percussion-fuzes is that of vessels firing shell at short and frequently changing ranges.

1496. *Requirements.*—The essential requirements of a good percussion-fuze are: that it should not be ignited by the shock of discharge or on striking water; that it shall be ignited on the impact of the shell against the object, and that it may not be liable to explode by handling or during transport.

The percussion-fuze has many points in its favor: it assures the bursting of the projectile; it can be used for all ranges, be they never so great; it admits—a very important desideratum in war—of estimating distances, and of correcting the error of the estimation; it augments the result of firing by adding great moral to physical effect, due to the explosion of the projectile in the midst of the enemy.

Its only inconvenience is its inability to cause the bursting of the projectile before it has touched the object, thus rendering the effects of fire dependent upon the nature and conformation of the target at the point of impact.

1497. SCHENKLE-FUZE.—One of the simplest forms of this kind of fuze is the Schenkle percussion-fuze, which has been found very reliable, and is now the only one issued in the Navy. It is a metal fuze-stock (Fig. 329), enclosing a movable core-piece, or steel plunger, bearing a musket-cap. The plunger, primed and capped, is confined inside the stock, in which it fits loosely, by a screw or pin, which passes through a hole in the side of the stock and plunger, to prevent it from moving. A safety-cap is screwed into the top of the fuze-stock, and its bottom is closed by a cork or leather stopper.

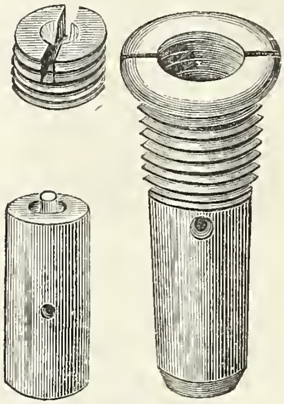


FIG. 329.

1498. When the projectile is set in motion, the plunger by its inertia carries away the pin which confines it, and presses against the bottom of the fuze-stock. When its motion is arrested, the inertia of the plunger causes the percussion-cap to impinge against the safety-cap, which ignites the priming, when the stopper in the bottom of the fuze-stock is blown out and the shell exploded.

1499. As a precaution against danger while handling, the brass safety-cap is countersunk on one end and flat on the other. It is kept with the countersunk end down at all times except when loading; while this end is down, should the plunger become loose, the percussion cap is prevented from coming in contact with the hard surface of the safety cap, but on being turned end for end a plane surface is opposed to the percussion cap, upon which it may strike. There is a slit cut in the top of the fuze-stock and cap which is designed for the entrance of the fuze-wrench.

These fuzes are made of two sizes, the smaller size being fitted to 20 and 12 pdr. rifle-shell, while the larger ones are used for the heavier shell.

1500. PARROTT PERCUSSION-FUZE.—This consists of a metal fuze-stock, A B (Fig. 330), enclosing a plunger, P; but the arrangement is different from the Schenkle. In the Parrott fuze the plunger closes the bottom of the stock, and is prevented from slipping through by a shoulder, *c d*, on the plunger, taking against a projection on the interior of the stock. The plunger is surmounted by a long nipple, N, armed with a percussion-cap, which strikes against a safety-cap, S, screwed into the top of the fuze-stock. The ring, R, being placed over the plunger, its lugs, *x x*, take against the lip, N, and in this position the cap of the fuze-stock screws close down on the ring, holding the shoulder of the plunger at *c d* firmly against the projectile on the inside of the stock. The plunger, capped and primed, is held firm until the projectile strikes the object, when its inertia carries away the lugs, *x x*, and the plunger impinges against the safety-cap, producing the explosion.

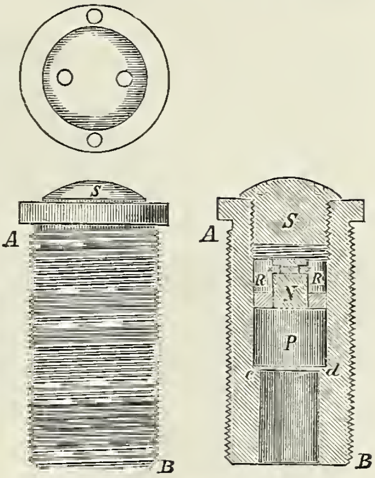


FIG. 330.—Parrott Percussion-fuze.

1501. GERMAN PERCUSSION-FUZE (Fig. 331).—In this fuze the plunger, *a h*, having a central fire-hole, *b*, is let into the fuze-hole and rests against the shoulders, *c c*. This plunger is surmounted by a perforated cap, *p*, having a terminating point on the top side.

The plunger is retained in its place by a pin, E, which passes tranversely into the fuze-hole, the side of which is put in contact with the point of the cap.

The outer end of the pin projects on the side of the shell, the projection being limited by the line of the cylindrical portion. The fuze-hole is closed by a screw-cap, *f f*, having a small central screw-hole into which the fulminate-cap, *g*, is screwed.

When fired from a rifle-piece, the centrifugal force generated by the revolution of the shell throws out the pin, E; the plunger by its inertia is retained at the bottom of the chamber during the flight of the projectile; at the moment of impact the plunger impinges against the fulminate, which, exploding, ignites the charge in the shell.

1502. This is one of the simplest, and, at the same time, most safe and reliable percussion-fuzes yet invented. The ful-

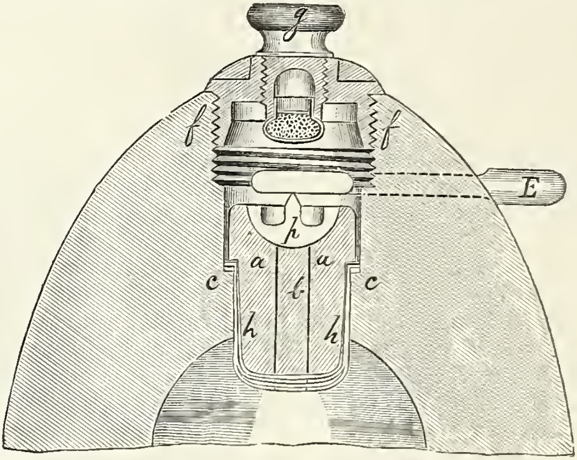


Fig. 331.

minate-cap, *g*, and pin, E, are not applied to the shell until the instant of loading, when the loader, who carries these articles in a pouch, screws in a fulminate-cap and inserts the pin, previously feeling that the plunger does not stick.

To keep the bursting-charge in place in the shell, a brass thimble, *h*, with a flange about the top, and a small hole in the bottom, is first pressed into the fuze-hole and takes against the shoulder, *c*. It is made a trifle large, and a small slit on either side at the top gives it sufficient spring to fit snug and tight. A piece of cloth is pasted over the fire-hole in the bottom of the thimble. In this thimble the leaden plunger rests.

Failure to Ignite.—Percussion-fuzes frequently fail if fired into a bank of soft earth, sand, or other material which does not offer a sufficiently sudden resistance; also if fired at high elevation, owing to the fact that the rifle-shells may not strike point foremost.

1503. Mortar-fuzes.—The mortar-fuze now used is a paper-case time-fuze, similar in general appearance to the ordinary paper-case fuze, of long time of burning. They are made up in packages and marked with the kind and length of fuze. For any shorter time the fuze is cut with a sharp knife or fine saw. With this fuze is used a wooden fuze-plug, having a conical opening, which is reamed out to fit the paper case.

When the shell is loaded, and the fuze cut to the required length, it is pressed in the plug and the plug firmly set in the fuze-hole.

The head of the fuze having been covered with tow or something to prevent breaking the composition, the fuze-setter is placed on the plug, and it is driven with the mallet until the head is about $\frac{1}{4}$ of an inch above the surface of the shell.

1504. The old form of mortar-fuze consists of a conical plug of wood, of the proper size for the fuze-hole (Fig. 332). The axis of this plug is bored out cylindrically, from the large down to within a short distance of the small end, which is left solid. At the large end a cap is hollowed out, and the outside of the plug is divided into inches and parts, commencing at the bottom of the cap. Seven inches extreme length, and each inch burning seven seconds, giving a total length of forty-nine seconds.

Fig. 332.

The orifice is filled with composition pressed hard and evenly as possible.

The cup is filled with mealed powder and moistened with alcohol. The rate of burning is determined by experiment, and marked on a water-proof paper cap, which is tied over the cup.

This is removed when the fuze is used. Knowing the time of flight, the fuze is cut with a saw at the proper division, and firmly set in the fuze-hole with a fuze-setter and mallet.

The great disadvantage of this fuze is its irregularity, it being very difficult to press such a large column of composition so that equal lengths will burn in equal times.

1505. Running-fuzes for Mines and Blasting.—The running fuzes most used are those known in England as *Bickford's fuze*, and in this country as *safety-fuze* and *Toy's fuze.* The common fuze ordinarily used in blasting with powder is of this kind.

It consists essentially of a column of fine gunpowder enclosed in flax, hemp, or cotton, and made up with different coverings according to the use to which it is applied. When intended for immediate use on light work in dry ground, it is unprotected by additional coverings. When intended for use in wet ground or under water, it is covered with varnished tape or gutta-percha.

These fuzes cause ignition, by conveying flame to the charge to be exploded. They are somewhat uncertain in their rate of burning, but average about one yard in a minute.

The ordinary varieties must be kept in a cool, dry place, and preserved from contact with grease or oil.

The gutta-percha-covered varieties are liable to become injured by keeping, from the deterioration of the gutta-percha. Before using, care must be taken that cracking of the gutta-percha has not occurred. They should be able to resist water for twenty-four hours.

1506. *Quick-match Fuze* is made by enclosing quick-match in a paper case with plaited cotton covering, and water-proofed. (Art. 1455.)

Gun-cotton Fuze.—Gun-cotton thread or rope burns with great rapidity : not less than thirty feet per second.

1507. Detonating-fuzes or Exploders.—By a detonating-fuze, or detonator, is meant one that causes a detonating explosion. The ordinary method of producing explosion is by the direct application of flame. By the detonating method, explosion of the main charge is caused by the concussion exerted by a small charge of explosive material in the fuze. Fulminating mercury seems to possess peculiar properties as a detonator, and practically is the only body so used.

Detonating-fuzes are used when violent shattering explosions are desired. Thus nitro-glycerine, gun-cotton, and their preparations are always fired by means of a fulminate exploder. The ignition of the fulminate may be accomplished in the ordinary manner, or by the use of electricity.

1508. The simplest fulminate exploder is made by attaching a copper case or large cap containing the fulminate to the end of a piece of common running-fuze. If the fuze fits the cap closely, it may be retained in place, and the cap protected against moisture by pressing round it wax, hard soap, or other similar substance. If the fuze is too small, it must be passed through a plug of wood or small cork fitting the cap, and the whole fastened on as above. Before it is fastened into the cap, the end of the fuze must be spread out so as to ensure contact with the fulminate. Fifteen grains is the usual amount of fulminate placed in the cap ; it should be put in when wet, with some gummy solution or varnish, so that it will dry to a solid lump which will not shake loose.

Even in exploding powder there is often great advantage in using detonating-fuzes. It is difficult to prove that actual detonation of the powder is brought about, but experiment has shown that a much more violent action can be obtained by using this mode of firing.

1509. Electric Fuzes and Exploders.—Evidently when ordinary running-fuze is employed as the means of ignition, but one charge or mine can be exploded at a time. In large blasting operations, and in military engineering, simultaneous firing of many charges is constantly required. Again it is often desired to explode charges from a distance, as in torpedo work.

The applications of electricity to this purpose have become quite extensive, and offer many advantages in the greater certainty of their action, and the ease with which they can be employed under circumstances where the ordinary running-fuze would be useless. Electric fuzes are always used with guncotton, nitro-glycerine, and their preparations, when any continuous or extensive work is to be done with them.

Electric fuzes or exploders may be divided into two classes: those in which the heat is obtained by the passage of the electric spark over a break in the circuit, and those in which the heat is obtained by the passage of the current over a conductor of great resistance.

1510. The first, or tension-fuzes, may be used with the Leyden jar, induction-coil, or any statical electric machine, such as Von Ebner's, Smith's, etc. The forms in which they are made are numerous, but essentially they are all alike.

All that is necessary for a fuze or exploder of this class is, that there shall be a break in a circuit not greater than the spark can easily be made to pass over ($\frac{1}{16}''$ to $\frac{1}{32}''$ is the usual distance), and that between the two points of the break shall be placed some composition that will be ignited by the passage of the spark.

Gunpowder can be so fired, if packed closely between the points, but it is better to use some more sensitive material as a priming. Fulminating mercury is fired by the spark, and may be used for this purpose, either pure or mixed with other substances, as in percussion-cap composition. Abel's composition has been thus used. It is composed of sub-sulphide of copper, 64 parts; subphosphide of copper, 14 parts; and chlorate of potash, 22 parts. Other priming compositions are also employed.

The wires of the fuze must be firmly held in a wooden block or similar contrivance, in such a manner that the priming cannot be displaced, or the distance between the points altered. Outside the priming-material is placed fulminating mercury, gunpowder, or other substance, and the whole properly enclosed in a wooden or metallic case. In other respects the fuze may be made up as desired, by coating with water-proof composition, varnishes, gutta-percha, etc.

1511. The principle difficulty connected with the use of statical electricity for causing explosion is the high insulation of the conducting-wires that is required. If the insulation is imperfect, the loss is so great as to render the firing of the fuze uncertain or impossible. Some persons have tried to avoid this need of perfect insulation by the use of very sensitive priming-compositions. Many fatal accidents have been occasioned by this recklessness.

1512. The second class of electric fuzes or exploders are those in which, by the passage of the current, a portion of the circuit having a great resistance becomes sufficiently heated to ignite some explosive or inflammable body in contact with it. These fuzes are used with the voltaic battery and the various magneto-electric machines, such as Farmer's, Gramme's, Wheatstone's, Beardslee's, etc.

For convenience, these may be divided into two divisions: those in which plumbago, copper sulphide, Abel's composition, or other similar highly resisting substance forms the part of the circuit which is to be heated, and those in which a fine platinum wire or other comparatively good conductor occupies that position.

1513. Of the first division are the fuzes made for Wheatstone's, Beardslee's, or other similar machines. They consist essentially of a break in the circuit which is bridged by a layer of plumbago or composition which has a certain conducting-power, and which will burn when heated. In contact with this is placed the gunpowder, fulminating mercury, or other substance which is the charge of the fuze. This arrangement is made up in any desired shape.

The difficulties connected with the use of these fuzes and the machines for which they are made are, that good insulation of the leading-wires is necessary, and that they are somewhat uncertain for various causes.

The current from these machines has less intensity and greater quantity than the static, but is more intense, and has less volume than the voltaic current, or that generated by Farmer's or Gramme's machines. Safe fuzes of this sort may be made, since no very sensitive composition is required as a priming.

1514. Of the second division are those known as platinum-wire fuzes or German-silver-wire fuzes. These are used with the galvanic battery and Farmer's or Gramme's machines. Several varieties are made in this country and in Europe. Of this kind are the fuzes made at the Torpedo Station, and issued for torpedo purposes, to be used with Farmer's dynamo-electric machine.

The essential point in the construction of all the fuzes of this division is the placing of a short piece of very fine metallic (platinum or German silver is generally used) wire in the circuit, and in contact with it a priming-material which when fired ignites the fuze-mass, or the wire may be embedded in the fuze-mass itself, and thus inflame it directly, without the intervention of a priming.

1515. This form of electric fuze has many advantages. The current with which it is used is one of great quantity and low intensity, so that the insulation of the conducting-wires need not be as complete as in the other cases. In fact, no insulation is required, if the fuze is sufficiently delicate and the whole circuit is not too long.

As long as the fuze is whole, the current is complete, as may be shown by the passage of a weak current. It may, therefore, be tested at any time before using it, even when in the charge and the certainty of firing demonstrated, whereas with the other kinds, actual trial is necessary.

Greater uniformity is attained, since these fuzes can be made to conform to any standard of resistance. This point becomes of great importance when firing takes place at great distances, or when a great number of simultaneous explosions are to be made. These fuzes are safe to handle, since no highly sensitive composition is needed as a priming.

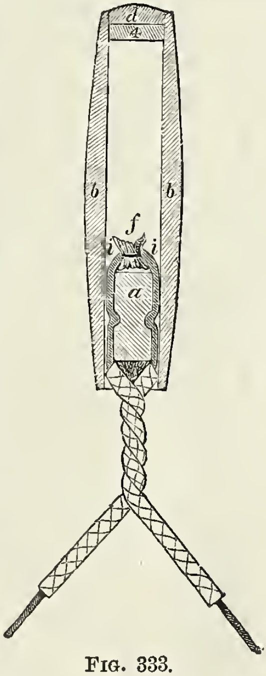


Fig. 333.

1516. The Dynamo-electric Igniter now supplied to the service (Fig. 333) consists of a hard wooden plug, *a*, half an inch in length, and about $\frac{3}{16}$ of an inch in diameter, having a score cut about its centre, and a longitudinal groove on either side (the bottoms of which are $\frac{3}{16}$ of an inch apart) for the reception of the copper wires. There are also two cotton-covered (braided) copper wires, which are twisted together for about an inch, and are stripped of their insulation almost to the twist; these uncovered parts are pressed firmly into the grooves in the sides of the plug, and cut off, so that they project about one-eighth of an inch above the plug; the ends of the wires are now split with a very fine saw, in the direction of the plane passing through them, and the distance between the ends carefully adjusted to $\frac{3}{16}$ of an inch, after which platinum wire No. 40 is stretched between them, to form the bridge, and securely soldered to the ends of the split wires, *i i*.

A wisp of gun-cotton, *f*, is next wrapped around the platinum wire, and the ends of the copper wire pinched together sufficiently to take all strain off the platinum wire. The plug is now inserted in a hollow wooden case, *b*, two inches long, countersinking it about an eighth of an inch. The resistance of the wire is next found and marked upon the case; it should not vary more than five-tenths either side of 0.42 ohms. The upper part of the case is filled with rifle-powder, the top being closed with a disk of cork, over which is poured some waterproof composition, and the whole is properly coated with shellac to render it water-proof.

1517. The Dynamo-Electric Fuze is made by enclosing one of the D. E. Igniters in a stout paper case about six inches in length, which is filled with rifle-powder to give more flame and consequently a more perfect ignition of the charge than can be obtained by the igniter alone. (Fig. 334.)

The ends of the case are properly closed, a wooden plug, B, with grooves cut in the sides for the wires, being used for the bottom, and a disk of cork for the top, which is coated with collodion, and seals the cork firmly into the case. The fuze is given two coats of brown shellac. The ends of the wires below the plug are stripped of their covering and brightened.

Fig. 334.

Section IV.—Signals.

1518. Kinds.—The preparations employed for signals are; *rockets*, *signal-lights*, *navy red*, *white*, and *blue lights*.

1519. Signal-rockets.—A signal-rocket is a cylindrical case of paper or metal, *a* (Fig. 335), attached to one extremity of a light wooden rod, *f*, and containing an inflammable composition, *b*, which, being fired, shoots the whole of the arrangement through the air, by the principle that an unbalanced reaction from the heated gases which issue from openings in fireworks, gives them motion in the opposite direction. The principal parts of a signal-rocket are: the case, *a*; the composition, *b*; the head, *c*; the decorations, *e*; and the stick, *f*.

1520. *Case.*—The case is made by rolling stout paper covered on one side with paste around a *former*, and at the

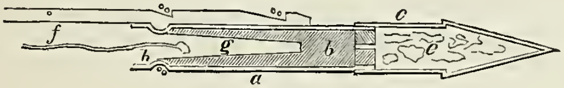


FIG. 335.

same time applying a pressure until all the layers adhere to each other. The vent is formed by choking one end of the case while wet, and wrapping it with twine.

The paper case is covered outside with paste, and enclosed in a cylindrical case of tin, $1\frac{3}{16}$ inches in diameter and 9 inches long. The lower edges of the tin case are turned under slightly, to keep the paper case from going through.

1521. *Composition.*—A variety of compositions are employed for signal-rockets; the best can only be determined by trial, as it varies with the condition of the ingredients.

The following proportions are used in the Naval Laboratory:

Nitre	4 lbs.	8 oz.
Sulphur		1.2 oz.
Charcoal	2 lbs.	
Mealed-powder		4 oz.

To increase the length and brilliancy of the trail, add steel or cast-iron filings.

1522. *Driving.*—The case is placed in a steel mold, which has a conical spindle attached to the centre of its base to form the bore, *g*. This spindle is made of composition, $6\frac{1}{2}$ inches long, and goes up through the vent into the centre of the case, having a hemispherical bottom to fit the choke, *h*.

The composition is driven with a screw-press regulated to a pressure of about 5 tons. The first and second drifts are made hollow to fit over the spindle, and the third is solid. A small ladleful of pulverized clay is first put in and pressed down around the spindle, forming a bottom $\frac{1}{4}$ inch thick. The composition is next put in, a ladleful at a time, each one pressed down separately.

The top of the case is closed with clay, which is one diameter thick, and perforated with a small hole for the passage of the flame from the burning-composition to the head; through this hole a strand of quick-match is placed.

The rocket is primed by inserting one end of a strand of quick-match, eight or ten inches long, through the vent into the bore, and coiling the remainder in the recess formed by the choke. A piece of paper is pasted over the end to protect it.

1523. *Head.*—The head is formed by a tin cylinder $1\frac{3}{16}$ inches diameter and $2\frac{1}{2}$ inches long, joined to a hollow tin cone $2\frac{1}{2}$ inches high, making the length of head 5 inches. (Fig. 336.)

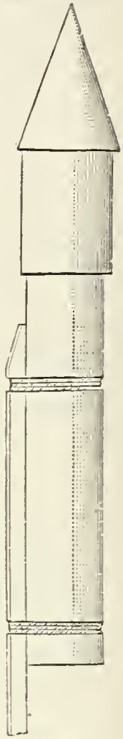


Fig. 336.

The long tin case goes about $\frac{1}{2}$ inch into the cylindrical part of the head, and a piece of paper is pasted over the joint. The object of the head is to contain the decorations, which are scattered through the air by the explosion which takes place when the rocket reaches the summit of its trajectory. The explosion is produced by a small charge of rocket-composition, which is put into the head with the decorations. When the composition is consumed, the bursting-charge explodes the head and ignites the decorations, which, falling, produce a brilliant light that can be seen at a great distance.

1524. *Decorations.*—The decorations of rockets are of various kinds; those used in the navy are white stars.

Stars.—Stars are formed by driving the composition moistened with alcohol and gum-arabic in solution in port-fire molds, or molding it in brass cylinders of the desired diameter. It is then cut into short lengths and dredged (sprinkled) with mealed-powder. The gum-arabic is intended to give such consistency to the stars that the explosion of the head of the rocket may not break them in pieces, and thereby destroy the effect.

White Star Composition.

Nitre	$3\frac{1}{2}$ oz.
Sulphur	$1\frac{1}{2}$ oz.
Mealed-powder	$\frac{3}{4}$ oz.

1525. *Sticks.*—The stick is a tapering piece of pine, about nine times the length of the case, and the large end is tied to the side of the case, to guide the rocket in its flight, as it has no rotary motion.

The common centre of gravity of the rocket and stick is a little below the former. The stick counteracts by the resist ance of the air upon it and tendency to turn over, and maintains the rocket, during its flight, as nearly as possible in the direction in which it is fired.

1526. *Motive-power.*—The object of having the cavity or bore in the interior of the rocket is, that a large surface of composition may be at once ignited when the rocket is fired, and so great a quantity of gas generated in the case that it cannot escape from the vent as quickly as formed, and therefore exerts a pressure in every direction on the interior surface of the rocket. The pressures on the sides of the rocket mutually balance each other, but the pressure on the head is greater than that on the base, in consequence of the escape of gas from the vent; it is this excess of pressure on the head over that on the base which causes the rocket to move forward, this being merely a similar action to the recoil of a gun.

The force which produces motion in a rocket is therefore different from that which acts upon a projectile fired from a piece of ordnance; the former is a *constant* force producing accelerated motion in the rocket until the resistance of the air is equal to the force or the composition is consumed; while the latter may be considered merely as an impulsive force, which ceases to act upon the projectile when it has left the bore of the piece.

1527. Packing Rockets—The cases are painted red and packed in laboratory-boxes, 30 to 50 in a box. The sticks are tied up in bundles and packed separately.

1528. Firing Rockets.—A few rockets are always kept mounted and ready for use. To fire a rocket, the stick is placed in a *trough* or tube, as a guide; a musket-barrel will answer the purpose. The paper covering the bottom is torn off, exposing the priming. Holding the guide vertical or nearly so, a slow-match is applied to the priming, which ignites the composition. The inflamed gas issues violently from the bottom of the case as the rocket ascends.

The time of ascent is from 7 to 10 seconds, and they will attain a height of about 500 yards.

Under favorable circumstances, a signal-rocket may be seen within a circuit of from 30 to 40 miles. In mounting rockets the stick is attached so that it will hang end down, when supported, close up along side the bottom of the rocket.

1529. Coston Signal-lights.—These are the usual night-signals of the Navy. They consist of red, green, and white lights, and their various combinations, representing the different numbers and pendants. The colors assimilate as far as possible with those of the day-flags.

1530. The case is made of fuze-paper three inches long and $1\frac{1}{4}$ inches in diameter. A cylindrical block of soft wood $\frac{1}{2}$ inch long forms the bottom, A, with a wooden nipple attached, to fit into the signal-holder, or firing-pistol. (Fig. 337.) Through

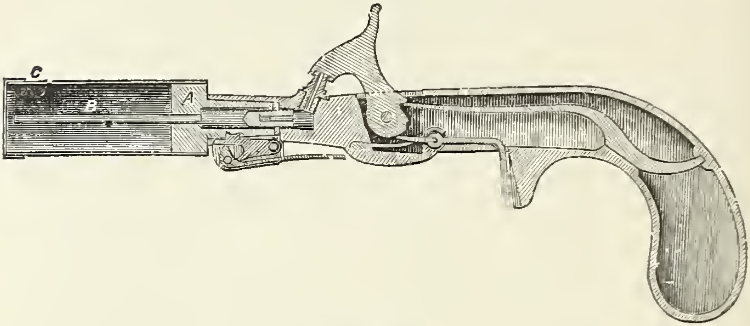


FIG. 337.

the centre of the bottom is a small hole, with a thin copper tube $\frac{3}{16}$ inch in diameter, B, extending through the middle of the case to within $\frac{1}{4}$ inch of the top. Hollow drifts are used in filling, which are struck 15 moderate blows with a half-pound mallet for each charge. The case is filled to the top of the copper tube; the last charge being $\frac{1}{4}$ ounce of mealed-powder. A small strand of quick-match is put through the copper tube and wooden bottom, the upper end stitched to the side of the paper case above the mealed-powder, and the lower end split to

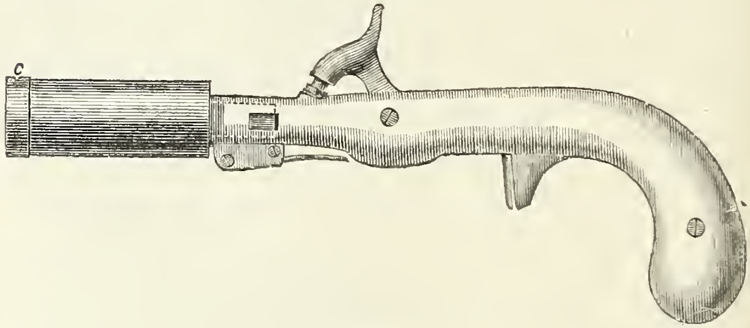


FIG. 338.

make sure of its ignition by the cap from the pistol. (Fig. 338.)

1531. The top of the case is covered with a thin wafer of brown paper, immediately over the quick-match and mealed-powder; then over all is a pasteboard top, with a rim secured to the body of the case by a strip of paper pasted on both, C. The wooden bottom is covered with shellaced paper. The signal is finally covered with white, red, or green paper, according to the color of the composition, and packed in laboratory-boxes for issue.

The several colors in the Coston signals are intended to burn from 8 to 10 seconds.

1532. In a signal composed of three colors, $1\frac{1}{2}$ charges of the composition of the last color to be burned are put in first and driven; a thin circular disk of paper is put in the case on top of this composition, then $1\frac{1}{2}$ charges of the second color are put in and driven, a piece of paper put on, and then $1\frac{1}{2}$ charges of the first color to be burned are driven.

When a signal is composed of but two colors, the lower third of the paper case is filled with powdered clay, and driven the same as the composition, then on top of this clay the second colored composition is driven, and on that the first. When but one color forms a signal, two-thirds of the case is first filled with clay, and the composition driven in the upper third.

1533. *Composition of White Signals:*

5 parts of Sublimate of Sulphur,
5 " " Sulphuret of Antimony,
2 " " Red Oxide of Lead,
3 " " Sulphuret of Arsenic,
$\frac{1}{2}$ " " Bleached Shellac,
24 " " Nitrate of Potash.

For the Red Light.

16 parts of Chlorate of Potash,
6 " " Oxalate of Strontium,
2 " " Bleached Shellac,
2 " " Sugar of Lead,
$\frac{1}{4}$ " " Desiccated Lampblack.

For the Green Light.

4 parts of Chlorate of Mercury,
2 " " Bleached Shellac,
12 " " Chlorate of Barium.

Red, White, and Blue Lights are made in the same manner as the Coston signals, and are of the same size. They only differ in the burning composition, which is, for the

Navy White Light.

Composed of	68	parts	of	Nitre,
	18	"	"	Sulphur,
	13	"	"	Mealed-powder,
	4½	"	"	Orpiment,
	3½	"	"	Antimony.

Navy Red Light.

Composed of	64	parts	of	Strontium,
	20	"	"	Shellac,
	37	"	"	Chlorate Potash,
	3	"	"	Charcoal,
	7	"	"	Sulphate Antimony.

Navy Blue Light.

Composed of	24	parts	of	Ammoniated Copper,
	18	"	"	Oxide of Copper,
	12	"	"	Shellac,
	6	"	"	Orpiment,
	68	"	"	Chlorate of Potash.

1534. STOWAGE OF FIREWORKS.—The fireworks, after carefully removing all fulminating matter, such as caps or primers, if any such be used to ignite them, are stowed in their proper packing-boxes, or other light boxes of suitable length, made water-tight and secured with lock and key.

These boxes are made to fit between the beams and carlines of the gun-decks of frigates and berth-decks of single-decked vessels.

Those for instant use are placed near the after-hatch, and the remainder abaft that position, if possible, so as to be constantly under the care of the sentinel at the cabin-door. In no case, however, are they to be placed over any standing light or lantern on any deck.

Section V.—Preparing Ammunition.

1535. COMPOSITION.—Ammunition is composed of *projectiles, cartridges, etc.*

The cartridges and projectiles used with heavy ordnance are fitted and stored separately.

1536. Making Cartridge-bags.—Cartridge-bags are made of two shapes: conical, for gomer chambers, and cylindrical for other ordnance. The cartridge-cloth from which the bags are made is woven expressly for the purpose, being entirely of wool, and of close and uniform texture. It is manufactured in pieces varying in width from sixteen to thirty-six inches; the different widths being adapted for the several lengths of cylinders to save waste in cutting.

Cartridge-bags for cylindrical chambers are made of a rectangle to form the cylinder, and a circular piece to form the bottom. The flat patterns, by which the cartridge-bags for the 8-inch and 32-pounder guns are cut, are consequently to be made rectangular for the cylindrical part of the bag, and circular for the bottom. The length of the rectangle is equal to the development of the cylinder, together with the allowance for seam; and its width, to the whole length of the bag before sewing, including the allowance for seam and tie. Special patterns are furnished for those of XV-in., XI-in., X in., IX-in., 8-inch of 6,500 lbs., and 32-pounder of 4,500 lbs., shell-guns, all of which have gomer chambers.

Cartridges for gomer-chambered ordnance are made conical in shape, and out of two pieces. In cutting, the length of the rectangle should be taken in the direction of the length of the stuff, as it does not stretch in that direction, and the material should be chosen, as nearly as possible, of the width required for the length of the bags, to save waste in cutting.

The bags are to be sewn with worsted yarn, with not less than eight stitches to the inch; they must be stitched within four-tenths of an inch of each edge, and the two edges of the seam felled down upon the same side, to prevent the powder from sifting through. The edges of the bottom are felled down upon the sides.

The bags when filled must be tied with woollen thrums.

1537. *Cartridge-bags for Saluting-charges.*—Old cartridge-bags which have been condemned for service-charges are to be repaired and used for saluting-charges; and whenever it is necessary to make bags expressly for the purpose, or for immediate use, they may be formed by sewing together two rectangular pieces with semi-circular ends.

1538. *Inspection.*—The material especially procured for cartridge-bags is to be carefully inspected, to detect any mixture of cotton with the wool, by burning a few bits taken at hazard from each piece, or by dissolving it in a solution of half an ounce of caustic potassa in a pint of water—the cloth to be put in when the water is boiling, which is to continue until dissolution takes place. The texture of the stuff is also to be examined and its strength tried, such standard for the latter being established as may be found sufficient to ensure perfect efficiency.

1539. *Preservation.*—Cartridge-bags, as well as the material for making them, must be frequently examined, to prevent their being damaged by moisture, as well as to guard against moths. And they are never to be exposed on the shelves in store, but must be carefully packed by hydraulic press in linen cloth, or by enveloping them in water-proof paper hermetically sealed.

1540. Filling Cartridge-bags.—Standard powder-measures for filling cartridges for great guns are distributed as they may be required for the use of vessels and shore-magazines. As the gravimetric density of powder varies from 860 to 940, the weight of the contents of ten measures should be ascertained for each lot, and allowance made accordingly before filling the cartridges. In taking the weights, the powder is to be scooped up from the filling-chest with the measure until it is heaped, tapped twice moderately on the sides with the palms of the hands, and then struck with a wooden straight-edge. If the weight differs materially from that marked on the measure, a small compensating-measure should be used to supply the deficiency or remove the excess.

When cartridges are filled for issue, the powder should be selected, as far as practicable, from deliveries made by the same person, and at the same time or date.

1541. *Marking Cartridge bags.*—The color of the cloth is white, and when made up each bag is stencilled in black with the calibre of gun and weight of charge in figures two and a half inches long, for all service-charges.

The cylinders, or cartridge-bags, in which the powder is put up for "saluting," "torpedo," "howitzer," "shell-powder," or "shell-charges" are also to be distinctly stencilled as such, in the same manner.

1542. Service-charges.—There are certain fixed charges termed *service charges* for all guns.

The amount of powder in the service charge of a gun should be such that it will give the greatest initial velocity to the projectile without too great strain on the metal of the piece, or a too violent recoil of the gun.

The service-charges for the different calibres and classes of Naval smooth-bore guns now used in the Navy are as follows, and the cartridges are to be filled accordingly, viz.:

Service Charges for Naval Guns.

Guns.		Charges.				
Calibre.	Weight.	Battering-charges—solid shot.	For distant firing, 1-10th.	For ordinary firing, 9-10ths.	Saluting, 50 rounds for each gun.	Shape of Cylinder.
Shell guns.	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	
XV-in.	43,000	100 M. P.	50	35	......	Conical
XI-in	16,000	30, rifle	20	15	7	"
X-in	12,500	....	15	12.5	6	"
IX-in	9,000	....	13	10	7	"
VIII-in.	6,500	....	7	7	4	"
32-pdr	4,500	....	6	6	4	"
VIII-in.	63 cwt.	....	9	8	4	Cylindrical
VIII-in.	55 "	....	7	7	4	"
Shot guns.						
X-in., or 130-pdr.	16,000 lbs.	....	30	18	6	"
64-pdr.	106 cwt.	....	16	12	4	"
32 "	61 "	....	10	8	4	"
32 "	57 "	....	9	8	4	"
32 "	51 "	....	8	7	4	"
32 "	46 "	....	7	7	4	"
32 "	42 "	....	6	6	4	"
32 "	33 "	....	4.5	4.5	4	"
32 "	27 "	....	4	4	3	"

Charges for Naval Rifle Guns.

Gun.	Calibre.	Weight.	Diameter of bore.	Charge of Powder.		
				Weight.	Kind.	Diameter of guage.
		Pounds.	*Inches.*	*Pounds.*		*Inches.*
Parrott.	100-pdr.	9,700	6.40	8	Rifle	5.50
"	60 "	5,400	5.30	6	"	4.60
"	30 "	3,550	4.20	3.25	Cannon	3.70
"	20 "	1,750	3.67	2	"	3.25
Dahlgren.	20 "	1,340	4.00	2	"	
"	12 "	880	3.40	1	"	

With the XV-inch guns at close quarters against iron-clads, 100 pounds of hexagonal or mammoth powder and a solid shot *may* be used for twenty rounds; so also with the XI-inch, 30 pounds of rifle and a solid shot.

With all other guns, under like circumstances, and where penetration is desired, the distant firing-charges should be substituted for the ordinary firing.

Saluting charges are to be of under-proof powder.

Experiments have established the ability of our XV-inch guns to endure charges of one hundred pounds of powder and a solid shot, and it is believed that they will stand even heavier charges.

The service demanded of them requiring a wide range of charge, the service-charge will vary with the object to be attained.

1543. For Mortars.—The bag is only used to carry the powder, and when the piece is loaded the powder is poured into the chamber; bags of any suitable size will answer for this service.

1544. For Hot-shot.—Cartridge-bags should be made double by putting one bag within another. The charge ought not to exceed three-fourths the service-charge, for in consequence of the expansion of the shot the windage is reduced and a greater strain will be exerted on the metal of the gun. The expansion of the gas will also be increased by the heat generated within the bore; and, moreover, very great penetration is not required, the object to be attained being that the shot shall merely lodge in the timber.

1545. Strapping Shell.—All spherical shell and shrapnel are fitted with *sabôts*.

The sabôt is a thick circular disk of wood, cut with the grain running plank-ways, about the diameter of the low gauge of the projectile, and with a cavity or saucer on one end to receive it. The projectile is secured to it with four straps of tin. The straps are fastened to a ring of tin encircling the fuze-hole by cutting four slits in the ring, into which the upper ends of the straps are hooked, turned down on the inside of the ring, and soldered. The lower ends of the straps are tacked to the side and under the bottom of the sabôt, at equal distances from each other. A piece of twine is passed around between the sabôt and projectile to frap the parts together.

The English attach the sabôt by a single expanding rivet through its centre, the hole in the projectile into which the rivet fits being under-cut, so that, on a blow being given, the end bulges out and grips the edge of it. This method is preferable to the straps.

1546. *Advantages.*—The sabôt secures the position of the fuze in loading, which should be in the axis of the piece and from the cartridge. It tends to prevent the formation of a *lodgment* in the bore. It moderates the action of the powder on the projectile and helps to keep the projectile in its place. The fragments of the sabôt are scattered as soon as the projectile leaves the bore of the piece.

1547. FILLING SHELLS.—All shell are filled with shell-powder of the highest initial velocity. The shell must be filled and the powder well shaken down, leaving room only for the insertion of the fuze. A wooden plug the size of the lower part of the fuze will always determine this.

For the purpose of increasing the effectiveness of hollow projectiles, a quick and strong bursting-charge is required to break the projectile into a large number of fragments.

1548. THE CHARGES OF POWDER FOR SHELL ARE AS FOLLOWS:

Charges for Spherical Shell.

	XV-inch.	XI-inch.	X-inch.	IX-inch.	VIII-inch.	32-pdr.	Boat and Field Howitzers.		13-in. Bomb.		
							24-pdr.	12 pdr.	Full Charge.	Bursting Charge.	Blowing Charge.
	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs. oz.	lbs. oz.	lbs. oz.
Bursting or Service Charge........	13.	6.00	4.00	3.00	1.85	0.90	1.0	0.5	11 0	6 0	0 6
Blowing Charge.....	1.0	0.25	0.25	0.25	0.25	0.25					

Charges for Parrott's Shell.

100-pdr.	60-pdr.	30-pdr.	20-pdr.
lbs. oz.	*lbs. oz.*	*lbs. oz.*	*lbs. oz.*
3 11	2 2	1 8	1 0

Charges for Dahlgren Rifle-shell.

20-pdr........................... 0.86 lbs.
12-pdr........................... 0.50 lbs.

The weight of charges for shells varies slightly from those given in the tables, according to the size of the grain and density of the powder.

1549. *The Bursting-charges for Shell* are made up in cotton bags and packed in separate tanks. Shells are filled by capacity, and not by weight. When it is not required to burst the shell, but merely to blow the fuze out at practice, small charges called " blowing-charges " are used. In naval practice, however, it is seldom possible to recover the shells.

1550. Whenever it is necessary to load and fuze shell on board ship—a properly secured place being first prepared, not in the shell-room, and as far as convenient from the magazine—the shell, being strapped and sabôted, are to be examined to see that they are clean, both inside and out, and thoroughly dry. The greatest care is taken to remove every particle of sand or fragment of iron from the interior. The prescribed charge of powder is next poured into them through a proper funnel, care being taken that the end of the funnel passes below the screw-thread in the top, or bouching, to prevent any grains of powder from entering it. Any grains of it which may remain sticking to the thread of the bouching are brushed away carefully, and then, after putting a light coat of lacquer for small-arms, or sperm oil, on this thread and on that of the fuze, the latter is screwed in carefully with the fuze-wrench. The fuze must be screwed in tight, care being taken to have the proper leather washer under the head. The lacquer should be of the consistency of cream, and when, from evaporation, it becomes too stiff, should be thinned by adding more spirits of turpentine.

1551. The date when shell are fuzed or filled, as well as that on which any of these arrangements are changed, or the shell are examined before issue, together with the initials of the officer superintending these operations, should be legibly written and pasted on the shell.

Projectiles are filled only as required for ships fitting for sea. No projectile should be fuzed until it has been filled, and they must be fuzed as soon as filled.

1552. Packing.—Loaded shell, as well as the sabôts attached, are to be painted red and placed in boxes or bags marked with a red cross on the sides, and with the length of fuze in black.

All spherical shell are packed singly. The smaller calibres of rifled shell are packed several in a box, and the larger calibres singly.

1553. Wads.—No wad is required over a shell, but a grommet-wad may be used in heavy rolling, or to prevent the projectile moving forward should the bore be depressed; also if it is shaken by the running out of the gun.

When loading with shot, a *grommet-wad* is placed over it. No wad is placed between the charge and the projectile in ordinary service, and it is positively prohibited to place a wad over an elongated projectile.

1554. GROMMET-WAD.—This consists of a selvagee, or circle of rope equal in diameter to the bore of the gun. They are made by a wad-machine. This consists of pairs of disks adapted to each calibre of guns, which, being placed face to face on a spindle and keyed, present an annular score grooved in such a way as to make, when fitted, a grommet of the required size. Transverse notches are cut in the circumference of the disks to the bottom of the score, for the convenience of marling the wad before taking it off the mold. In making the wad, the end of a rope-yard is left in the score, and the mold is turned by a crank until the score is filled.

The grommet thus formed is marled like a selvagee-strap, and a section of about an inch is taken out of it, in order to make the wad, when swelled by the dampness, enter the bore of the gun readily. Grommet-wads should be made neither too hard nor too soft; and to avoid either of these two extremes, a sufficient number of hitches only will be taken to give the wad the consistency required for service. Sections of one-third or one-fourth of these wads will answer as well in case of need.

1555. JUNK-WADS.—They are now seldom used. They are made of oakum or cuttings of old "junk" compressed into a solid cylinder and bound around with spun yarn. They are of similar diameter to the bore of the gun, and somewhat less than one calibre in thickness.

1556. BOAT AMMUNITION.—When the cartridge is attached to the projectile, the two together are termed "*fixed ammunition*"; this is employed for service with boat-howitzers. It has the advantage of great convenience in the hurried preparation that frequently precedes boat operations, and the guns can be served more rapidly with fixed ammunition, simultaneous loading is more simple, and the cartridge is sure to be placed correctly in the bore, and not with the choked end first, as is sometimes the case when the projectile and cartridge are separate.

Fixed ammunition has, however, the disadvantage that in packing or stowing much greater space is required, and it is more difficult to arrange and to preserve.

The charges for "Boat and Field Howitzers" are:

For the 24-pdr. of 1300 lbs.	2.00 lbs.
For the medium 12-pdr. of 760 lbs.	1.00 "
For the light 12-pdr. of 430 lbs.	0.625 "

The strength of the pieces would justify greater charges than these; but the carriages, the fixtures, and the frame of the boat might be injured by the severe recoil of pieces so light, and even be disabled by the continued repetition of the firing with heavier charges.

1557. Stand of Ammunition.—A stand of ammunition is composed of the projectile, the sabôt, the straps, and the cartridge-bag. (Fig. 339.)

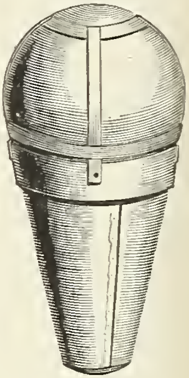


Fig. 339.

The projectiles used in howitzers are shell, shrapnel, and canister.

For the two former the sabôt has a spherical cavity and a circular groove to which the cartridge-bag is tied; in the latter the spherical cavity is omitted and a circular offset is added.

1558. Packing.—As soon as the ammunition is finished it should be gauged to see that it is of the proper calibre; it is afterwards packed in well-seasoned pine boxes, so disposed that the sabôt may rest on a ledge in the box, leaving the charge below free from any pressure.

The shell, shrapnel, and canister for the 24 and 12 pdr. howitzers are packed in boxes containing nine each. A fuze-cutter (for the Bormann fuze) is placed in the rim of each box containing loaded projectiles. The boxes are painted black and marked with the contents. The lids are fitted with hinges and secured with screws.

A key is becketed to each box for unscrewing the lid.

1559. In consequence of the objection to packing powder in wood on board ship, thereby rendering it more liable to deterioration, various plans have been suggested for fitting the cartridge to be attached to the sabôt at will, and stowing them separately; and it has been lately ordered that this be done.

The cartridge-bag has a brass wire ring sewed into the cloth outside of the tie, for the purpose of attaching it to the sabôt of the projectile, the ring being made to open and fit into the fillet of the sabôt, being retained in place by the force of the spring.

1560. Metallic Cartridges.—The metallic cartridge furnished the navy is a central-primed metallic cartridge, and is manufactured by the United States Cartridge Company, Lowell, Mass.

It consists of a brass case or shell having a solid head, made from one continuous piece, and by a peculiar process the metal throughout is of the same condition, and therefore not liable to burst at the head or rim, nor stick in the barrel of the gun after firing.

The method of priming is very simple and effective, being arranged so that the case or shell, which forms the greater part of the cost of the ammunition, can be reprimed and reloaded many times.

The primer consists of two copper cups fitting inside of one another, fulminating compound being contained between them. The inside or smaller cup has two small perforations through the bottom to allow for the passage of the flame to the charge of powder, the bar formed between the perforations serving as an anvil against which the fulminate is exploded.

The head of the case is made with a small circular cavity for the reception of the primer, the latter being applied from the outside; there is also a perforation in the centre of the cavity to allow the flame from the primer to communicate with the powder-charge in the case.

The charge of powder is 70 grains; the bullet is cylindro-conical in shape, having three rings and a concave base, and is well lubricated; the calibre .50, weighing 450 grains.

They come in packages of 20 each, and weigh 2 lbs. 2 oz.

The regular packing-box contains 50 packages, or 1,000 cartridges, and weighs 118 lbs. 4 oz.

The empty shells or cases are to be carefully preserved, replaced in their boxes, and returned to the navy-yards for reloading.

1561. Dummy Cartridges, made of the same size and form as the service cartridge, are supplied to ships, and must always be used during the manual exercise with the Remington rifle, in order to prevent injury to the striker by snapping the piece at "Fire."

1562. Blank Cartridges are supplied for funeral firing only; they are not to be used in drill.

1563. Incendiary Preparations are *fire-stone*, *carcasses*, *incendiary-match*, and *hot-shot*.

Fire-stone is a composition that burns slowly but intensely; it is placed in a shell along with the bursting-charge, for the purpose of setting fire to ships, buildings, etc.

Composition.—It is composed of:

10 parts of Nitre,
4 parts of Sulphur,
1 part of Antimony,
3 parts of Rosin.

Preparation.—In a kettle in the open air, melt together one part of mutton-tallow and one part of turpentine. The composition, having been pulverized and mixed, is added to the melted tallow and turpentine in small quantities. Each portion of the composition should be well stirred to prevent it from taking fire, and each portion should be melted before another is added.

How used.—When fire-stone is to be used in shell it is cast into cylindrical molds, made by rolling fuze-paper around a former and securing it with glue. A small hole is formed in the composition by placing a paper tube in the centre of each mold. When the melted composition has become hard this hole is filled with a priming of fuze-composition.

The object of this priming is to insure the ignition of the fire-stone by the flame of the bursting-charge.

1564. Carcass.—A carcass is a hollow cast-iron projectile filled with burning-composition, the flame of which issues through several fuze-holes, to set fire to combustible objects.

The fuze-holes are situated in the upper hemisphere, equidistant from each other.

Composition.—The composition is the same as for port-fires, mixed with a small quantity of finely chopped *tow*, and as much *white turpentine* and *spirits of turpentine* as will give it a compressible consistency.

Preparation.—The composition is compactly pressed into the carcass with a drift, so as to fill it entirely. Sticks of wood one-half inch diameter are then inserted into each fuze-hole with the points touching at the centre, so that when withdrawn corresponding holes shall remain in the composition. In each hole thus formed three strands of quick-match are inserted and held in place by dry port-fire composition, which is pressed around them. About three inches of the quick-match hang out when the carcass is placed in the piece; previously to that it is coiled up in the fuze-hole and closed with a patch. The metal of a carcass is considerably thicker than that of a common shell, because, being much weakened by the vents, there would be danger of the carcass breaking up under the shock of the discharge; and besides, as the carcass is not required to burst, it must have sufficient strength to withstand the pressure exerted upon it by the gas which is generated in the interior by the burning-composition.

A Common Shell may be loaded as a carcass by placing a bursting-charge in first, and covering it with carcass-composition driven in until the shell is nearly full, and then inserting strands of quick-match secured by driving more composition. This projectile, after burning as a carcass, explodes as a shell.

1565.—Incendiary-match is made by boiling slow-match in a saturated solution of nitre, drying it, cutting it into pieces, and plunging it into melted fire-stone. It is principally used in loaded shells.

1566. Hot-shot may be fired for the purpose of setting fire to vessels or buildings, though they are rarely used. Shot of low gauge should be chosen for this purpose with reduced charges. They can be made red-hot in from 15 to 30 minutes, but care must be taken not to bring them beyond a *bright red*, as they are then liable to fuze and become misshapen. The part resting on the furnace-bars heats more quickly than the upper part, so they must frequently be turned. Shot expand $\frac{1}{65}$ of their diameter when brought to a red-heat; therefore, to prevent accidents, each shot should be passed through a red-hot shot-gauge before being taken from the fire-room. Should the shot jam in the bore it must be cooled by pouring water in at the muzzle; but if that fails, the charge must be drowned before attempting to blow out the shot.

Precautions in Loading.—Junk and grommet wads which have been soaked in water for two or three hours, and the water pressed out of them, are to be used in loading. The junk-wads must be small enough to fit easily when swelled by being soaked. The cartridge must be perfectly tight, so that powder will not be scattered along the bore. Sufficient elevation having been given to enable the shot to roll home, first enter the cartridge, a dry junk-wad, and then a wet junk-wad, and ram them home. Bring the shot in a bearer and enter it, with a wet grommet-wad on top; as it cools rapidly, no time should be lost. Quantities of smoke will come up through the vent, but a red-hot shot does not burn more than the outer yarns of a well-soaked junk-wad, even if left in the gun till it becomes cold.

CHAPTER X.

PRACTICE OF GUNNERY.

Section I.—Service of Ordnance.

1567. LOADING.—The charge is placed in the muzzle with seams from the vent, small end in and tie outwards. It is pushed steadily to the bottom of the bore and on no account to be struck. The space which the powder occupies effects the initial velocity.

Cartridges that have left the magazine are not to be returned until after the "Retreat" is beaten, in order to prevent confusion.

Powder-passers are to throw all cartridges that are injured in the slightest degree overboard, or in tubs of water prepared for that purpose.

The shell is entered sabôt first and fuze out. After removing the fuze-cap it is pushed gently to its place and never struck.

1568. MARKS ON RAMMER.—With the view of affording the Loader a certain and independent means of knowing when the load is really home, the handle of the rammer has a mark upon it, for the place of both charge and shell, easily distinguishable either by night or day.

This mark is a narrow circular indentation, in a portion of which a strip of brass is secured, which is marked, for the outer one, with the charge in pounds, and for the inner one, with the projectile used.

1569. REMOVING FUZE-PATCH.—In loading with shell, the cap is never to be removed until the shell is entered in the gun. With high elevations, or when rolling, care should be taken that the shell does not slip down the bore before this is done.

The cap or patch is removed by taking hold of the lug with the forefinger and thumb, first raising it a little, and without twisting; a pull readily removes it.

The patch is passed to the Gun Captain, as an evidence that the priming has been exposed; the patches are to be preserved and accounted for at the end of the firing.

The Loader must be careful not to touch the fuze-composition with his fingers, for fear of injuring it with moisture.

In loading with percussion-shell, the screw-head of the fuze must be reversed. (Art. 1497.)

1570. The XV-inch Shell, being very heavy, is apt to slip in the straps by which it is secured to the sabôt; therefore, in loading, care must be taken to examine the position of the fuze-hole.

When the distance is known to be less than the range of the shortest fuze, uncap all the fuzes. At other times uncap the fuze suited to the distance and the one of longest time of burning. (Art. 1477.)

1571. Withdrawing Projectiles.—If, in loading, a projectile jams in the bore, no attempt should be made to force it down, but it should be withdrawn.

This may be done with the *ladle*, by depressing and striking the muzzle against the lower sill of the port, or by running the gun out hard against the side, at extreme depression. Should these means fail to start the projectile, it will be necessary to destroy the charge by pouring water down the vent and muzzle, and then introduce a small quantity of powder and blow it out.

Should a projectile jam in the bore in action, the Gun Captain will not attempt to withdraw it, but discharge the piece at once.

A gun is not to be loaded with more than a single projectile, and solid shot are not to be fired from shell-guns unless specially directed.

1572. Care in the Use of Shell.—In action, shell should never be allowed to accumulate on deck. Experiments have proved that any loaded shell at rest, when struck by a solid shot, fired with even a moderate charge will be exploded, with force sufficient to scatter in every direction, and to considerable distances, any other shells that may be placed in near proximity.

1573. Keeping Guns Loaded.—Guns should never remain loaded longer than necessary, as the cartridge speedily deteriorates by the effects of moisture. If a shell has been loaded twenty-four hours, it should be drawn and refuzed.

1574. Running Out.—As the projectile slides in the gun with very little friction, particular care should be taken not to let the carriage strike with too great a shock in running out, as it will surely start the projectile from its seat.

1575. Closing the Vent.—After a piece has been discharged, the vent should be cleared with the priming-wire and the bore well sponged to extinguish any burning fragments of the cartridge that may remain.

To prevent the current of air from fanning any burning fragments that may collect in the vent, it should be kept firmly closed with a thumb-stall in the operation of sponging. A moist sponge is always to be used.

After sponging, the vent must again be cleared with the priming-wire and closed with the thumb-stall. These precautions are taken to prevent the possibility of the vent becoming obstructed.

1576. Clearing the Vent.—If at any time the Gun Captain should find the vent obstructed, and be unable to clear it with the *priming-wire* or *boring-bit*, he will at once report to the officer of the division, who will order the *vent-punch* used; or, if this should fail, have recourse to the *vent-drill* and *brace* in charge of the Quarter Gunner. The boring-bit, vent-punch, and drills should be used with caution, as, being of steel, they are liable to be broken off in the vent and thus effectually spike the gun.

After clearing the vent, the bore should be sponged.

1577. Spongers and Loaders should keep their bodies clear of the muzzle, and as much within the port as practicable for their own protection.

1578. Rapidity of Loading.—Loading can not be executed with too much rapidity, provided neither the safety of the gun nor of its crew be compromised.

1579. Use of Projectiles not adapted to the Piece.—If it should become necessary to use a projectile much smaller than the bore, it is strapped to a stout sabôt which fits the bore; if a mortar-shell, it is placed in the centre of the bore with wedges and the surrounding space is filled up with earth or old junk.

We may also fire from a gun, shot of a greater calibre placed upon the muzzle; this species of fire is generally at an angle of 45°; the bomb placed upon the muzzle is secured by a cord which is broken by the first impulse; the accuracy is nearly equal to that of shells from a mortar, and the range of an 8-inch shell fired from a 24-pdr. cannon, with 8 lbs. charge of powder, is about 600 yards: the shorter the gun, the greater the range.

1580. Loading Mortars.—The powder is to be emptied into the mortar from the cartridge-bag, which must be well shaken to remove dust and fine grains of powder. The bag is retained in the hands of the Loader to be used in wiping the shell before it is lowered into the bore. The powder is levelled off with a *spatula*, when the bomb, loaded and fuzed, is carefully lowered into the bore by the hooks, and allowed to rest upon the charge, keeping the fuze exactly in the axis of the bore. In mortars, where a sponge is seldom used, the stopping of the vent is not necessary; but it should always be cleared out with the priming-wire before the powder is placed in. The bore is cleared with a scraper, and wiped out with an empty cartridge-bag or swab. If a sponge is used, it is much smaller than the bore.

1581. Loading Small-arms.—Bring the piece to full-cock and open the breech-block; if there be an empty shell in the chamber, it will be removed by the extractor. The firing-pin may be made to protrude by being choked with rust, or by wedging of the firing-pin spring, and in this position lead to a premature explosion in closing the breech-block. Pass the finger over the face of the breech-block, to ascertain that the firing-pin does not protrude.

Place the cartridge in the chamber and close the breech-block. Should there be any difficulty in closing the breech-block, it is probable that the rim of the cartridge is too thick; it should be withdrawn and another tried.

The chamber should be kept clean, and great care observed to prevent cartridges fouled with dirt, and particularly sand, from being inserted or discharged in the piece, as the expansion of the shell presses the sand into the metal and mars the surface of the chamber, and thus causes the shells to stick. Care should also be taken in cleaning the chamber for the same reason. The shell of an exploded cartridge should not be allowed to remain in the chamber any length of time, for fear it may adhere by corrosion.

To prevent premature discharges, and to relieve the firing-pin spring, the piece should be always kept at half-cock.

In coming to "order arms," the butt should be brought to the deck without shock, as a jar may injure the piece.

1582. POINTING.—To point or aim a fire-arm is to give it such direction and elevation that the projectile shall strike the object. To do this properly, it is necessary to understand the relations which exist between the *line of sight*, *line of fire*, *trajectory*, etc.

1583. Definitions.—The *line of sight* is the right line containing the guiding points of the sights. The sights are two pieces on the upper surface of the gun, the situation of which with regard to the axis of the bore is known.

The *front sight* is usually situated between the trunnions or on the rim base, and is generally fixed; the *rear sight* is placed on the breech, and is movable in a vertical plane.

The *natural line of sight* is the line of sight nearest the axis of the piece; the others are called artificial lines of sight.

The *line of fire* is the axis of the bore prolonged in the direction of the muzzle.

The *angle of fire* is the angle included between the line of fire and horizon; on account of the balloting of the projectile, the angle of the fire is not always equal to the angle of departure or projection.

The *angle of sight*, or angle of elevation, is the angle included between the line of sight and line of fire; angles of sight are divided into natural and artificial angles of sight, corresponding to the natural and artificial lines of sight which enclose them.

The *plane of fire* is the vertical plane containing the line of fire.

The *plane of sight* is the vertical plane containing the line of sight.

1584. Point-blank.—The term *point-blank* originated when it was imagined that a shot travelled for some distance in a straight line, or *direct;* it is of no practical use, and is differently defined in different countries.

The French definitions of *point-blank* and *point-blank range* are as follows:

The *point-blank* is the second point at which the line of sight intersects the trajectory; and the distance from the face of the muzzle to this point is the *point-blank range.*

The *natural point-blank* corresponds to the natural line of sight; all other points-blank are called *artificial points-blank.*

In the British service, as well as in our own, the point-blank distance is the distance at which the projectile strikes the horizontal plane on which the trucks of the carriage rest, the axis of the piece being horizontal.

1585. Range is the distance from the muzzle of the gun to the second intersection of the trajectory with the line of sight.

In practice the range is usually measured from the muzzle to the point of impact on the object, or to the first graze of the projectile.

The range depends upon the initial velocity, the form, and density of the projectile, the angle of elevation of the gun, and the difference of level between the planes upon which the gun and object respectively stand.

Extreme range is the distance to the point at which the projectile is brought to a state of rest.

1586. Range at Level.—The gun being placed a certain height above the water, depending on the class of vessel and the deck on which it is mounted, it is evident that, when the axis of the bore is horizontal, the projectile will have a range proportionate to this height.

The distance to which the projectile will range in this case, before it grazes the water, is called the *range-at-level*, and depends upon the class of gun, the charge, and the height above the water.

1587. SIGHTING CANNON.—In order that a projectile fired from a gun may strike a required object, it is necessary to adjust the line-of-fire with reference to the horizon and the vertical plane passing through the object in such a manner that the trajectory will reach it.

The axis of the gun is not visible, and it is necessary to resort to notches or sights on the exterior surface to determine practically the position of the axis.

The *line of metal* is a visual line, joining the notches cut on the highest points of the base-ring and swell of the muzzle.

The inclination of the line of metal to the axis of the bore varies in guns of the same class as well as in those of different classes. Aiming, therefore, by the line of metal cannot be relied on for definite ranges; besides that, within those ranges it is apt to mislead by giving too much elevation to the piece. If a gun be pointed at an object by means of a line of metal, it will be seen, by prolonging that line and the axis of the bore, that the latter will pass over the object.

1588. DISPART-SIGHT.—A dispart is a piece of metal placed on the top of the gun to give a line-of-sight parallel to the axis of the bore.

The *dispart* is generally defined as *half the difference between the diameters of those parts of the gun upon which the sights are placed.*

Half the difference between the diameters of the gun at the base-ring and swell of the muzzle, or at any intermediate point on the line of metal, will give the proper height of the dispart-sight at the point where the least diameter was taken.

In the absence of other means of sighting, wooden dispart-sights lashed on the reënforce can be used. A narrow groove in the upper surface of the wooden sight, made to coincide with the plane of the line-of-sight marked on the gun, will assist in getting the true direction.

The guns of the Dahlgren pattern are cylindrical for a certain distance forward of the base-line, always giving a line-of-sight parallel to the axis of the bore.

Guns are marked on the top of the base-ring, the sight-masses, and swell of the muzzle, by notches, which indicate a vertical plane passing through the axis of the bore at right-angles to the axis of the trunnion.

In *range-at-level*, the bore being horizontal, the dispart-sight is directed at a point above the water-line or point struck equal to its own distance above that line.

If the gun is pointed by dispart directly at an object, the projectile will fall short, more or less, depending upon the distance.

In pointing by dispart, therefore, it is necessary to direct the sight a certain height above the object, to allow for the fall of the projectile during flight; the height to be pointed above must depend upon the distance of the object.

1589. TANGENT FIRING.—Before the introduction of the tangent scale or breech-sight, all pointing at sea was done with the dispart-sight. When desiring to strike an object beyond the *range-at-level* of the piece, it was necessary to direct the line-of sight, which was parallel to the axis of the piece, at a point a certain distance above the object; this elevation being intended to allow for the space through which the projectile falls by the action of gravity in the time of flight.

The vertical space through which the projected body in its flight descends below the line of fire is equal to the tangent of

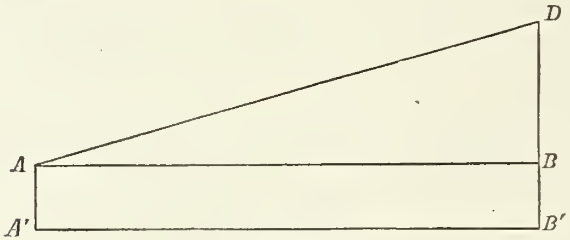


FIG. 340.

the angle of elevation multiplied by the range or horizontal distance of the object from the gun.

In the figure (340), $\tan A = \frac{BD}{AB}$

$$BD = AB \tan A.$$

Thus, suppose a gun to be, at A, at a known height, AA′, above the level of the water and at a known distance, AB, from a vertical object, B′D, as a ship's mast. For any particular nature of ordnance we know the elevation necessary to project the projectile a certain distance.

Now in the equation

$$BD = AB \tan A,$$

AB, equal to the distance, is known, as is also the angle A, which is the angle of elevation necessary to give the gun in order to project the ball the distance, AB. But we have no means of pointing the gun at this angle, except by finding the length of the vertical, which will subtend this vertical angle at the distance of the object. The required length of the vertical, BD, is found by the equation,

$$BD = AB \tan A.$$

If, then, the line of sight parallel to the axis, be directed at the point D, we know that the gun has the elevation that is required in order to make the ball reach to the distance, AB. Adding to both sides, BB′, we have

$$B'D = AB \tan A + BB'.$$

To strike an object, then, at the water-line, at the distance AB, greater than the range at level, the aim being taken with the dispart-sight, it is necessary to direct the line of sight at a point situated at the distance, B′D, above the water-line.

The heights of certain points on the masts of foreign men-of-war being known, tables have been constructed, in the columns of which are designated the points at which the line of sight must be directed, corresponding to certain distances of the object which it is desired to hit. Such tables are to be found in the old editions of the Ordnance Instructions.

This mode of firing presents serious disadvantages. The points arrived at have often to be estimated, as well as the distance of the enemy's vessel: the class of which can seldom be accurately determined. The men are taught to aim where they are not expected to hit, and the chances of the ricochet are lost; hence, tangent firing should only be resorted to when there are no other means of regulating the elevation of the guns.

1590. Tangent Sights.—To facilitate the operation of pointing guns according to the distance of the object aimed at, sights are prepared and fitted to each gun.

The ordinary sights consist of two pieces of bronze gun-metal, one of which, called the reënforce or dispart-sight, is a fixed point, firmly secured to the sight-mass, upon the upper surface of the gun between the trunnions.

The other, or breech-sight, is a square bar or stem with a head, in the top of which is a sight-notch. It is set diagonally so as to expose two faces to the rear; the rear angle chamferred, to afford a bearing for the clamp-screw. This bar or stem is made to slide in a vertical plane, in the sight-box fixed to the breech-sight mass, and is held at the various elevations for which it is graduated by means of a thumb-screw. Its length is sufficient for all the elevation which can be given—about 5° —before the muzzle appears above the front sight, after which a long wooden sight must be used, graduated for the whole length of the gun, using the notch in the muzzle.

1591. The brass tangent-scale or breech-sight may be said to be a tangent to an arc the radius of which is the distance from the outer point of the fore-sight to the fore part of the hind-sight, and the divisions are calculated accordingly; this distance is called the short radius.

The wooden tangent-scale may be said to be a tangent to an arc of which the radius is the distance from the notch on the swell of the muzzle to the front of the hind-sight; this distance is called the long radius.

The tangent-scale is set at an angle of 60°, so that it may slide up and down without touching the breech of the piece.

Every gun is furnished with two sight-bars, a long wooden and a short brass one; the longer is used for ranges over 1,700 yards; for all ranges less than this, which is the extreme distance at which accurate practice may be expected at sea, the short bar is used.

1592. *Pivot Guns* have their tangent-scales fitted to be placed on the side of the breech, and the forward-sight is placed on the trunnion or rim-base.

The advantage of this arrangement is that the tangent and trunnion sights can be used at any elevation; for, being placed at the side of the gun, the muzzle of the piece does not interfere with the line of sight when pointing.

The sights of all howitzers are fitted in this way:

1593. *Sights for Rifled Guns.*—These consist of a fixed sight upon the right rim-base, and a brass movable sight in a socket which is screwed into the rear of the reënforce at the breech of the gun. The movable sight is furnished with a sliding eye-piece, and is graduated up to 10°. The eye-piece is also capable of lateral adjustment to allow for the *drift* as far as 10°, and for the effect of the wind. It is desirable that the sights should be placed on both sides of the breech; otherwise, in firing from a port at extreme train, there may be considerable loss of lateral aim.

1594. The radius between the sights should be as long as possible for sea-practice, with an unsteady platform, and where the eye is far removed from the rear-sight.

In order to see the object in line with the outer sight, the eye must pass a certain vertical distance above the rear-sight. The amount of vertical height between the rear-sight and the line of vision depends upon the state of the weather, and upon the motion of the ship. When the ship is steady it will probably be 0.1 or 0.2 of an inch. When the ship is very lively it may be half an inch.

At all known distances, all considerable errors in firing at sea are dependent upon the height that the line of vision passes above the rear-sight. Take a given vertical height of visual error, say half an inch: the effect it will have upon the range depends upon the distance between the sights; if they are but a few inches apart, the error will cause some thousands of yards increase of range.

If they are as far apart as they can be placed, the same visual error will probably cause an error in range of less than a 100 yards with a IX-inch gun.

1595. Adjustment of the Sights.*—Roll the gun in the direction of its trunnions until the line of sight is uppermost. The cylindrical portion of gun forward of base-ring is supposed to be turned at the foundry parallel to axis of bore, so the next object is to trim down the reënforce and breech sight-masses until they are level with the cylindrical portion of gun. To do this, scrape off all the paint which may be on the gun in line of sight. Place a straight-edge on the portion, its two ends resting respectively on the reënforce and breech sight-masses. Trim down both masses until daylight cannot be seen between the straight-edge and the gun along its whole length where the straight-edge takes.

1596. If possible, all sighting of guns should be done under cover, as the wind outside deflects the thread of the tompion-arm when fixing the point of the reënforce-sight. If the gun, however, is out of doors and difficult to move, build a screen, fore and aft, the length of the gun to windward. The gun being in Gun Park, lying on wooden skids taking at chase and breech, build up with blocks under muzzle and at trunnions, using these in connection with chocks to bring the gun to an exact level both as to axis of bore of gun and axis of trunnions.

1597. The bore having been thoroughly cleansed, its axis is levelled by inserting a small steel T-square in bottom of bore at the muzzle. The square itself is first levelled by placing an ordinary level on the transverse branch. When the T-square is levelled, the level is then placed on the longitudinal branch of the T-square lengthwise with the bore of gun, and the axis of gun is then levelled by striking the chocks previously placed on each side under chase of gun, which of course either raise or lower the muzzle. When the gun has been levelled as to axis of bore, it is to be levelled as to axis of trunnions.

* By Lieutenant C. H. West, U. S. Navy.

1598. To level as to axis of trunnions: First, scrape off the paint on top of each trunnion, then place the trunnion-square as seen in Fig. 341, and put the spirit-level on it as at *s*. Ad-

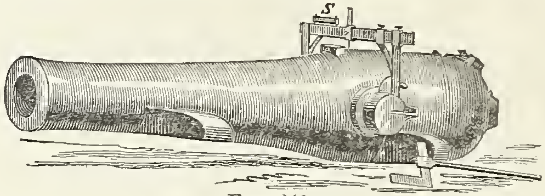


Fig. 341.

just the piece by means of the chocks under the trunnions until they are horizontal. This levelling the gun by axis of trunnions may throw out the axis of gun-level, in which case return to that, and then to the other, approximating closer and closer each time until the gun is levelled.

If the gun be lying on *wooden* skids, the levelling must be verified from time to time, as the great weight will cause it to sink trifle by trifle, thus throwing the level out.

1599. Fitting Centre-sights.—The gun being levelled, next proceed to find initial point on base-ring. Encircle the breech of the gun at the base-ring with the trunnion-square, first scraping off the paint on gun where the legs of square take on either side, and level the square by a spirit-level. Then take the sliding pointer on transverse branch of square, and set it at a point exactly half way on the branch, by means of the graduated scale. Hit the gun on the base-ring a slight tap with the pointer. Take the square off and turn the legs end for end, again embracing the gun, and again level square with spirit-level. Again hit the gun on the base-ring a slight tap with the pointer. Should the pointer not strike in the same point as it did in the first instance, choose a point half way between the two for the initial point.

1600. The initial point on base-ring being determined, place

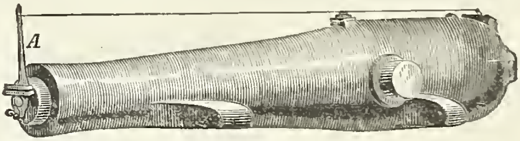


Fig. 342.

the *sighting-tompion* (Fig. 342) in bore of gun. When the tompion is being placed in, be guided by the rings on the side to insert it *evenly*, so as to prevent jamming. In large calibres it is also better to *close* the *vent* before inserting the tompion, as thus, with the compressed air, it can be taken out more easily. Adjust the vertical arm of tompion by the spirit-level and tangent-screw. Extend the thread from vertical arm to the rear, resting for a second point on the initial point established by trunnion-square on base-ring.

1601. Now with a slight dent of the centre-punch, mark the point where the thread crosses the reënforce sight-mass. Take a straight-edge and lay it in the straight line determined by the two points, namely, the initial point on base-ring and the point determined on the reënforce sight-mass by thread of tompion-arm. Take a scriber and, with the straight-edge lying on these two points, scribe out a centre-line on the cylindrical portion of breech, also extending the line to the rear sight-mass.

1602. Proceed to cut out the breech sight-mass to its proper size (using as an initial line the line just described by means of straight-edge). For proper width, length, and bevels of breech sight-mass use templets and gauges. There is a standard distance given for distance of front part of rear sight-mass from base-ring.

1603. As soon as the rear sight-mass is marked out by the templets, proceed to cut down the mass and fit rear sight-box. To fit the rear sight-box so as to bring the rear sight-box to proper angle, and also to a true plane perpendicular to axis of trunnions, use the levelling-bar. (Fig. 343.) Lay the reënforce-sight on the reënforce sight-mass. Then lay the levelling-bar with one end on the reëenforce sight, the sight taking in the line scribed on bottom of levelling-bar.

1604. *The Levelling-bar*, B (Fig. 343), is a square steel bar with parallel faces, somewhat longer than the distance between the sights on the largest gun. The rear end is bevelled at an angle of 60°, the angle at which the sight is placed. It has a

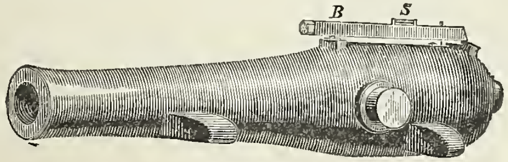


FIG. 343.

central line marked on it throughout its length, on the under side, and along the bevelled end. It has also marked on its sides, near the forward end, the distance at which the sights should be placed for each class of gun. It is also fitted with screws for bringing it to a level.

1605. The levelling-bar being laid on the reënforce-sight, and its bevelled end taking against the rear-sight-bar, bring it to a level with the spirit-level and screws. This will give the true guide for angle of rear-sight-bar, and the latter's proper plane. As soon as rear-sight-box is fitted, bore hole for same through rear-sight-mass. This hole is bored with the rear-sight-box *on*, and the latter is kept down in its place by a sling around cascabel set up by a handspike.

1606. The rear-sight being fitted true as to the levelling-bar, again level the arm of sighting-tompion, and stretch the thread back over gun, this time bringing the thread to the exact middle of the rear-sight-bar notch. Now in theory, the thread ought to come directly over the initial point of base-ring, and over the mark already laid off on reënforce-sight-mass; but practically this is never the case, as it is *almost impossible* to fit a rear-sight box so true as to bring the middle of the sight-notch in the exact line of sight already laid off. It will be found, upon stretching the thread the second time, that it will fall a trifle one side or other of the initial point on base-ring. So, virtually, it is necessary again to lay off a line of sight.

1607. With a measure take the distance that the thread falls to one side of the initial point on base-ring. Take this same distance that the thread is out, and lay it off horizontally on the cross-bar of the vertical sighting-arm. Of course when the thread is also moved this distance on the sighting-arm, the thread will fall the same distance to one side on the reënforce-sight-mass; therefore mark this last point where the thread falls over the reënforce-sight-mass, and thus is established the second and final line of sight. Also mark the point where the thread now crosses the base-ring, and this is the final initial point to be marked for a fall due on the base-ring. Where the thread crosses the reënforce-sight-mass, hold the reënforce-sight itself directly under the thread. When the reënforce-sight-mass was lined out, at the same time with the breech-sight-mass, a regulation distance was given from base-ring to centre of reënforce-sight-mass, and from this central point the mass was marked out and cut.

1608. *To Fit Sight on Reënforce-Sight Mass.*—Holding the sight directly under the thread, mark out the places of the screw-holes on mass. These screw-holes are then drilled and tapped. The reënforce-sight being screwed on to the mass, cut off a certain portion of the steel bar in the sight, determined as follows: Let the rear-sight bar drop to a level. Then lay the levelling-bar on gun as in determining the angle of rear-sight bar. A distance is given on the levelling-bar from rear-sight bar to forward part of the steel-bar of the reënforce-sight, and this distance being measured, cut off all the steel bar of reënforce-sight which is over.

1609. After the reënforce-sight is finally fitted as above described, again stretch the sighting-tompion-thread over all parts, and the thread must coincide as follows: it must pass directly over the steel bar of the reënforce-sight; then directly over the initial point on base-ring, and then directly through the exact middle of the notch of the rear-sight-bar. This must be particularly observed when inspecting the gun for final stamping of Inspector's initials.

1610. Next to determine the amount of *shoulder* that the rear-sight-bar is to have. The projection on head of sight-bar that takes on rear-sight-box is called the *shoulder* of sight-bar. This is done by again putting the levelling-bar on reënforce-sight, and bringing it to a level by the spirit-level. The shoulder is then trimmed down until daylight can be just seen through the notch when the rear-sight-bar rests on sight-box. Do not cut the shoulder down so low that the extreme tip of the reënforce-sight can be seen, as that will bring the rear-sight-bar too low. The bar is then graduated by the scale furnished. On no account must the bar be cut as to the shoulder, after being stamped.

1611. *To mark the line of sight on swell of muzzle.*—Again stretch the thread from arm of sighting-tompion to middle of notch of rear-sight, at the same time raising the rear-sight to its greatest elevation, and lowering the thread on vertical arm of tompion. This of course brings the thread down to touch the swell of the muzzle, and it is there marked with a long cut of a cold-chisel. This line-of-sight mark on muzzle is to determine the position of the reënforce-sight in case the latter should be knocked away. With the initial point on base-ring and mark on swell of muzzle, there are two points available for determining the straight line.

1612. In case a gun should be received rough-turned at its cylindrical part from foundry, and it should become necessary to sight the gun, the breech and reënforce sight-masses will be brought down to a horizontal plane parallel to the axis of the bore as follows: the straight-edge will be laid on the upper side of cylindrical portion of breech, and brought to a level with the spirit-level. The mass can then be trimmed down to this plane.

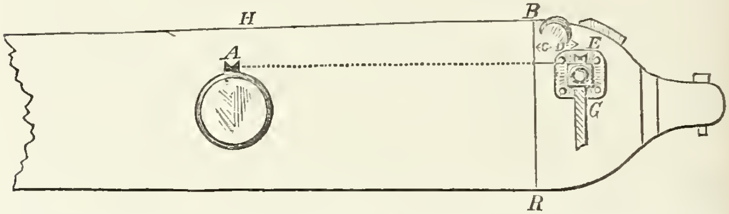
1613. *Instruments used in sighting a gun:*

Trunnion-square.	Levelling-bar.
Sighting-tompion with arm.	Steel T-square for levelling at muzzle.
Common spirit-level.	

Steel straight-edge.
Scribers.
Drills.
Steel wedges for slot of lock-mass.
Beam compasses (with XV-inch gun.)
Tamplets.
Dividers.
Gauges.

1614. Fitting Side-sights.—This is considered the most difficult kind of the ordinary sighting of guns, and requires an experienced mechanic. First level the gun as to axis of bore and trunnions in the same way as already described. Then determine the initial point on base-ring in the same manner as above. This point was probably determined when the gun was central-sighted, but it is always preferable to commence anew. especially when the central-sighting was done by some other mechanic. To fix the position of the rear-sight-box on the side of the gun, proceed as follows:

1615. First to determine the distance that the sight, EG (Fig. 344), ought to be in rear of base-ring, BR: A standard



B R.—Base-ring. A.—Sight on Rim-base. E G.—Breech-sight and Box.

Fig. 344.

distance is given for this, measuring from base-ring. Now to determine the distance below BH that the rear sight ought to be. Take a small, hard piece of wood of a thickness equal to the rim-base-sight when the latter is finally screwed into rim-base. Lay this piece of wood on rim-base. Next take a steel straight-edge and lay it with its edge one end on the block of wood and the other end on the sight fitted to the box, with the shoulder of sight resting on top of box. The end of the straight-edge that rests on the notch of rear-sight is so cut away that its edge fits in the notch neatly. The straight-edge is now levelled by moving the rear-sight-box up or down. When levelled take off straight-edge and hold rear-sight-box firmly in its place on side of gun. Take out the rear-sight from its box and place therein, in its stead, a steel T-square, the longitudinal branch of which is round.

1616. The T-square being in the rear-sight-box, place the level on top of T-square, and bring the box itself to a level. This of course will require the slightest possible movement of the box, as when the straight-edge was on, the sight-box was approximately adjusted. The rear-sight-box being levelled, withdraw the T-square and hold the box firmly. Then mark out its place on the gun, and also the places of its holes for securing to gun. Bore out the screw-holes with drill and tap them. Fit box to side of gun with screws, remembering to place *rubber washers* on screws between the gun and rear-sight-box. As soon as the box is fitted to gun with screws, replace its sight-bar, and again go through the operation of testing the position of the box as to height, by placing the straight-edge on block of wood and notch of sight as before. Some of the screws may be set too tight, and others too slack, which can be remedied before proceeding.

1617. To find the distance of the rear-sight from the axis of the bore, place the steel T-square in the rear-sight-box as before, raising it until it touches a straight-edge resting on top of rear-sight-mass, and crossing the gun. Now measure with accuracy on this straight-edge the distance from the initial point established on base-ring to a point on top of T-square at the exact intersection of its longitudinal and transverse branches, which will be the distance required.

1618. To fit the rim-base-sight: Having obtained this distance, lay it off on the horizontal arm of a sighting-tompion.

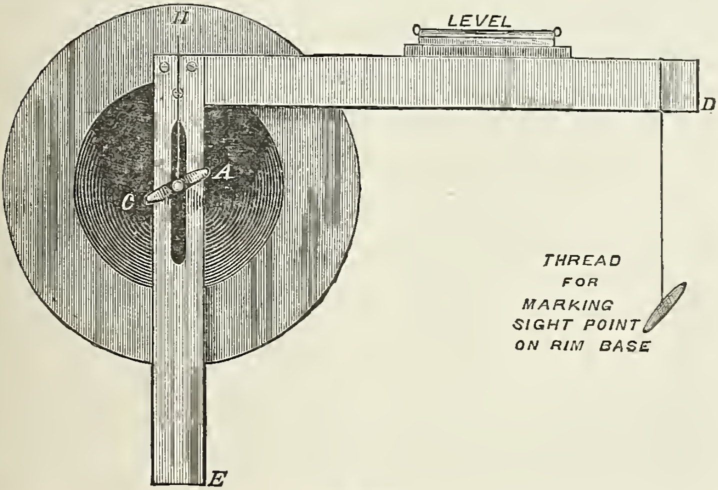


FIG. 345.

This tompion and arm are to be placed in the muzzle as represented in Fig. 345. At the point H have a centre-line marked on sighting-arm, and when the arm is levelled it will be in the same vertical plane as the initial point already established on base-ring. Now take the distance already found from initial point on base-ring to point on T-square when in rear-sight-box, and lay it off on horizontal arm of tompion, thus establishing a plane parallel to axis of bore. Take the thread on the horizontal arm at this point, and stretch it so that it falls on the exact centre of the notch of rear sight-bar, and mark the point where it touches the rim-base.

1619. The distance that the sights should be apart is furnished by authority. With a straight-edge mark off this distance, and drill a hole for rim-base-sight. Then counter-bore rim-base-sight. As soon as it is screwed in, lay one end of the straight-edge on it, and its other end on notch of breech-sight. Place level on straight-edge. Now the level will generally be found to be slightly out, and it can be brought to a level by either screwing the rim-base-sight up or down as occasion requires, or by cutting down the notch-of-breech sight if it should want to be lowered at that end.

1620. For side-sights, the breech-sight-bar is generally supplied with the proper firing distances marked on it. Whenever a sight-bar is received already marked with ranges, the level should never be remedied by cutting away the *shoulder* of bar, as the edge of shoulder is the initial point from which the bar is marked. If, however, the sight-bar is marked after it is fitted to the gun, the shoulder can be thinned down. The *levelling-bar* is not used in side-sighting a gun.

The straight-edge is now applied as before, resting on rim-base-sight and notch of rear-sight-bar, and verified as to the level of that plane. If the spirit-level remains at level, the gun is properly sighted as to the level of sights.

1621. Fitting Trunnion-sights to Mortars, Guns, etc.—The gun is first levelled as to axis of bore and axis of trunnions. Get with dividers the exact centre of exterior side of trunnion that the sight is to be fitted to. Drill and tap hole in trunnion large enough to receive the screw of "stud" which clamps the sight to trunnion. As soon as this hole is drilled, screw the "trunnion-plate" to trunnion. Where the trunnion is not of sufficient length to admit of a trunnion-sight without extension of the trunnion, a "trunnion-box" is fitted, which prolongs the trunnion and admits of the sight being fitted to it. The "trunnion-plate" being screwed on, screw in the "stud" with the "heaver." Fit the trunnion-sight on this stud by means of the hole through sight at the centre. Place washer on stud and set up the whole with "wing-nut." Some of these trunnion-sights are fitted with levels in them, and others have to be used

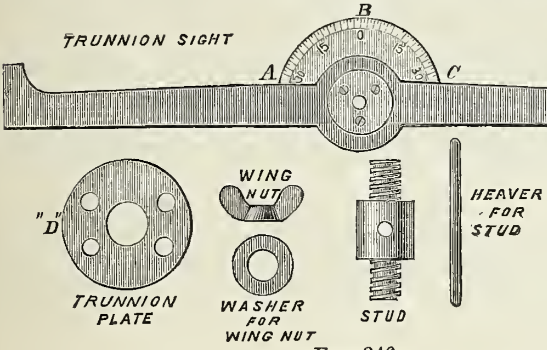


FIG. 346.

in connection with an outside level. In either case bring the trunnion-sight to a level, and then mark on the trunnion-plate where the point zero degrees of trunnion-sight comes. Have this point for a permanent mark on trunnion. (Art. 1678.)

1622. MARKING TANGENT-SIGHTS.—The uppermost line on the stem marked level is the zero of the other graduations; and when adjusted to the level of the top of the sight-box, the bottom of the notch in the head of the breech-sight and the apex of the reënforce-sight show the dispart of the gun. When the line of sight coincides with these points it is parallel to the bore; and when continued to a distant horizon, the gun is laid level or horizontal.

Sights should invariably be made so that the level line on the stem will correspond with the bottom of the head when it rests on the sight-box, and thus secure a dispart-sight in case of accident to the screw in sight-box.

1623. The ranges are marked in even hundreds of yards, beginning with 100 yards, and marking downwards to the greatest range. The longer lines, representing the odd hundreds, have the number marked upon them; the shorter lines not marked, the even hundreds. The proper time of fuze is also marked for the corresponding distance.

These sights being each adjusted to a particular gun, and marked with its class and number, do not, in strictness, admit of being transferred to other guns, even of the same class. The graduation differs for each class of guns and for the same guns for different charges.

1624. When used, the stem of the breech-sight must be raised or lowered, to correspond with the ascertained or estimated distance, in yards, of the object aimed at, and firmly secured there by the thumb-screw. Then, if the ship be steady, elevate or depress the gun until the line of sight from the bottom of the notch of the breech-sight, the top of the reënforce-sight, and the point to be struck will coincide; but if the ship have a rolling motion the gun must be so laid after the sight is set for the distance, that this coincidence may be obtained, if possible, at the most favorable part of every roll which the ship makes.

1625. Graduation for Degrees.—To determine the graduation of the breech-sight for degrees involves the solution of a triangle of which one side and the three angles are known. Thus in the figure (347), A is the position of the front-sight, A

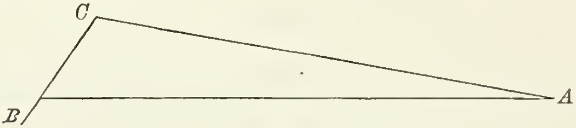


Fig. 347.

B is the distance from the front-sight to the rear face of the breech-sight-bar; this line being parallel to the axis of the bore, the angle B is 60°; the problem is to determine the length of the side BC for all the values given to the angle A.

We have

$$\sin C : \sin A :: AB : BC,$$

$$BC = \frac{AB \sin A}{\sin C} = AB. \sin A \cos C.$$

It will be sufficiently accurate, after having determined the value of BC for one degree, to multiply it by two, three, four, etc., in order to determine BC for these different values of A.

It is evident that, for the same value of A, the length of the side BC will increase with the length of the side AB: hence, when it may be necessary to shift the front-sight from the reënforce to the muzzle, the breech-sight must be replaced by another graduated in proportion to the increased length of the side AB. (Art. 1592.)

All guns fitted with a dispart-sight on the top of the piece near the trunnions have what is called a *clearance-angle.*

This may be defined as the angle of elevation obtained when the top of the tangent-scale and dispart-sight and the notch on the muzzle are in line.

If the scale is raised above this angle, the dispart-sight falls below the line, joining the head of the scale and the muzzle.

The muzzle-notch must then be taken as the second point of sight.

1626. Tables of Fire.—A properly constructed table of fire for a particular piece contains the range and time of flight for each elevation, charge of powder, and kind of projectile. Its object is to serve as a guide in pointing, without waste of time and ammunition, and also when the effect of the projectile cannot be seen. It aids in securing good practice.

The Ordnance Instructions contain approximate range-tables for the service cannon.

It is with great difficulty that tables are constructed from the results of the most careful experiments, owing to the very different ranges and deflections obtained in firing projectiles even from the same gun with similar charges and elevations.

It must be remembered that any practice table will only serve as a general guide, and that small alterations in elevation or deflection are required according to the force and direction of the wind, the position of the piece with respect to the object, the quality of the powder, and several other circumstances.

1627. In the instruction of men at gun practice, the inutility of constantly altering the elevation to correct small errors in range should be pointed out, and the necessity of observing the results of several rounds without making any change, so as to allow for the necessary probable errors, should be strongly inculcated, as, under the most favorable circumstances, with smooth-bore ordnance the variation of range is found to equal fifty yards more or less.

Errors can be diminished by allowing the Gun Captain to estimate the distance to windward or leeward, right or left, to be allowed for the deflection, by indicating the number of yards right or left of the object; which, after all, depends on his estimation of distance, or, by furnishing a sight which in addition to the elevation allows for the deviation, and permits the Gun Captain in all cases to aim directly at the target.

Such a sight is furnished to the Parrott rifle, and is desirable for all guns. (Art. 1593.)

1628. DETERMINING DISTANCES.—In all circumstances where ordnance is employed, whether in the field or on the water, a knowledge of the distance is the essential element of correct practice.

When considerable, it is usually estimated very vaguely; but the necessity of knowing it as correctly as possible at long ranges is greater than when the trajectory is nearly flat, as in short ranges; elevation being given according to the distance, and inaccuracy increasing with length of range.

At considerable distances, also, there is more leisure and opportunity, as well as greater necessity for determining those distances with precision, while in closer action all that is required is to be certain that the enemy is within range at level.

Within that range, if the hull of an enemy's ship is obscured by smoke or darkness, the aim may be directed by the flash of his guns.

1629. Various modes have been practised to ascertain at sea the distance from the object aimed at, so as to regulate the elevation of guns, but none can be depended upon for giving it with minute accuracy, and even when obtained, it is continually varying; therefore, when the projectile is seen to exceed or fall short of the object considerably, the sight-bar must be readjusted accordingly. It thus becomes, under ordinary circumstances, a good instrument for approximating distances.

The correction of the fire by previous rounds is a practical means which is much resorted to on all occasions, but it is hardly to be relied on when the observer is near the piece fired.

In departing from the line of fire, however, the means of noticing correctly the errors of range increase. Vessels in line, therefore, can easily amend their elevation of gun and time of fuze by the signals of those most remote from them.

Officers of divisions and Gun Captains should be occasionally practised in measuring the distances of objects by the eye, at times when opportunities offer, of verifying the accuracy of their estimates, by comparing it with the distance obtained by measurement, or by any other method which will afford the best means of comparison.

1630. Angle subtended by the Mast of the Enemy.—Among other methods of estimating distances is that of making use of the different angles subtended at different distances by the heights, when known, of the masts of the ships whose distance is desired. The heights and distances being arranged in a table so that by simply measuring with a sextant the angular height of the mast,—as is commonly done in chasing, to ascertain whether the chase be gaining or losing distance—and entering the column of angles, the corresponding distance may be taken out. In the old editions of the Ordnance Instructions, tables were inserted in which the distances corresponding to different angles subtended by the masts of English and French vessels were given, and the sights might be regulated accordingly, if circumstances should require it.

1631. Horizontal Angles taken at Bow and Stern.—Another method which has been recommended consists in taking simultaneously at the bow and stern of the ship the horizontal angles between the lines joining the stations of the observers and lines drawn from those stations to the object. This method requires a favorable position of the object.

1632. Using Ship's own Mast as the Given Height.—The distance may be determined by making use of the ship's own mast as a given height, causing an observer aloft to measure the angle formed by the mast *when vertical* and the line of sight from the observer to the object, and then computing the required horizontal distances.

Another application in an oblique plane of the horizontal method is to let two observers, each visible from the other, take their stations at the ends of a rope whose length is accurately measured, and simultaneously measure the angle between the other observer and the object; the three angles and one side of a triangle are thus obtained, and the side wanted can be readily calculated. Take, for instance, one observer at the main topmast cross-trees and the other in the main-chains, the main topmast back-stay will answer for a base.

1633. Buckner's Method.—To determine the distance of an object at sea by observing its angular distance from (within) the offing.

This is done as follows:

In the figure (348) let OB represent the sea-level; A, the

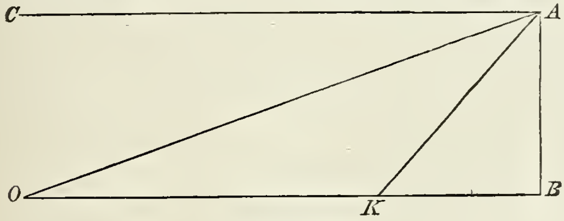


Fig. 348.

position of the observer at the height, AB, above it; AC, a horizontal line and parallel to it; O, the offing, or edge of the visible horizon; K, the object whose distance is required:

We have CAO = dip. Bowditch Table XIII.

OAK = angular distance of K within the offing.

Hence we have

$$\text{KAB} = \text{CAB} - (\text{CAO} + \text{OAK}),$$
$$\text{KAB} = 90^\circ - (\text{CAO} + \text{OAK}),$$
$$\text{AB} = \text{height of observer.}$$

Hence, in the right-triangle KAB, we know the angle A and the side AB.

We may find KB from the formula

$$\tan A = \frac{KB}{AB},$$
$$KB = AB \tan A.$$

No correct use can be made of this method when the proximity of land interferes with the distance of the horizon.

The corrections for curvature of the earth and terrestrial refractions, being slight, are neglected.

In the Ordnance Instructions there is a table for finding the distance of an object at sea computed by this formula, KB being taken for every 100 yards and the angle A calculated for the height of 20, 30, 40, etc., feet.

To use the table let an observer from the cross-trees or any other station measure the angle between the distant horizon and the object, and look into the table with that angle; opposite to it, in the column marked "Distances" will be found the distance of the object in yards.

1634. BY THE VELOCITY OF SOUND.—To estimate the distance by the bursting of shell, when the flash can be seen, multiply the number of seconds which elapse between it and the sound of the report by 1100, and the product will be nearly the distance in feet. (Art. 1696.)

1635. BY THE THREE-POINT PROBLEM.—It is sometimes convenient, when at anchor, and the object is fixed, to measure with a sextant the horizontal angles between any three points conveniently located, and whose positions are accurately laid down on the chart, then plotting the angles or working them out; or a base-line can be taken between the vessels at anchor, or measured on shore, then, by angling on the object to be aimed at, the distance can be calculated.

1636. THE MILITARY TELEMETER, represented by Fig. 348½, is the invention of Major P. Le Boulengé, of the Belgian Army. The want of some method of measuring the distance has not been satisfactorily supplied, for the reason that the *telemeters* hitherto proposed all depend upon more or less simplified processes of triangulation; and none of these instruments have been generally adopted.

This instrument measures the distance by observing the interval which elapses between the smoke or flash and the report of fire.

It is a glass tube graduated along its length into divisions which represent distances. This tube, closed at both ends, is filled with liquid, through which moves a metal index formed of two disks united by a central stem. The diameter of these disks is somewhat smaller than that of the tube, so that, when the latter is vertical, the index slowly descends with a uniform movement. The glass is protected by a brass casing having an aperture which discloses the scale and index.

FIG. 348½.

To use the telemeter, hold it horizontally in the hand, the index at the origin of the scale, and attentively regard the enemy's position. At the instant the smoke or flash is perceived quickly turn the wrist so as to bring the instrument into the vertical, when the index descends; upon hearing the report return it to the horizontal by the inverse movement of the wrist, and the index stops. The number on the scale corresponding to the lower disk, which serves as marker, is the distance sought.

This very simple chronometric device is characterized by a uniform movement and works with extreme precision. Hence, knowing the velocity of sound and that of the index, it is easy to graduate the scale into divisions which exactly represent distances.

An important attribute, which has been successfully given the instrument, is its power of self-adjustment for temperature. To effect this the volume and density of the index and the density and dilatability of the liquid are so combined that the velocity of the index is influenced by temperature in the same proportion as is the velocity of sound; consequently the readings are always correct.

A velocity 1-25000 that of sound has been adopted for the index, so that a millimetre on the scale represents twenty-five metres of distance. Each degree of the scale represents twenty-five metres, and with the eye the fifth of a division can be estimated.

When proved by vibrations of a pendulum or the beats of a watch, this telemeter is absolutely true, while the exactness of its indications in measuring distances depends upon the aptness of the observer.

From the results obtained, the following conclusions may be drawn: the accidental error committed by the ordinary observer does not generally exceed fifty metres; with practice this is diminished to twenty or twenty-five metres. Every one has his own personal equation, and this should be known to derive all possible advantage from the instrument; though it varies little among observers, and on the average lessens the distance fifty metres, the report being noted more quickly than the flash or smoke. This mean equation is corrected on the instrument itself by making the origin of the scale correspond not to zero but to fifty metres. It is an advantage always to use the same telemeter in order to unite in the personal equation the slight error which may exist in the graduation. An observer is liable to commit very great errors in his first attempts, because, unaccustomed to the duty, he is surprised by the flash or smoke and does not promptly note it. The error is independent of the distance, hence the personal equation decreases slightly with the distance. The fire of small-arms may be observed as exactly as that of artillery up to two thousand metres in favorable weather. The wind appears to have very little influence upon the observation; this, however, has not yet been fully proved.

1637. Plane-tables may be used on shore to determine

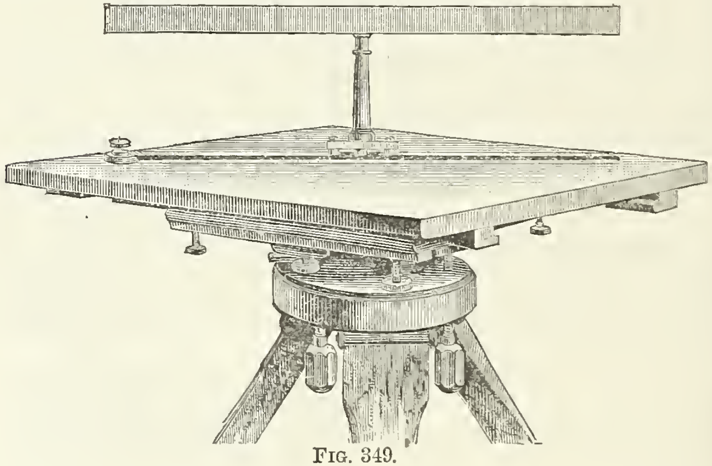


Fig. 349.

distances and to note the fall of projectiles in target practice or firing for ranges. An ordinary plane-table (Fig. 349) is a tripod surmounted by a drawing-board covered with paper. To be used in connection with it is an alidade for observing and marking the ranges.

This is a flat metallic ruler, resting and moving on the surface of the paper and carrying upon it a light upright column, at the head of which is another ruler having a vertical movement only; its extreme points are fitted with raised sights (a notch and a point) which collimate with the bevelled edge of the lower ruler. At one end of the lower ruler is an extension of the metal perforated to receive the head of a pin the centre of which is to concide with the bevelled edge of this horizontal ruler.

Near one of the corners of the plane-table, a small brass plate is counter-sunk in the wood and tapped, so as to receive a pin about half an inch long and screw-cut, having a milled-head above which is a continuation of the pin two-tenths of an inch in length, turned perfectly smooth so as to permit the rule to pivot about it as a centre.

1638. If the target is on the water, a point along the shore, the distance of which from the battery has been ascertained, is selected so that a line drawn from it towards the place where the first grazes are expected to occur will be at right angles to the line of fire, or nearly so: here, one of the plane-tables is placed. The other is situated as nearly in line with the target and battery as convenient; sufficiently removed, however, not to be inconvenienced by the smoke. The two stations should be so situated that lines drawn from them to the target will be nearly at right-angles to each other.

Their distances from each other and from the battery are known.

The table is adjusted with the small metal plate over the stake that marks the station, and levelled.

The observer places his alidade on the pivot-pin, sights carefully on a given point at the battery, and marks on the paper affixed to the table the direction assigned by the bevelled edge of the ruler. The direction of the other station is noted in the same way, as is also the target and any stakes which may be placed in the line of fire.

When the cannon is ready to fire, a preparatory signal is hoisted at the battery; seeing this, the observer points the alidade in the expected direction of the first graze.

The signal is lowered and the gun fired. The instant the jet takes place, the sights of the alidade are aligned upon it, and the direction indicated by the bevelled edge of the ruler marked upon the paper.

The line connecting the two stations is a base from which is determined the position of the point struck and of the battery. The projection of this base on any scale will enable one to ascertain in terms of that scale the distances desired.

After the firing, the tables are returned, the observations made on one table transferred to the other, and the intersections of the lines locate the positions of the points struck.

1639. Dangerous Space.—If the object fired at be wide but of small depth, the deflections, unless very great, will be of small importance so long as the ranges are regular: should the object be deep and only present a narrow front, uniformity in range will be of little importance when the deflections vary considerably.

The range varies with the angle of fire and the initial velocity, and depends at the same time upon the diameter and density of the projectile. The greater the velocity, the flatter the trajectory, and consequently the greater the chance of the object intercepting the projectile, and, also, the longer the extent of ground covered by the projectile, or the *dangerous space*, making the practice more accurate.

1640. ACCURACY OF FIRE.—*Firing for accuracy*, whether with artillery or small-arms, may involve two entirely separate and distinct things:

1st. The determination of the personal skill of the individual using the weapon.

2d. The determination of the qualities as regards accuracy of the weapon itself.

The most common way of determining the relative accuracy of guns is to ascertain their *mean differences of range* and *mean reduced deflection* for a given *mean range*, and compare them—that gun being the most accurate for which these quantities are smallest.

1641. *Mean Range.*—The mean range is found by adding all the ranges together, and dividing the sum by the number of shots fired.

1642. *Mean Difference of Range*, or the *mean error in range*, may be found by taking the difference between each range and the mean range: add the differences together, divide by the number of shots fired, and the quotient will be the *mean difference of range.*

1643. *Mean Deflection.*—Add together separately all the *right* deflections and all the *left* deflections; subtract the smaller sum from the larger, and divide the difference by the number of shots fired; the result will be the *mean deflection.*

1644. *Mean reduced Deflection*, or the *mean error in di-*

rection, is found by taking the distance of each deflection from a line passing through the *mean deflection*; add these distances, termed *reduced deflections*, together, and divide by the number of shot fired, for the *mean reduced deflection*.

1645. *Example.*—Five shot fired under similar circumstances give the following ranges and deflections:

RANGES. Yards.	DEFLECTIONS. Yards.
1010	4—Right.
1060	1— "
1040	2—Left.
1020	5— "
1030	3—Right.

$$\frac{\text{Sum of ranges}}{\text{Number of shot fired}} = \frac{5160}{5} = 1032 \text{ yards, } \textit{mean-range.}$$

The differences between each range and the mean range are 22, 28, 8, 12, and 2 = 72 yards.

$\frac{72}{5}$ = 14.4 yds., *mean difference of range.*

Sum of right deflections = 8 yards.
Sum of left deflections = 7 "
Difference = 1 "

$\frac{1}{5}$ = 0.2 yards, right *mean deflection.*

Deflections from line through *mean deflection*: 3.8, 8, 2.2, 5.2, and 2.8 = 14.8.

$\frac{14.8}{5}$ = 2.96 yds., *mean reduced deflection.*

1646. An exact definition of the accuracy of a gun is a matter of no little difficulty. Of two guns fired from the same place, the same number of rounds, at the same target, with their axis in the same direction, that would evidently be the more accurate which planted its shot more nearly together. But it is not always possible to test the practice of guns under precisely similar circumstances; therefore we must seek a definition equally true, but admitting, in addition, more elasticity in its application.

Upon reflection, it becomes evident that an absolutely accurate gun is one with which, fired under identical circumstances, the chance or probability of striking the same spot twice amounts to certainty. Adopting the mathematical notion of probability, this will be represented by *unity*—guns less accurate having probabilities represented by fractions. Such a mode, though suggested, has not been accompanied by the requisite tables to render it of general use.

1647. It is easier to determine, from the practice of the gun itself a rectangle with which there would be an equal chance of any shot from the gun striking or not striking; or, if a given number of shots were fired, half the number might be expected to fall within the area.

The accuracies of two guns would be inversely as these rectangles for the same range. This method was proposed by Captain Noble, R. A., who furnished the following formula for application. If a be the length, and b the width of the area or rectangle required, then

$$a = 3.12 \times .8453, \frac{\text{sum of differences of ranges.}}{\text{one less than number of ranges}}$$

$$b = 3.12 \times .8453, \frac{\text{sum of reduced deflections.}}{\text{one less than number of deflections}}$$

1648. Accuracy of Small-arms.—The relative precision of small-arms is decided by various methods.

Centre of Impact.—The point of impact of a ball is the point where it strikes the target, and the mean of all the hits is called the *mean point of impact*, or *the centre of impact.*

To determine this point, let the piece be pointed at the centre of a target stationed at the required distance, and fired a certain number of times, and let the positions of the shot-holes, measured in vertical and horizontal directions from the lower left-hand corner of the target, be arranged as in the following table :

No. of shot.	Distances from lower left-hand corner in feet.	
	Above.	Right.
1	9	10
2	0	4
3	5	8
	3) 14 4.67	3) 22 7.33

The sum of all the vertical distances divided by the number of shots gives the *height* of the centre of impact above the origin.

Similarly the sum of all the horizontal distances divided by the number of shots gives the *horizontal distance* from the origin to the centre of impact.

Thus from the above table the co-ordinates of the centre of impact are 4.67 and 7.33. The co-ordinates of the centre of the target being 6 each, the centre of impact is 1.33 below and 1.33 to the right of the centre of the target.

1649. ABSOLUTE MEAN DEVIATION.—The co-ordinates of the centre of impact being known, the point itself is known, and its distance from the centre of the target is called the *absolute mean deviation.* This is equal to the square-root of the sum of the squares of its vertical and horizontal distances from the centre of the target.

1650. MEAN DEVIATION.—To obtain the mean deviation it is necessary to refer each shot-hole to the centre of impact as a new origin of co-ordinates, and this is done by taking the differences between each tabular distance and the distance of the centre of impact and adding them. The sum of all the distances thus obtained in one direction divided by the number of shots gives the *mean deviation* or *figure of merit.*

A shorter rule may be found: for if there are m distances greater, and n distances less than the distance from the origin to the centre of impact, $\bar{x}$, calling a the sum of the greater and b the sum of the less, we may write

$$\frac{a - m\bar{x} + n\bar{x} - b}{m + n} = \frac{a - b + (n - m)\bar{x}}{m + n} = \textit{figure of merit.}$$

In using this formula, due care must be paid to the sign of $(n - m)$.

This method might be applied to the fire of cannon by reducing the grazes to an imaginary vertical target, the angles of descent being assumed equal for all shot fired at the same elevation.

Applying this formula to the table given above, we get 3.11 feet vertically, 2.22 feet horizontally for the *mean deviation* or *figure of merit.*

1651. MEAN HORIZONTAL AND MEAN VERTICAL ERROR.—The mean horizontal error is found by adding the horizontal distances by which the balls have missed the centre of the target, and dividing this sum by the number of balls; this quotient indicates how much the average of the balls have missed horizontally the point aimed at.

It may be directly and readily found by using the formula of the preceding article, substituting for $\bar{x}$ the horizontal distance of the *centre of the target* from the origin.

Similarly the *mean vertical error* may be found, by using the same formula, with the substitution for $\bar{x}$ of the height of the centre of the target above the origin. The result shows evidently by how much the average of the shots have missed vertically.

1652. The Absolute Mean Error.—To get this, there are two methods. The first is short and simple, and consists in calculating the hypothenuse of a right triangle, in which the other two sides are the mean horizontal and mean vertical errors.

The second, which should be called the calculation of the *mean* of the *absolute errors*, consists in measuring for each ball its *absolute error*, a distance from the point aimed at, and to take the mean of these absolute errors by dividing their sum by the number of balls fired.

This method is very long, since to have the *absolute error* of each ball it is necessary to square two numbers and then extract the square-root of these sums as the distance of the points struck have been measured upon the vertical and horizontal lines passing through the point aimed at.

The results are not exactly the same: the mean of the absolute errors will be greater than the absolute mean error.

1653. Radius of a Circle Containing a Fraction of the Balls.—The radius of a circle containing a fraction of the balls, the third, half, or two-thirds is a common test of accuracy. Its centre is the point aimed at; its radius is the absolute error of the *third*, *half*, or *two-thirds* of the other absolute errors arranged in order of size. Thus: 3, 4, 6, 7, 9, 15, 18, 21, 25, being the order in size of the absolute errors of *nine balls*, 6 will then be the radius of the circle containing the *third* of the best shots, 9 that containing the best *half*, and 18 that containing the best *two-thirds*. If the number of balls fired be even, the circumference of the circle should pass equally distant from the two balls which limit it.

For example, if we have twelve balls, and wish the circle containing the *best third*, the circumference should pass between the fourth and fifth balls at equal distances, the fourth within and the fifth without. If the number of balls be uneven, 9 for example, and we want the circle containing the *best half* of them, we pass it through the centre of the fifth ball.

1654. The Per cent.—This test of accuracy indicates how many of *one hundred balls* fired have hit the target. To get the per cent., count the number of balls, A, that have hit the target, of the number, B, that have been fired, and from the proportion B : a : : 100 : x., we have the per cent., $x = \frac{100 \times a}{B}$.

1655. COMPARISON OF THE DIFFERENT METHODS.—The determination of the *mean point of impact* can only be used in comparing the accuracy of two pieces that are of the same model and fired under precisely the same conditions; thus in general the *mean point of impact* gives only an imperfect idea of the accuracy of a piece. The *mean horizontal error* indicates only that the greatest number of balls have gone too far to the right or left. Moreover, it may occur that two pieces have the same horizontal error, while the mean vertical error will be very different.

The radius of a circle containing a fraction of the balls cannot give a perfect idea of the accuracy of a piece unless the balls are placed progressively distant, which cannot reasonably be expected.

The Per Cent.—If a piece be fired that has many causes of error, and we wish to test the skill of the marksman or the accuracy of the arm, only to the extent of ascertaining how many balls can be placed in the target, this method is simple and sufficiently exact. The *surface* covered by the balls should, however, be taken into account, for it may occur that with one arm the balls are scattered over the entire target, while with the other they are grouped in a small space; this latter piece would be the more accurate.

It would appear, then, that the *method of the absolute mean error* should be preferred: for it represents a quantity the ratio of which to the accuracy of the piece the mind can readily perceive; and this quantity depending upon the position of each one of the balls varies when one of them varies, and thus gives a clear idea of the accuracy of the piece.

1656. THE INCLINATION OF THE TARGET.—The most common modes of recording target-practice are: *vertically*, as for small-arms, and *horizontally* as for great guns.

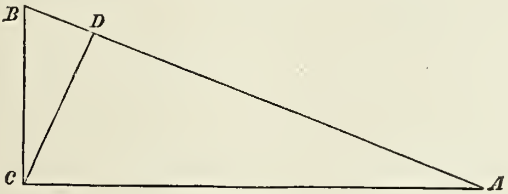


FIG. 350.

Slight vertical errors on a vertical target are magnified into large errors in range, while the deviations are unchanged. Doubtless the fairest position of the target is that which would receive the projectile at right angles to its own surface; for with this a *normal* target, there will be no distortion of errors either in favor of or against the gun.

There is no real objection to any of these positions of the target, as points on one can be transferred to each of the other two with facility, using the angles of fall from *Buckner's Tables*, and assuming that the path of the projectile from the vertical target to the ground is a straight line.

From an inspection of Fig. 354, it is seen that error on vertical target (B*c*) = error on horizontal target (A*c*) × tan A . . . (1)

Error on normal target (*c*D) = error on horizontal target (A*c*) × sin A . . . . (2).

If A, the angle of fall, be very small, there will be no appreciable difference between its *sine* and *tangent*, and the vertical and normal targets will virtually coincide. If A be large, however, all determinations of the accuracy of the guns should strictly be made upon the normal target.

1657. RECORD OF TARGET-PRACTICE AT SEA.—The record of a target-practice with great-guns should give for each shot the calibre and class of the gun, the weight of the charge, the nature of the projectile; if a shell, whether it burst before or after striking the water, or not at all, the observed distance of the target, the observed error in range, observed or estimated deviation, and the distance for which the sight was set. In the record should also appear the character of the wind and the sea, the motion of the ship, and the circumstances, so far as can be ascertained, attending any special occurrence.

1658. The following method of keeping the record is based upon suggestions by Capt. Jeffers, U. S. N.:

An officer and a recorder are stationed at the topmast cross-trees. The former takes *frequently* the angles between the sea horizon and the target, and gives them to the Navigator, who looks out the corresponding distances and reports them to the executive officer. The officer aloft also takes the angles between the horizon and each point of impact.

The recorder enters on a ruled form all the angles in succession, denoting target angles by a check. He also has a paper divided into quarters by two lines at right angles to each other through the centre of the page. Whenever a shot is fired, he notes in the appropriate quadrant the number of the shot; his own estimation of the distance short, over, right, or left; and the bursting of the shell as either before or after impact.

Thus the diagram (Fig. 351) indicates that the fifth shell in the order of firing burst before impact, and the pieces struck ten yards short and fifteen to the left; also that the seventh struck thirty yards over and five to the right, bursting after impact. Ricochet hits are marked by an R.

An observer furnished with a similarly ruled paper, and stationed forward or aft, depending upon the wind, keeps an independent record of his estimation of the fall of the projectile and the explosion of the shell as a check upon the first recorder.

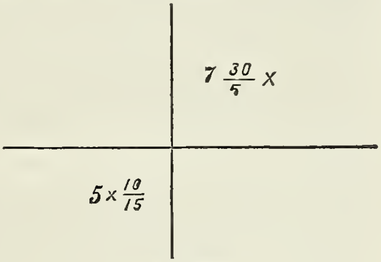


FIG. 351.

A competent person on the gun-deck records the number of the guns in their order of firing, and the distances for which the sights were set.

The clerk notes the time when firing began, and the distance of the target, the time (by the order of firing) when changes of fuze or elevation are ordered and the observations of the Captain.

1659. From these data a plan on the scale of one inch to sixteen yards should be made giving the positions of the several shot on the plane of the horizon. All shot not falling within 100 yards of the target should be rejected and reported in the aggregate as "wild."

Accompanying this should be an elevation on the same scale, of the ship's side, transferred to which are all the shot which would have struck it. This is easily made by means of tabulated angles of fall and eq (1) of the preceding article. (Art. 1656.)

In summing up, a proper proportional value should be allowed for any difference in distance. At 600 yds., the IX-in., XI-in., and 100-pdr. are equal. At 1,300 yds., the proportion of hits for IX-in. should be 3, for 4 of XI-in. or 100-pdr. in the same number of rounds.

With the same guns, the hits at 600 yds. should be twice as many as those at 1200 yds., to maintain equality of firing.

As the ordinary variation in range of a gun is about 50 yds., the sights should be altered only when the distance of the target changes by more than that amount.

It should be remembered that line shots over will appear to fall to the right or left of the target to observers on the right or left of the gun.

1660. QUOINS AND ELEVATING-SCREWS.—Most

Naval guns are now fitted with elevating-screws, passing through a hole in the cascabel or attached to the carriages; but the ordinary beds and quoins are also still in use; they are arranged to allow the extreme elevation and depression of the guns which the ports will admit with safety. When the inner or thick end of the quoin is fair with the end of the bed in place, the gun is level in the carriage, or horizontal, when the ship is upright.

The degrees of elevation above this level, which may be given to the gun by drawing out the quoin when laid on its base, are marked on the side or edge, and those of depression on the flat part of the quoin, so that when the quoin is turned on its side for depression the marks may be seen. The level mark on the quoin is to correspond with the end of the bed. When the quoin is entirely removed, and the breech of the gun rests on the bed, the gun has its greatest safe elevation; and when the quoin is pushed home on its side, the gun has the greatest safe depression that the port will admit.

Care must be taken that the stop on the quoin is always properly lodged, to prevent the quoin from flying out or changing its position, and that the bed is secured to the bed-bolt.

Porter's bed and quoin (Fig. 352) has been adopted for all carriages requiring quoins. This quoin, being graduated to

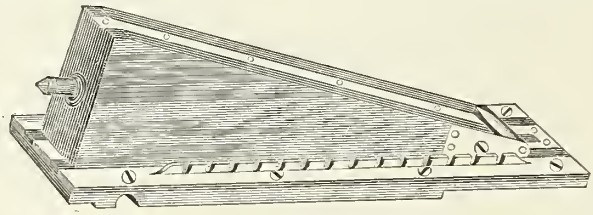


Fig. 352.

whole degrees, requires a small additional quoin for slight difference of elevation in smooth water.

1661. When the elevating-screw is used, a quoin should be at hand to place under the breech of the gun, when at extreme elevation, to relieve the screw from the shock of the discharge, and prevent a change of the elevation, as well as to take the place of the screw if it should be disabled.

1662. When the fire is continuous at the same distance, the lever of the elevating-screw should be secured by a lanyard, to prevent the screw from turning and altering the elevation.

1663. To obtain readily the changes of elevation necessary in the use of rifle-guns, the heavier calibres are made with very small preponderance, and are supplied with an elevating-screw which is attached to the carriage at the lower end, while the nut is connected with the cascabel of the gun.

Both screw and nut admit of movements by which the screw can take any position required in the various degrees of elevation. The parts should be allowed a certain amount of play.

1664. Dahlgren's screw is a single screw working through the cascabel and resting in a saucer in the carriage.

1665. Hart's screw consists of a male and female screw attached to the carriage.

1666. Pointing Guns and Howitzers.—In ordinary firing it is not supposed that the trajectory changes its position with reference to the lines of sight and fire for angles of elevation and depression less than 15°. In aiming at any object, therefore, the *angle of elevation* of which is less than 15°, aim as though it were in the same horizontal plane with the piece.

1667. In pointing guns and howitzers, under ordinary angles of elevation, the piece is first directed towards the object and then elevated to suit the distance. The accuracy of the aim depends, 1st: on the fact that the object is situated in the plane of sight. 2d: that the projectile moves in the plane of fire, and that the planes of sight and fire coincide or are parallel and near to each other. 3d: on the accuracy of the elevation.

The first of these conditions depends on the eye of the gunner and the accuracy and delicacy of the sights; the errors under this head are of but little practical importance.

1668. When the trunnions of the piece are horizontal and the sights are properly placed on the surface of the piece, the planes of sight and fire will coincide; but when the axis of the trunnions is inclined and the line of sight is oblique to the axis of the bore, the planes are neither parallel nor coincident, and the aim will be incorrect.

1669. When the line of sight is parallel to the line of fire—as when the tangent-sight is at level—the planes of sight and fire will be parallel and at a distance from each other equal to the radius of the breech multiplied by the sine of the angle which the trunnions make with the horizon.

To show this, let the circle, A B C D (Fig. 353), represent the section of the breech of the piece taken at right angles to the axis, and C the projection of the natural line of sight; upon this plane let A′ B′ be the inclined position of the trunnions. C′ marks the revolved position of the line of sight, and C′ D′, the trace of the plane of sight which is parallel to C D, the plane of fire. As the lines of sight and fire are parallel in their revolved position, the planes of sight and fire must also be parallel.

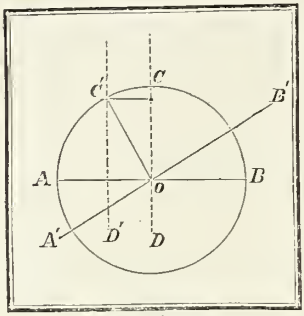


FIG. 353.

The angle C O C′ = B OB′, therefore C C′ = O C′ sin B O B′.

It is easily seen that in this case the error of pointing can never exceed the radius of the breech. By an inspection of the figure, it will also be seen that in the revolved position of the line of sight, the elevation is diminished by a small quantity, which is equal to the versed sine of the arc C C′.

1670. When the tangent-scale is raised and the line of sight is no longer parallel to the line of fire, the planes of sight and fire intersect at a short distance from the muzzle; hence it follows, that as the object is situated in the plane of sight, the projectile will deviate from the object to the side on which the lower trunnion is situated, and at a distance from it which is proportional to the distance of the object from the piece.

This is shown in Fig. 354, where the piece is directed by

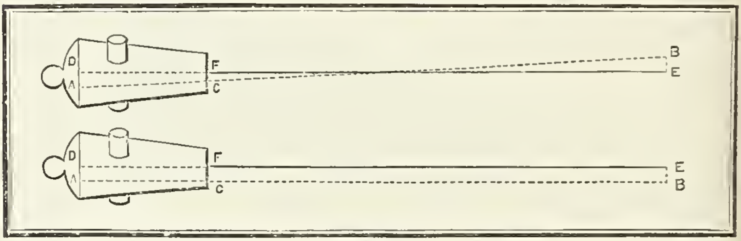


FIG. 354.

the notches at A and C on the object, B. The shot will proceed in the line, D E, to the right of the object, B, and at long range this deflection, B E, would be considerable.

1671. This cause of deviation is very common on ship-board, for the motion of the vessel renders it very uncertain that the axis of the trunnions will be horizontal at the moment that the gun is fired. The guns forward and aft are particularly subjected to the disadvantage arising from this cause, on account of the shear of the ship, and the guns amidships are usually more accurate in practice, because they rest on a more level platform.

1672. In *chase-firing*, this deviation must be taken into consideration. The pursuing and pursued have generally a considerable heel or inclination to leeward; in consequence of this, the trunnions of the guns in the bow and stern parts of each are inclined, and in pointing them it will be necessary to aim at the weathermost part of the hull in order to avoid the effect of this error. The proper elevation due to the distance must be given; as although the tangent-sight is slightly lowered by the heel of the ship, yet it is of no practical importance.

These deviations will, of course, increase with the elevation of the gun and its distance from the target. To give an idea of their extent, suppose the plane to have an inclination of 10°; distance of target, 900 yards; elevation, 6°: the lateral deviation will be six yards, and the projectile will strike too low by about 20 inches; if the inclination is but 5°, the lateral deviation is reduced to 3 yards, and the fall to five inches.

Then to correct for this source of error: point a little above the target and towards the side of the elevated trunnion, and make the corrections proportionally greater as the distance of the target and elevation of the gun are increased.

1673. POINTING SMALL-ARMS AND MORTARS.—In pointing small-arms and mortars the piece is first given the elevation, and then the direction necessary to attain the object.

1674. POINTING SMALL-ARMS.—The rear-sights of small-arms are graduated with elevation-marks for certain distances, generally every hundred yards; in aiming with these, as with all other arms, it is first necessary to know the distance of the object. This being known, and the slider being placed opposite the mark corresponding to this distance, the bottom of the rear-sight-notch and the top of the front-sight are brought into a line joining the object and the eye of the marksman.

The term *coarse-sight* is used when a considerable portion of the front-sight is seen above the bottom of the rear-sight-notch; and the term *fine-sight* when but a small portion is seen.

The graduation marks being determined for a fine-sight, the effect of a coarse-sight is to increase the true range of the projectile.

1675. POINTING MORTARS.—First give the elevation by adjusting the quoin or ratchet until the required number of degrees is obtained; then the direction is given. The circle on which the mortar stands, being fitted with eccentrics is made to revolve so as to point the mortar at the object without the trouble of swinging the vessel or moving the mortar around with handspikes. The elevation is given with *gunner's quadrant*, the *spirit-level-quadrant*, or *the trunnion-sight.*

1676. Gunner's Quadrant.—This is made of brass and consists of a quarter of a circle fixed to a long arm. (Fig. 355.)

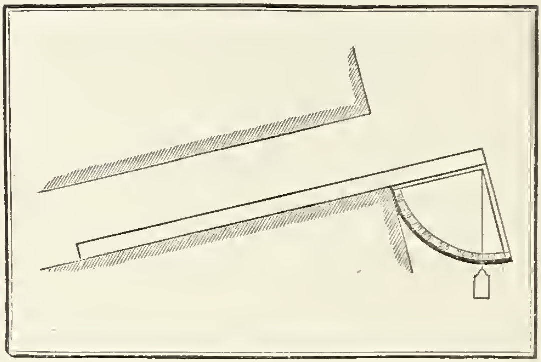


Fig. 355.

The edge of the circle is divided into degrees, and the inclination of the arm to the horizon is determined by a plummet which is fastened at the centre of the curve. This quadrant gives the elevation only to within a degree. To use it place the arm in the muzzle with the quadrant down; raise the muzzle until the plumb-line cuts the required angle on the graduated arc.

1677. Spirit-level Quadrant.—This is similar to the gunner's quadrant, having instead of the plumb-line a movable limb fastened at the centre of the arc, and a spirit-level attached to it. The end of this limb moves along the graduated arc, and has on it a vernier, by means of which parts of a degree can be read off. (Fig. 356.)

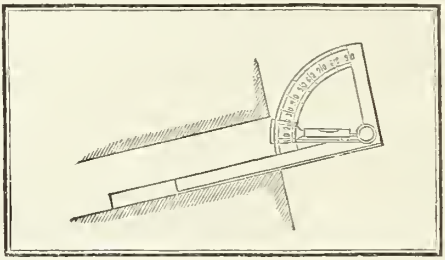


Fig. 356.

This instrument is more especially intended for use with long pieces of large calibre, when firing at great elevations. To use it, insert the long arm into the bore, with the quadrant up; there is a stop on the under side of the arm to prevent its slipping into the chamber; the spirit-level attached to the graduated arc being set to the required angle, and the piece elevated until the spirit-level becomes horizontal, which will appear by the bubble resting in the centre of the glass tube. (Art. 964.)

1678. Trunnion-Sight.—This consists of a bar of mahogany or other hard wood not liable to warp (Fig. 346), of about forty inches in length, two inches wide, and one inch thick, with a brass notch at the rear end and a point at the other, so placed that an imaginary line from the top of the point to the bottom of the notch is parallel to the upper edge. A semicircular plate, graduated to degrees, is attached to the middle of the bar, so that the bar's upper edge corresponds to the 0 of the graduation. A small spirit-level is let into the upper surface of the rear end of the bar, and a stout thumb-screw passes through the bar and the centre of the semi-circular plate.

To use this instrument a screw-hole is tapped in the axis of the left trunnion to receive the thumb-screw; a line is marked on the trunnion perpendicular to the axis of the piece and passing through the axis of the trunnions. The sight is secured by the thumb-screw, with its rear end raised until the mark on the trunnion coincides with the degree of elevation required. The piece is now elevated until the sight is level, which will be indicated by the spirit-level. This instrument is also designed to be used with pivot-guns when the required elevation passes the limits of the other sights.

1679. *To give Lateral Train* in mortar firing the trunnion-sight may be used, or it can be done by a white line drawn on the exterior of the mortar, in the same vertical plane as the axis of the piece when the trunnions are horizontal. The line is sometimes painted on the mortar-bed.

In pointing mortars on shore it is an easy matter to get the direction, because the mortar is stationary; but on ship-board, owing to the motion, it is attended with difficulty, especially when the vessel is rolling, and the line of fire can only be approximate.

1680. On shore, the plan of giving the direction is to determine practically, two fixed points, which shall be in a line with the piece, and the object, and sufficiently near to be readily distinguished by the eye. A plummet is held in the hand immediately behind the mortar and the string made to coincide with these points. The mortar is then trained until the line of the plummet covers the central line on the mortar.

1681. In mortars, if the axis of the trunnions is not horizontal, the vertical plane passing through the line of sight will still be parallel to the vertical plane of fire, and may be taken for it, so that it is not necessary to have the platform of mortars horizontal.

1682. Bearing of the Enemy.—It frequently happens in action that ships become quickly enveloped in a cloud of smoke so dense that when looking through the ports everything beyond the muzzles of the guns will be invisible. But, though objects are thus shut out from the view of the battery, a mast or a spar may generally be seen from the upper deck sufficiently defined to mark the position of a vessel, and enable her bearings to be accurately taken either by compass or by pointers.

The principal care of the Commander must be to keep his guns always bearing on the enemy, and never pass the limits of extreme train for all his guns, unless absolutely necessary in manœuvring.

1683. Director.—This may be regulated by the aid of a *bearing-plate*, or *director*, fitted in a convenient position on the upper deck. It is a species of alidade working on a graduated circle and giving the angular bearing of the object, The arc is marked in degrees and points, and the several bearings of concentration are indicated as well as the limits of extreme train for all the guns.

The sights of the alidade are graduated so as to be set to any degree of elevation or depression, according to the heel of the ship.

1684. In Pointing, the amount of lateral train required is usually designated by points, and the elevation by the corresponding number of yards of range.

In the case of guns which work upon pivots or on centres, the motion of the rear of the gun-carriage being strictly confined to the arc of a circle, the position of the gun with reference to the vessel can always be exactly defined by an arc divided into points, half-points, and quarter-points, being marked on the deck.

The ordinary broadside carriage, having no centres or pivots to work on, will rarely occupy the same place in the ports when the guns are run out for firing, so that an arc marked on the deck would not be strictly applicable.

1685. Concentrated Fire.—When all the guns of a battery are directed to the same point and are discharged simultaneously, it is called "concentrated firing." This kind of firing is used to the greatest advantage at short distances. One of the guns of the battery is selected as the directing-gun.

To Concentrate a Ship's Broadside, the guns are trained in the direction of the object by means of *The Directing-batten*, or *The Converging-line*, and laid according to the heel of the ship and the distance of the object: the direction being given by the aid of the *Director* from the upper deck.

1686. The Directing-battens.—These consist of metal or wooden battens, *a* (Fig. 357), sliding in two beckets attached to

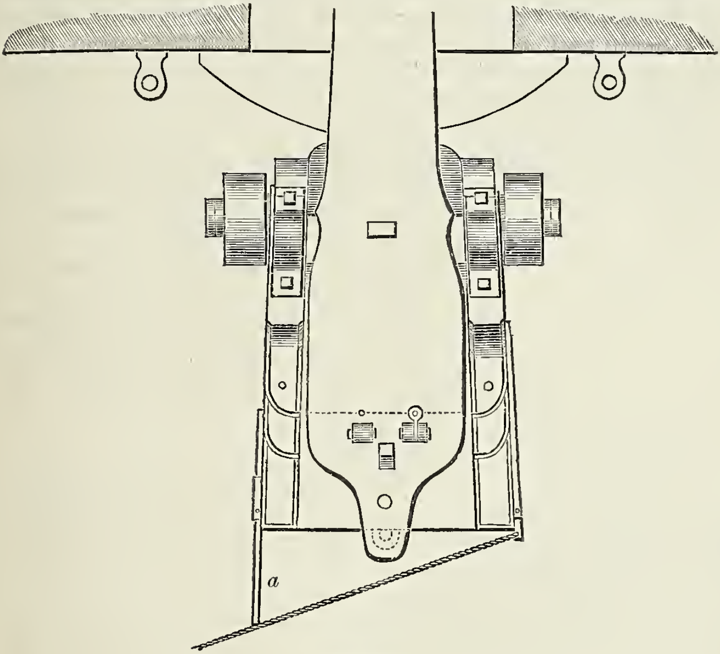


Fig. 357.

each of the brackets of the carriage, and retained in any position by a thumb-screw. They are arranged to slide out parallel to the deck, directly to the rear of the carriage.

The upper sides of the battens are marked for the convergence on the bow, beam or quarter, and the outer sides in degrees for parallel firing.

To give direction, one of the battens is clamped at zero, the zero mark coinciding with the rear face of the becket in which it slides; the other batten is drawn out to the mark designating the points of convergence ordered, and clamped. A cord or bar is now placed over the ends of the two battens and the gun trained until this is parallel to a mark on the deck indicating the direction of the keel.

1687. THE CONVERGING-LINE.—This is a line hooked to the centre and near the outside of the upper port-sill, and held immediately under marks made on the beams or deck overhead, for the several bearings of a-beam, on the bow and quarter; when the gun is trained until the sights are parallel to it.

The midship gun is usually employed as the directing-gun, and the angles of training ascertained for the different bearings at a constant distance of say 500 yards. Though the calculations are made for this distance, yet this method of training will answer for all ranges within 1,000 yards.

1688. TO CALCULATE THE ANGLES FOR CONCENTRATION.—*On the Beam.*—Let A (Fig. 358) be the midship gun trained right a-beam, B the foremost one, C the object at a constant distance of 500 yards. Let the distance from A to B, supposed known, equal 96 feet, and the distance from the centre of port in-board be taken as 14 feet, being the same for all the guns. Then the angle C can be easily found for $\frac{AB}{AC}$ = Tan. C, the angle of training for the foremost gun.

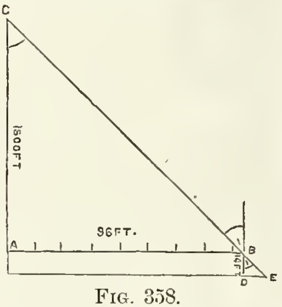


FIG. 358.

Again, in triangle B D E, we have D E = B D · Tan. C, the length of the tangent to be set off overhead, from the point opposite the centre of the port. For the intermediate guns divide the length D E by the number of guns *before* the midship one, which will give the length of the tangent before the gun next to the midship one; twice this will be the length for the next gun, and so on: Thus, if D E = 10.7 inches, and the number of guns before A be 8, we have $\frac{10.7}{8}$ = 1.3 inch, or the length for the gun next to A; 2.6 inches = the length for the next gun, and so on. The same measurement answering for the guns abaft A.

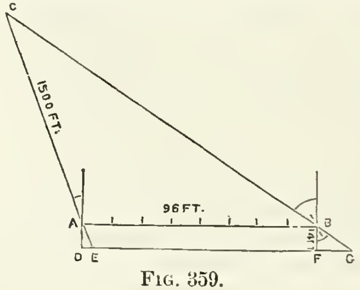


FIG. 359.

1689. *On the Bow or Quarter.*—Let A (Fig. 359) be the midship gun trained 3 points abaft the beam, B the foremost one, C the object distant 500 yards. Let the distance from A to B, supposed known, equal 96 feet, and the distance from the centre of the port in-board equal 14 feet as before. Then from the expression,

$$\frac{AC + AB}{AC - AB} = \frac{\text{Tan. } \frac{1}{2}(B + C)}{\text{Tan. } \frac{1}{2}(B - C)}$$

the angle B can be easily found, which, taken from 90°, will give the angle of training for the foremost gun. Again, in triangles A D E, B F G, we have D E = A D · Tan. A and F G = F B · Tan. B, which are the required lengths of the tangents to be set off overhead from the points opposite the centres of these ports. For the intermediate guns, divide the difference between the two lengths D E and F G by the number of guns *before* the midship one, and *add* this common difference to the length D E for the gun next before the midship one, and so on to each gun in succession. Thus, let F G = 10 ft. 5 in., and D E = 9 ft. 4 in., the difference = 1 ft. 1 in.; let the number of guns before A be 8, then we have $\frac{13}{8} = 1.6$ in., the common difference for each gun; therefore 9 ft. 5.6 in. = the length for the gun before A; 9 ft. 7.2 in. = the length for the next gun, and so on.

The measurements for the corresponding guns abaft the midship one will be found by *subtracting* the common difference from D E, and so on, from each gun in succession.

The calculation of the angles for 3 points before the beam, or for $1\frac{1}{2}$ points before and abaft the beam, is performed in the same manner.

1690. To Mark the Beams.—Having a line parallel to the keel, overhead, at any convenient distance in rear of the guns, measure the assumed distance 14 ft. from the centre of port in-board, and place a perfectly straight-edged batten there, parallel to the keel line; then transfer the centre of the port to the batten by stretching a line taut across from the centre of two opposite *upper* port-sills; or with any length of line as radius, from the centre of the port, describe an arc cutting the batten before and abaft the centre; half the distance between these marks will give the point corresponding to the centre of the port. From this centre, measure off on the batten, to the right and left, the lengths of the tangents for the different bearings, as calculated above; and then transfer these points to the beams or deck immediately over the batten.

1691. The Elevation.—Each turn of the elevating-screw represents 1°; therefore, if the gun is once levelled, by stretching a line across from the reinforce sights of opposite guns, and raising the screws until this line just touches the bottom of the sight-notch at level, and the number of threads above the cascabel noted, it is apparent that each turn raises or lowers the breech by 1°, and that the gun can be first made parallel with the deck and then laid level to compensate for the degree of heel given by the pendulum or director.

1692. *Pendulums to Mark the Heel of the Ship.*—The tangent sights give the elevation of the gun above the horizontal plane, and when the deck is steadily inclined from the horizontal line, by the pressure of the wind for instance, the tangent-scale will give the elevation of the gun above the plane of the deck, and not above the plane of the sea.

Pendulums are fitted in convenient localities, working in a graduated arc, to indicate the amount of heel or inclination at any time, and show the number of degrees of elevation or depression required to bring a ship's guns to a horizontal position. In practice, however, very little reliance is placed upon these contrivances (Art. 1660).

Section II.—Different Kinds of Fire.

1693. Classification.—The different kinds of fires are distinguished, 1st. By the flight of the projectile, as *direct*, *curved*, *ricochet*, and *plunging-fires*; 2d. By the nature of the projectile, as *solid-shot*, *shell*, *shrapnel*, *grape*, and *canister* fires; and 3d. By the angle of elevation, as *horizontal* fire, or the fire of guns and howitzers under low angles of elevation, and *vertical* fire, or the fire of mortars under high angles of elevation.

1694. Direct Fire.—A fire is said to be direct when the projectile hits its object before striking any intermediate object, as the surface of the ground or water.

This species of fire is employed where great penetration is required, as the force of the projectile is not diminished by previous impact; it is necessarily employed for shrapnel fire and for rifle-projectiles, which from their form are liable to be deflected by previously striking a resisting substance.

This kind of fire requires a good knowledge of distance, and precision both of elevation and lateral direction, in order to strike an object which is comparatively a point. It is always to be preferred when the distance is accurately known, or when the object is so near that the chances of hitting it are very great; also when the intervening surface between the gun and object is so rough or irregular that a projectile striking it would have its velocity much diminished or destroyed, and its direction injuriously affected.

1695. RICOCHET FIRE.—When the angle of fall is small enough, the projectile rises and continues to move on, forming a series of bounds or ricochets. A ricocheting ball makes a furrow in the surface struck, and each time the angle under which it leaves that surface is greater than that under which it enters it; for, having lost a portion of its velocity in passing over the first part of the curve, it has no longer the same power to overcome resistance, and must pass out by a shorter path than the one it followed in entering, and consequently the angle is increased, which causes the more or less rapid extinction of the ricochet.

The number, shape, and extent of the ricochets depend on the nature of the surface struck, the initial velocity, shape, size, and density of the projectile, and on the angle of fall.

1696. The most favorable circumstances under which this fire occurs are where the angle of fall is least, and the surface perfectly smooth. A 32-lb. spherical projectile will then roll 3000 to 3500 yards on water, rising but little above the surface —never as high as the hull of a frigate—while the greatest range obtained from an elevation of 5° with the same gun and charge is less than 1800 yards.

At first the bounds are of considerable extent, perhaps 350 to 400 yards between the first and second grazes; they diminish gradually, so as to leave intervals not exceeding fifty yards as they approach the end of the range, and finally roll along the top of the water as if ploughing it. Long before this, however, they are apt to curve off to the right or left from the true direction, so as to make an extreme deviation, often amounting to 100 or 200 yards.

1697. Ricochet firing, properly so called, is performed at level, or at most at three degrees of elevation; shot will often ricochet at much greater angles, but it is not what is meant by ricochet firing.

Upon smooth surfaces within certain distances this fire has some important advantages over direct firing. When the guns have very little or no elevation and are near the water, as they are in a ship's battery, the projectile strikes the water at a very small angle; its flight is not greatly retarded by the graze, and it rises but little above the surface in its course, but the penetration is not to be depended upon beyond 1500 yards against ships of war.

1698. Ricochet firing at low elevations requires only correct lateral direction, since the projectile would rarely pass over, and would probably strike a vessel, if within its effective range, whether the actual distance had been ascertained or not.

The deviation of projectiles is, however, generally increased by ricochet, and in proportion to the roughness of the surface of the water. Even a slight ripple will make a perceptible difference, not only in direction, but in range and penetration, and the height to which the projectile will rise in its bounds.

1699. Although these facts demand attention, yet when the estimated distance does not require an elevation of more than three degrees, projectiles from guns pointed rather too low for direct firing will probably ricochet and strike the object with effect, even when the water is considerably rough. This may be called "accidental ricochet."

When the water is not smooth, the most favorable circumstances for ricochet-firing are when the flight of the projectile is with the roll of the sea, and the roll is long and regular.

1700. Ricochet will be effective against small objects up to 2000 yards, but should not commence at less than 600 yards: at less distances it is preferable to fire direct.

Ricochet is of no value from rifled guns firing elongated projectiles, as they lose all certainty of direction on the rebound.

Projectiles rarely ricochet at all with elevations above 5°, and the bounds are always higher, with equal charges from the same gun, as the elevation of the gun is increased.

1701. Curved Fire.—When a projectile is fired so as just to clear an interposing cover and then descend upon the object without ricochets or rebounds, such practice is termed *curved fire.*

Smaller charges and higher angles are required than for ordinary direct fire. On shipboard it is more convenient to fire with service-charges from such distances as to obtain the proper angle of fall.

1702. Plunging Fire.—A fire is said to be plunging when the object is situated below the piece. This fire is particularly effective against the decks of vessels.

1703. Solid-Shot Firing.—Solid shot are generally used when great accuracy at very long range and penetration are required. From their great strength they can be fired with a large charge of powder, which gives them great initial velocity: and having great density, which diminishes the effect of the resistance of the air, they have great range and accuracy.

In rifle-guns of large calibre it is found that solid shot strain the guns from their weight, and shoot comparatively badly from their length, which is usually less than that of shell. It appears that the minimum length for good shooting is two calibres, and that shell have an advantage from having the weight so disposed as to give a longer radius of gyration, and therefore a better spin.

1704. SHELL-FIRING.—The diameter and velocity of two projectiles being the same, the retarding effect of the air is inversely proportioned to their weight; hence a shell has less accuracy and range than a solid shot of the same size. The shot has superior accuracy, but the shell superior power, as it acts both by impact and explosion.

If there be any difficulty in striking a given object, the shot will do so oftener than the shell; or the shot will cluster more closely about any desired spot. On the other hand, the power exerted by a single exploding shell is infinitely more destructive than that of many shot. The shot has greater penetration, but the shell does not require this property to the same extent, because the former must always perforate entirely to operate with effect, while the action of the latter will be materially lessened in its explosive power, if it does pass through instead of lodging. Hence, it may be assumed that the penetration of the shell is adequate to its special purpose at any distance where shot of like weight are effective; that is, if the shot pass entirely through, the shell may do likewise and explode inboard; or it may lodge and work great destruction to the side.

1705. A shell may be made to burst either while in motion or when at rest; in the first case, each of the fragments will have a forward velocity proportioned to that of the shell at the moment of fracture, and spreading out will act in the same way as a charge of grape; while, if the shell is stationary when it bursts, its effect will mainly depend upon the size of the bursting charge and the consequent violence of explosion.

Shells may, therefore, be considered as having two distinct applications; they may be used as missiles or as mines. As missiles they are most formidable, and most generally used against the *personnel* of an enemy; but as mines they are most destructive against his *materiel.*

The effects of shells depend in part upon the number of fragments produced by the explosion.

Shells should be used against ships at all distances where the penetration would be sufficient to lodge them. They are of no service in breaching solid stone walls, but are very effective against earthworks, ordinary buildings, and for bombarding.

1706. In firing shells with time-fuzes it is necessary to know the time of flight, in order to regulate the burning of the fuze for the range required. The times of flight can be found with sufficient accuracy for such purposes by observation; but they may be roughly calculated for low angles of elevation by the formula—

$$t = \tfrac{1}{4}\sqrt{\text{R (in feet)} \tan a.}$$

Where R = range,
a = angle of elevation.

Example.—An 8-inch shell is fired at an object 1400 yards distant, and for this range four degrees of elevation is required; find the time of flight.

$$t = \tfrac{1}{4}\sqrt{4200 \times .07} = 4.3 \text{ second.}$$

The times of flight found by the above formula are, however, too short, the resistance of the air retarding the projectiles in their descent.

1707. At ranges from 1000 to 1100 yards, the $3\frac{1}{2}$-second fuze is employed.

The 5-second fuze is serviceable between..1200 and 1400 yards.
The 7-second fuze between..............1500 and 1700 "
The 10-second fuze between.............1800 and 2000 "

At ranges exceeding this, fuzes of longer time are employed.

It is best to employ the shortest time fuze that will reach the object, because its combustion is more powerful, and therefore less liable to extinction than the fuze of greater duration.

The times of flight and length of fuze for all projectiles, so far as ascertained, are given in the Table of Ranges, Ordnance Instructions.

It is preferable, when circumstances will admit, to take up such distances as will correspond with the time of flight of one of the regulation lengths. When firing against ships or earthworks, the fuze should be a little longer than necessary in order to reach the object before bursting: but a little shorter when firing against boats or masses of troops, in order to insure its bursting in front of them.

1708. Shrapnel Firing.—The shrapnel may be defined as a combination of the shell and the canister, by which the former is made to serve as a case or envelope to the balls of the latter, carrying them to the desired point near the object, and then opening to permit their egress. Its sphere of operation can only begin where the dispersion of the common canister becomes too great, and its effect feeble.

With shrapnel the effect produced by the bullets will chiefly depend upon the bursting of the shell at exactly the required instant; no precise rule can be absolutely laid down as to the distance short of the object at which the shell ought to burst, as so much will depend upon the velocity of the shell just before it opens, and other circumstances. They are fired with the heaviest charges allowed for the guns.

The bursting of a shrapnel at the proper distance is of the very greatest importance; if the shell bursts too soon, the whole or greater part of the balls will fall short, the velocity and penetrating power being greatly diminished in consequence; if the shell pass the object before exploding, its effect as a shrapnel will be entirely lost.

1709. The effect of shrapnel greatly depends on the correct estimate of the results that are being produced, and in most cases on the judgment displayed in the constant efforts to improve on the shooting; when used intelligently the effect is most excellent. It is possible generally from the gun to estimate the line and the height of the burst of the shell, but not the distance at which it occurs, and bad practice commonly arises from a too sanguine estimate of effects, judging from the appearance of the smoke of the burst alone; particular attention should therefore be paid to any visible marks of the bullets grazing; on water, splashes will be seen; on dry ground, puffs of dust; and the greater their velocity at the moment of bursting, the greater will be the effect.

Shrapnel should be used from 300 to 900 yards with the 12-pdrs., and from 400 to 1500 yards with XI-inch.

A well-delivered shrapnel shell from a heavy gun must sweep away the crew of a pivot or other gun, on a spar-deck not protected by bulwarks.

1710. *Rifle-Shrapnel.*—The effect of the oblong shrapnel is said to be inferior to that of the spherical, but this has been disproved by practice. At all ranges the effects of the oblong shrapnel are found to be superior to those of the spherical.

Such a projectile fired from a rifled cannon, having previous to breaking up a rotatory motion, considerable lateral spread is given to the bullets when released. The charge is usually placed in a chamber at the base, so that on explosion there is no tendency to increase the lateral spread of the bullets, but rather to increase their velocity and penetration.

1711. Grape and Canister Firing.—In grape and canister firing, the apex of the cone of dispersion is situated in the muzzle of the piece, and the destructive effect is confined to short distances. The shape of this cone is the same as in shrapnel; its intersection by a vertical plane is circular, while that of a horizontal plane, as the ground, is oval, with its greatest diameter in the plane of fire.

The greatest number of projectiles are found around the axis of the cone, while the extreme deviations amount to nearly one-tenth of the range.

Grape and canister are effective at short distances against boats, exposed bodies of men, and the rigging of vessels. Grape being larger than canister, are effective at greater distances. Canister can only be used with effect at short ranges, on account of the rapid dispersion of the balls, and from the fact that their velocity is soon lost in consequence of their comparative lightness.

1712. The fire of canister does not always produce the effect anticipated for it, because the object is often thought to be nearer than it really is, and the firing sometimes commences too soon; also, the danger is often thought to be more imminent than it really is, and consequently proper care is not observed in aiming.

On hard flat ground, the effect of canister depends chiefly on its ricochet. The guns being level, the projectiles will effectually sweep the ground for several hundred yards in front.

When the men on the spar-decks of the enemy are exposed, by the heeling of the ship, grape or canister may be used against them, at distances ranging from 200 to 300 yards. Against light vessels a single stand of grape from heavy guns may be used at about 400 yards.

1713. *Rifled Canister.*—It has been believed that the canister practice of rifle-guns is inferior to that of smooth-bores, but the comparative trials instituted by various countries prove that the canister practice of rifle-guns is at least as effective as that of smooth-bores.

The smooth-bore practice does not usually extend beyond the dangerous fire of modern small arms, so that generally at all distances where it can act usefully, the canister as well as the shrapnel practice of rifled-guns is superior to that of smooth-bores.

1714. Horizontal fire includes all kinds in which the projectile strikes its object with a velocity due wholly, or nearly so, to the charge. In this fire the ranges are regulated by alteration in the elevation of the axis of the piece, a fixed charge being generally used with each nature of gun; this charge is the largest the piece is capable of firing, so as to give very high velocity to the projectile, and consequently a low trajectory, upon which accuracy of fire and the extent of ground effectively covered by the projectile mainly depend.

1715. Vertical fire includes all kinds in which the projectile strikes with a velocity due wholly, or nearly so, to gravity.

The usual angle of fire of mortars is 45 degrees, which corresponds nearly with the maximum range. The advantages of the angle of greatest range are:

1st. Economy of powder. 2d. Diminished recoil and strain on the piece, bed, and platform. 3d. More uniform ranges. When the distance is not great, and the object is to penetrate the roofs of magazines, buildings, etc., the force of fall may be increased by firing under an angle of 60 degrees.

The ranges obtained under an angle of 60 degrees are about one-tenth less than those obtained with an angle of 45 degrees.

If the object be to produce effect by the bursting of the projectile, the penetration should be diminished by firing under an angle of 30 degrees.

When the object and the mortar are not on the same level, the angle of greatest range, instead of being 45°, is $45° \pm \frac{1}{2}$ the angle of elevation or depression of the object. Thus, to reach an object elevated 15° above a mortar, the angle of greatest range would be $45° + 7\frac{1}{2}° = 52\frac{1}{2}°$; while, if the object was depressed 15°, the angle would be $45° - 7\frac{1}{2}° = 37\frac{1}{2}°$.

1716. The angle of fire being fixed at 45° for objects on the same level with the piece, the range is varied by varying the charge of powder. The practical rule is founded on the knowledge of the amount of powder necessary to diminish or increase the range a certain quantity.

The 13-in. mortar with a charge of 3 lbs. of powder gives a range of 850 yards, and every additional $\frac{1}{2}$ lb. increases the range about 180 yards. The elevation being 45°.

1717. A practical rule for finding the time of flight by which the length of the fuze is regulated, is to take the square-root of the range in feet, and divide it by four; the quotient is the approximate time in seconds.

1718. The greatest difficulty in firing mortars is to regulate the charges properly; very great differences are found to exist between ranges obtained under the same circumstances, and these increase with the range, whilst the lateral deviations are much less.

The utmost exactness is to be observed in measuring and filling the cartridges, as an ounce of powder makes an important variation in the range.

Tables of charges, elevations, and ranges for the 13-in. mortar are given in the *Ordnance Instructions*.

1719. To estimate the distance by the bursting of the shell, where the flames can be seen, multiply the number of seconds that elapse between it and the report by 1100, and the product will be approximately the distance in feet.* (Art. 1636.)

1720. *Falling Velocity.*—The falling velocity of a mortar-shell at ordinary range may be found with sufficient accuracy for practical purposes as follows: The shell may be assumed to be rising during half the time of flight and falling during the other half; therefore, if t be the time of flight, and V the velocity required, the latter will be due to $\frac{1}{2}t$; thus, if for 500 yards $t = 10''$, $V = gt$ $\therefore$ $V = 32 \times 5 = 160$ feet.

1721. Mortars afloat are usually not to be much dreaded; though mortar-vessels moored in smooth water may be very effective.

Large mortars should be used for the defence of navy yards, or other important stations on the sea-board; for, although their inaccuracy of fire may cause many shells to be wasted, the chance of one or two falling upon the deck of any vessel would usually prevent its coming within short range.

1722. Vertical fire is of all practice from ordnance the most uncertain as regards precision. The chief causes of inaccuracy of vertical fire are: that the shells having comparatively low velocity, but long times of flight, are peculiarly liable to considerable deviation from wind and other disturbing causes; that the angles of descent of mortar shells, fired at the usual angle of 45°, are so great that unless the object be of some extent, an error in range of a few yards might render the shell useless; whereas, when a projectile is fired at a low angle of elevation, so much ground is covered by it before and after grazing that an error of some yards *under* or *over* would not generally be of much consequence; also, that it is difficult in practice to ensure the requisite care in weighing out the charges, or to obtain powder of uniform quality. In vertical fire, as the object cannot generally be seen, and the piece is usually short, it is very difficult to point the mortar exactly in the same line for a number of rounds; but if the pointing could be performed with the greatest accuracy, irregularities must always occur in practice with projectiles fired at high angles and with low velocities.

1723. Small-Arm Firing.—The fire of the rifle-musket is not effective beyond 1200 yards; the angle of fall, however, is so great that great care must be exercised in determining the exact distance of the object. If the ground be favorable, the

* At the temperature of 33° the mean velocity of sound is 1092.5 feet in a second. It is increased or diminished *half a foot* for each degree of temperature above or below 33°.

projectile will ricochet at 1000 yards, which increases the dangerous space, and therefore the chances of hitting the object.

The limit of any fire is determined by the distinctness of vision.

The effect of small-arm firing depends much on the skill and self-possession of the individual, for without these qualities the most powerful and accurate arms will be of little avail.

*Section III.—Gun Implements.**

1724. STAVES.—The staves of all implements are made of tough ash, round, 2 in. in diameter for all lengths of over 150 in., $1\frac{3}{4}$ in. for all other lengths above 100 in., and $1\frac{1}{2}$ in. for all below. A tenon is made on one end, $\frac{1}{4}$ of an in. less in diameter than that of the staff.

1725. SPONGES.—The sponge complete is 18 in. longer than the bore of the gun for which it is intended.

The staff is 2 in. shorter than the implement complete. The tenon is $1\frac{1}{2}$ in. shorter than the head. In the end of the tenon a worm is secured by means of a copper pin passing through a hole in its shank and the tenon. The worm, 2 in. in length and $1\frac{1}{4}$ in. in diameter, is made of elastic composition wire $\frac{2}{10}$ of in. in diameter, tapering at the points. It is right-handed in order to act when turned to the right, or with the sun. (Fig. 360.)

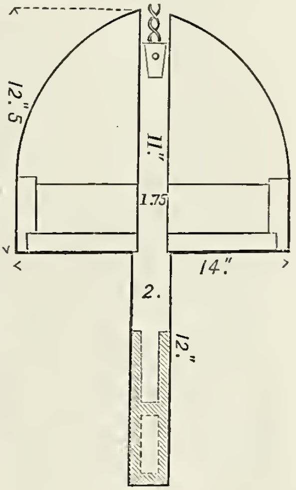


FIG. 360.

The sponge-head is made of poplar or other suitable light wood, and for smooth-bore guns consists of a cylindrical body 4 in. in length, surmounted by a section whose surface is similar to that of the chamber of the gun. This section is $\frac{1}{2}$ in. shorter than the chamber, and the diameter of the head at any point is 1 in. less than the diameter of the chamber, or bore, at that point. For unchambered guns the sponge-head conforms in shape to the bottom of the bore; the radius of its curve being $\frac{1}{2}$ in. less than that of the bore, the cylindrical body is retained.

* *Dimensions and Weights of Gun Implements.* Bureau of Ordnance, 1874.

1726. Sponge-heads for all rifled guns are 2 calibres in length. A hole of the size of the tenon is bored through the axis of the head, and the head is secured to the staff by means of a copper pin $\frac{2}{10}$ in. in diameter, through the cylindrical body. When the head is properly fixed to the staff it bears firmly against the shoulder of the tenon, allowing the end of the worm to project $\frac{1}{2}$ in. (Fig. 361.)

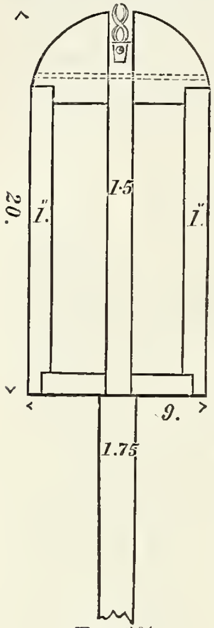


FIG. 361.

Sponge-heads for greater calibres than XIII-in. smooth-bore and VIII-in. rifles are built up, hollow. All sponge-heads, when finished, are primed with several coats of boiled linseed oil or varnish.

1727. *The woollen sponge* is made of the shape and size requisite to fit the head, with an allowance of 1 in. in length for tacking over the edge of the base. The wool is sheared so as to allow no windage.

Sponge-caps for guns on covered decks are made of duck, of a size to fit the sponge snugly, lapping 1.5 in. over the base. The mouth is fitted with a draw-string, and a becket is fitted to the other end. These caps are not painted but kept scrubbed. For uncovered guns and all howitzers, the sponge-caps are similar to the others, except that they are long enough to gather around the staff. Ties are fitted to secure them instead of a draw-string; and they are kept painted white. The cap is never put on the sponge unless both are clean and dry.

1728. *Bristle sponge-heads* are 1.5 in. less in diameter than the chambers and bores of the gun for which they are intended. The bristles are sheared so as to work easily and leave no windage. Three spiral spaces are left the whole length of the sponge-head, in order to bring out unconsumed portions of cartridge; these spaces are right-handed. Two-thirds of the head is covered with bristles, one-third bare; the end of the sponge is entirely covered; there is no worm in bristle sponges.

1729. RAMMERS.—The rammer complete is shorter than the sponge, by the length of the sponge-head. The rammer staff for smooth-bores is equal to the length of the complete rammer, minus one-third the length of the head.

The rammer-head for smooth-bores (Fig. 362) is made of ash, birch, beech, or other tough wood, and consists of a cylindrical body and hemispherical neck. The neck is struck with a radius of 2 in. The necks of rammer-heads nbove 13 in. are cylindrical, with the same radius, and one-third the length of the head. The diameter of the body is .25 in. less than that of the bore; its length, two-thirds that of the whole head. The head of a 32-pdr. rammer is 1 calibre in length. For every change of calibre of 1 in. there is a corresponding change of .25 in. in the length of the head. The rear of the body is bevelled off to the neck, in a curve of 1 calibre. The front end is hollowed out with the same radius, the bottom of the curve being bevelled off where it meets the hole for the staff, leaving the exterior of the hole 2 in. in diameter. An annular surface is left around the face of the head, 1 in. in width, for calibres above XI-in.; .75 in. for all others. The staff tenon is two-thirds the length of the head, its shoulder coming square up to the base of the neck. The head is secured to the staff by a copper pin .2 in. in diameter through the thickest part of the neck. Rammer-heads for greater calibres than XIII-in. are strengthened by copper bands .5 in. wide around the ends of the head and neck; the copper is No. 17 American wire-gauge.

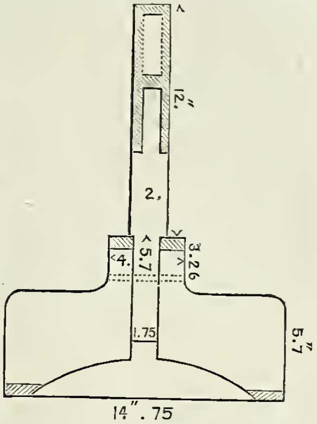


FIG. 362.

1730. *Rammer-heads for rifled guns* are made of composition (Fig. 363), cup-shaped, 1 calibre in length, with a neck two-thirds the length of the body, and tapering from 2 in. in diameter at the throat to 1.75 in. at the end. The extreme diameter of the head is .25 in. less than that of the bore. The diaphragm between the hollow of the head and neck is .2 in. in thickness. The hollow of the head, for a depth of 1.25 in., corresponds to the head of the projectile in shape; the rest is cut away, so as to leave a shell .2 in. in thickness. The head is secured to the staff by two composition pins .2 in. in diameter through the neck. Metal rammer-heads for all guns above VI-in. calibre are lightened by having segments cut out of the body.

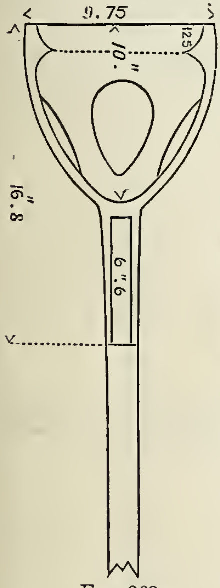


FIG. 363.

1731. LADLES.—The ladle complete is of the same length as the rammer. The staff and head are of the same dimensions, except the length of the staff, which is $1\frac{1}{2}$ calibres shorter than the rammer-staff. (Fig. 364.)

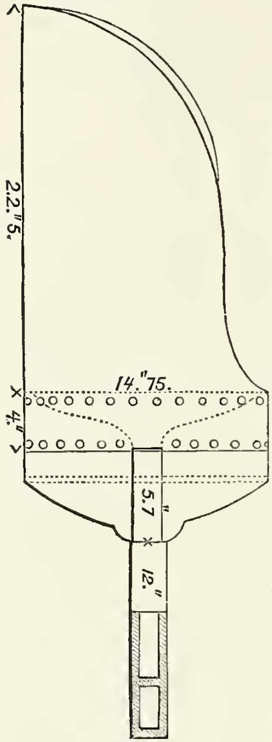


FIG. 364.

The diameter of the head is reduced (to make a seat for the scoop) 4 in. in length for calibres above XI-in.; 3 in. for all others. The scoop is secured to the head by two rows of copper tacks. The copper used for making scoops is No. 11 for calibres above XI-in., No. 13 for XI-in. and IX-in., No. 15 for VIII-in. and 32-pdr., and No. 17 for all howitzers (American wire-gauge).

1732. WORMS.—The worm complete is the same length as the rammer. (Fig. 365.) The head consists of a round composition shaft, having a worm 2 in. in length at one end, and two straps 8 in. long at the other, the total length being 20 in. At 8 in. from the end of the worm is a shoulder, for a disc of composition .25 in. less in diameter than the bore for which it is intended. It is kept in its place by a key. The staff fits into a socket formed by the straps, and is kept in place by two composition pins passing through both straps.

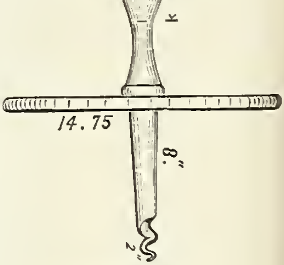


FIG. 365.

1733. SECTIONAL STAVES. — The staves for turret and casemate guns, where stoppers and shutters are used, are sectional, with spring connecting joints. (Fig. 366.) One section is permanently fixed to the head of the implement, projecting 12 in. beyond its base. As the length of the implement is arbitrarily fixed, by the necessity of having a certain amount of staff beyond the end of the bore when the implement is home, one length is made longer or shorter than the average, according to necessity. All other sections are 36 in. long exclusive of the tenons, which are 3 in. in length, a corresponding socket being fitted in the other end of the section. All detacha-

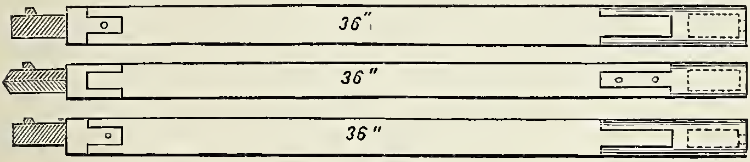


FIG. 366.

ble sections are interchangeable. Each gun is supplied with three of the 36-in. sections. These, together with the fixed and odd sections, make the length of the different implements.

CHAPTER XI.

THE MOTION OF PROJECTILES.*

1734. A knowledge of the motion of projectiles in a *non-resisting medium* is useful as an introduction to the discussion of the motion of projectiles in air; the following investigation, in which the resistance of the air is not considered, is therefore introduced here. The attraction of gravitation is assumed to be constant and parallel to a fixed line.

THE EQUATION OF THE PATH OF A PROJECTILE IN A NON-RESISTING MEDIUM.—Let the origin be taken at the point of projection, and let the axis of y be vertical, and that of x horizontal and in the plane of projection; x and y are the current co-ordinates of the centre of gravity of the projectile. It is

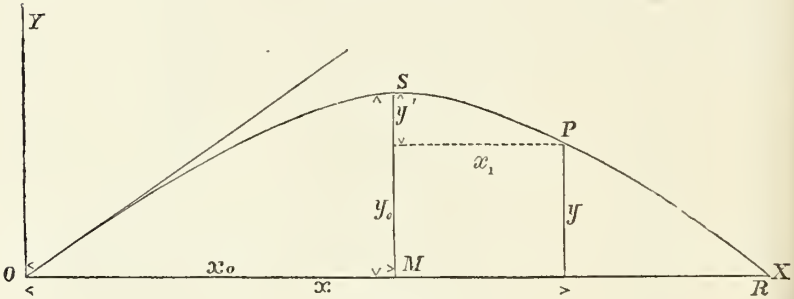


FIG. 367.

evident that this point will continue to move in the plane xy, as it is projected in it, and is subject to no force tending to withdraw it from that plane. u denotes the initial velocity, a the angle of projection, and t the time reckoned from the instant at which the projectile starts from O.

* By Professor J. M. Rice, United States Navy.

The equations of motion are

$$\frac{d^2x}{dt^2} = \text{acceleration parallel to the axis of } x = 0 \ldots\ldots(1),$$

and $$\frac{d^2y}{dt^2} = \text{acceleration parallel to the axis of } y = -g \ldots(2).$$

Integrating equations (1) and (2), we obtain

$$\frac{dx}{dt} = constant = u \cos a,$$

and $$\frac{dy}{dt} = constant - gt = u \sin a - gt \ldots\ldots\ldots\ldots(3).$$

Integrating again,

$$x = u \cos a . t \ldots\ldots(4), \text{ and } y = u \sin a . t - \tfrac{1}{2} gt^2 \ldots\ldots\ldots(5).$$

Eliminating t between (4) and (5), we obtain the equation of the path or trajectory

$$y = x \tan a - \frac{gx^2}{2u^2 \cos^2 a} \ldots\ldots\ldots\ldots\ldots(a),$$

or, putting $h = \frac{u^2}{2g}$,

$$y = x \tan a - \frac{x^2}{4h \cos^2 a} \ldots\ldots\ldots\ldots\ldots(b),$$

h is evidently the height from which a body must fall to acquire the velocity u. (b) is the form in which this equation is usually employed. It is evidently the equation of a parabola.

To find the Vertex of the Trajectory.

1735. Multiplying (b) by $4h \cos^2 a$ and transposing, we have

$$x^2 - 4h \sin a \cos a . x = -4h \cos^2 a . y.$$

Completing the square by adding $4h^2 \sin^2 a \cos^2 a$, we have

$$(x - 2h \sin a \cos a)^2 = 4h^2 \sin^2 a \cos^2 a - 4h \cos^2 a . y,$$

or $$(x - h \sin 2a)^2 = 4h \cos^2 a \, (h \sin^2 a - y).$$

If we pass to a new system of co-ordinate axes parallel to the old, by putting $x_1 = x - h \sin 2a$, and $y_1 = h \sin^2 a - y$, we obtain

$$x_1^2 = 4h \cos^2 a . y_1,$$

the equation of a parabola referred to the vertex and principal axes. The co-ordinates of the new origin, which is also the vertex, are

$$x_0 = x - x_1 = h \sin 2\alpha \ldots\ldots\ldots\ldots\ldots (6),$$

and

$$y_0 = y + y_1 = h \sin^2 a \quad \text{(see diagram)} \ldots (7).$$

Since the curve is symmetrical with reference to SM, OR, which is called the range on a horizontal plane, is equal to $2x_0$; but

$$2x_0 = 2h \sin 2a = R \ldots\ldots\ldots\ldots\ldots (8),$$

R denoting the range.

$2h \sin 2a$ is a maximum when

$$2a = \frac{\pi}{2}, \text{ or } a = \frac{\pi}{4} \text{ or } 45°.$$

That is, the greatest range is obtained when the angle of elevation is 45°; its value is $2h$, and the corresponding maximum height is $\frac{h}{2}$ [see equation (7)]. When a is 45°, the range is therefore four times the greatest height.

Again, since

$$\sin 2a = \sin (180° - 2a) = \sin 2 (90° - a),$$

the complement of any angle gives the same range as the angle itself.

To find the Time of Flight of a Projectile on a Horizontal Plane.

1736. To find the time of flight, we divide the range $[2h \sin 2a]$ by the horizontal velocity $[u \cos a]$ thus,

$$t = \frac{2h \, 2 \sin a \cos a}{u \cos a} = \frac{4h \sin a}{u} = \frac{2u \sin a}{g} \ldots\ldots\ldots\ldots (9).$$

This equation gives the time of flight in terms of u and a; to obtain t in terms of R and a, which is sometimes desirable, we put $x = R$ and $y = 0$ in equations (4) and (5), which then become

$$R = u \cos a . t \text{ and } 0 = u \sin a . t - \tfrac{1}{2} g t^2.$$

Eliminating u, we obtain

$$R \tan a = \tfrac{1}{2} g t^2,$$

or

$$t = \sqrt{\frac{2 R \tan a}{g}} \ldots\ldots\ldots\ldots\ldots\ldots (10).$$

1737. TO FIND THE ELEVATION NECESSARY TO CAUSE THE TRAJECTORY TO PASS THROUGH A POINT GIVEN BY ITS CO-ORDINATES x' AND y', THE INITIAL VELOCITY BEING GIVEN.

We have $y' = x' \tan a - \dfrac{x'^2}{4h \cos^2 a}$, to find $\tan a$;

putting $\tan a = z$, we have

$$\frac{1}{\cos^2 a} = \sec^2 a = 1 + \tan^2 a = 1 + z^2;$$

substituting in the above equation, it becomes

$$y' = x'.z - \frac{x'^2}{4h}\left(1 + z^2\right),$$

or

$$\frac{4h}{x'^2} . y' = \frac{4h}{x'} z - 1 - z^2.$$

$$z^2 - \frac{4h}{x'} z = - \frac{4h}{x'^2} . y' - 1,$$

or

$$\left(z - \frac{2h}{x'}\right)^2 = \frac{4h^2}{x'^2} - \frac{4hy'}{x'^2} - 1 = \frac{1}{x'^2}\left(4h^2 - 4hy' - x'^2\right)$$

$$\therefore \quad z = \frac{2h}{x'} \pm \frac{1}{x'} \sqrt{4h^2 - 4hy' - x'^2} \ldots\ldots\ldots (11).$$

If y' and x' have such values as to make

$$4hy' + x'^2 < 4h^2$$

there will be two real values of z, but if

$$4hy' + x'^2 > 4h^2$$

the values of z will be imaginary; in this case it is therefore impossible to so change a as to make the trajectory pass through the point.

If $$4hy' + x'^2 = 4h^2 \ldots\ldots\ldots\ldots\ldots\ldots (12),$$

there will be one real value of z.

Making x' and y' variables in equation (12), we have

$$x^2 = 4h^2 - 4hy = 4h(h - y) \ldots\ldots\ldots\ldots (13),$$

the equation of a parabola having its vertex on the axis of y at the height h above the origin.

Since the co-ordinates of any point in this curve will give, when substituted in equation (11), a single value of z, all the trajectories thus formed *touch*, but do not *cut* the curve of equation (13); this curve is called an *envelop.*

1738. To find the Velocity of a Projectile at any Point of its Path.

We have $$v^2 = \left(\frac{ds}{dt}\right)^2 = \left(\frac{dx}{dt}\right)^2 + \left(\frac{dy}{dt}\right)^2;$$

substituting the values of $\frac{dx}{dt}$ and $\frac{dy}{dt}$ from equations (3) we deduce

$$v^2 = u^2 \cos^2 a + [u \sin a - gt]^2;$$

expanding and reducing

$$v^2 = u^2 - 2g\,(ut \sin a - \tfrac{1}{2}gt^2),$$

therefore, by equation (5), $v^2 = u^2 - 2gy$.

If we put for u^2 its value $2gh$, we obtain

$$v^2 = 2g\,(h - y) \ldots\ldots\ldots\ldots\ldots\ldots (14).$$

1739. To find the direction of the path at any point, we differentiate equation (b); thus

$$\frac{dy}{dx} = \tan a - \frac{x}{2h \cos^2 a} = \tan \phi \ldots\ldots\ldots\ldots (15),$$

ϕ being the angle of inclination of the curve to the axis of x.

Putting $\frac{dy}{dx} = 0$, we have $x = 2h \sin a \cos a = h \sin 2a$, for the abscissa of the summit, or highest point of the path. The corresponding value of y is

$$h \sin^2 a,$$

which is therefore the greatest height the projectile attains; it is also, as might have been anticipated, the ordinate of the vertex; see equation (7).

1740. To find the Co-ordinates of the Point where a Projectile will strike an Inclined Plane passing through the Point of Projection, the Range on the Inclined Plane, and the Time of Flight.

Let $y = x \tan \beta$ be the equation of the line OP, which is the intersection of the inclined plane with the vertical plane of the path of the centre of gravity of the body.

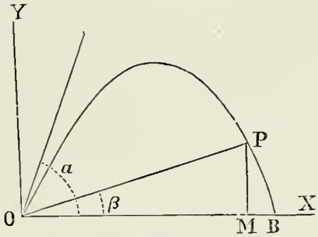


FIG. 368.

Let x_1 and y_1 be the co-ordinates of P, and let $OP = r$, the range; then

$$x_1 = r \cos \beta \text{ and } y_1 = r \sin \beta.$$

Substituting in equation (a) we have

$$r \sin \beta = r \cos \beta \tan a - \frac{r^2 \cos^2 \beta}{4h \cos^2 a};$$

whence $r = 0$, or $r = \dfrac{4h \cos^2 a \,(\cos \beta \tan a - \sin \beta)}{\cos^2 \beta}$,

and reducing $$r = \frac{4h \cos a \sin (a - \beta)}{\cos^2 \beta} \quad \ldots\ldots\ldots\ldots\ldots (14),$$

$$r \cos \beta = x_1 = \frac{4h \cos a \sin (a - \beta)}{\cos \beta},$$

and $$r \sin \beta = y_1 = \frac{4h \cos a \sin \beta \sin (a - \beta)}{\cos^2 \beta}.$$

If the inclined plane cut the path of the projectile below the axis of x, β will be negative.

The time of flight is found by dividing x_1 by $u \cos a$, the horizontal component of initial velocity; thus,

$$t = \frac{4h \cos a \sin (a - \beta)}{u \cos \beta \cos a};$$

putting for h its value $\frac{u^2}{2g}$ and reducing,

$$t = \frac{2u \sin (a - \beta)}{g \cos \beta} \ldots\ldots\ldots\ldots\ldots\ldots (15).$$

1741. The resistance of the air to the motion of spherical solid shot evidently increases with the *square* of the diameter, while the weight of the shot is proportional to the *cube* of the diameter. This resistance is therefore less effective with *large* spherical shot than with *small* shot; but it is nevertheless so considerable, even in the case of the heavy shot now in use, as to render the above formulas inapplicable in practice, except to cases of low initial velocities not exceeding 400 ft. per second. It increases rapidly with the velocity, being nearly proportional to the cube.

1742. Equations (8), (9), and (10) are sometimes used in mortar practice. If in equation (10) we put $g=32$ ft., we have approximately

$$t = \tfrac{1}{4} \sqrt{R \tan a} \ldots\ldots\ldots\ldots\ldots\ldots (16).$$

If a is 45°

$$t = \tfrac{1}{4} \sqrt{R} \ldots\ldots\ldots\ldots\ldots\ldots (17).$$

Example 10 will serve to show that the results obtained by these formulas are sufficiently accurate for some purposes, when the velocities are small. The charge of powder used in the experiments which furnished the data of Ex. 10, was a little less than two pounds in the first case, and a little more than two pounds in the second case. The following example, taken from *Owen's Modern Artillery*, will show how entirely untrustworthy these formulas are in the cases of ordinary practice.

The range of a 32-lb. shot, fired with an initial velocity of 1600 ft., and with an angle of elevation of 4°, was 5070 ft.; as computed by formula (8) it should be 11,130 ft.

EXAMPLES.

1. The horizontal range of a projectile is 1000 ft. and the time of flight is 15 seconds. Required the angle of elevation, velocity of projection, and greatest altitude.

Ans. $a = 74° 33' 09''$.
$v = 250.29$ ft.
$H = 904.69$ ft.

2. Find the velocity and angle of elevation of a ball that it may be 100 ft. above the ground at the distance of one quarter of a mile, and may strike the ground at the distance of one mile.

Ans. $a = 5° 46' 05$.
$v = 921.566$ ft.

3. What must be the angle of elevation of a body in order that the horizontal range may be equal to three times the greatest altitude? What, that the range may be equal to the altitude?

4. A body is projected at an angle of elevation of 60°, with a velocity of 150 ft.; find the co-ordinates of its position, its direction, and velocity at the end of 5 seconds.

5. A body is projected from the top of a tower 200 ft. high, at an angle of elevation of 60°, with a velocity of 50 ft.; find the range on the horizontal plane passing through the foot of the tower, and the time of flight.

6. A body, projected in a direction making an angle of 30° with a plane whose inclination to the horizon is 45°, fell upon the plane at the distance of 250 ft. from the point of projection, which is also in the inclined plane; required, the velocity of projection and the time of flight.

7. At what elevation must a shot be fired with a velocity of 400 ft. that it may range 2500 *yards* on a plane which *descends* at an angle of 30°?

8. Find the velocity and angle of elevation that a projectile may pass through two points whose co-ordinates are $x=300$ ft., $y=60$ ft., $x'=400$ ft., and $y'=40$ ft.; also find the horizontal range, greatest altitude, and time of flight.

9. Show that the maximum range on an inclined plane, of a projectile having a given initial velocity u, is $\frac{u^2}{g}\left(\frac{1-\sin\beta}{\cos^2\beta}\right)$ in which β denotes the inclination of the plane to the horizon.

10. The observed time of flight of an 8-in. mortar shell was $16^s.0$. the range being 3760 ft., and the angle of elevation 45°; find the difference between this observed range and that obtained by computation when the formulas of the preceding articles are employed. Find the difference when the range was 5879.4 ft., and the observed time $20^s.8$.

Ans. −0.7 and −1.6.

The Motion of a Projectile in Air.

1743. A complete and satisfactory solution of this problem has not hitherto been published; in fact, the law of resistance of the air, which must be found by experiment, is not yet fully established.

Some recent experiments made in England by Professor Francis Bashforth show that the resistance of the air to the motion of a projectile is approximately proportional to the cube of its velocity. The *direction* of the resistance of the air at any point of the path of a projectile is evidently that of a tangent to the path drawn through the point.

The following mathematical investigation is, with some changes in the notation, substantially that of Professor Bashforth, and the accompanying tables which will be found in the appendix to this work are reprinted from his treatise*; by means of these tables the trajectory of a projectile and its time of flight may be approximately found.

1744. R denoting the resistance of the air, and V the velocity of the projectile, the cubic law of resistance is expressed thus—

$$R = 2bV^3.$$

In this expression $2b$ is a quantity to be determined by experiment; it is not the same for all values of V, and has therefore been tabulated. The following notation is adopted for the purpose of simplifying the formulas:

Let u denote the horizontal component of the velocity, v the

* *A Mathematical Treatise on the Motion of Projectiles, founded chiefly on the Results of Experiments made with the Author's Chronograph. By Francis Bashforth, B.D.* Asher & Co., London, 1873.

vertical component, and ϕ the inclination of the curve to the axis of x,

then $$u = V\cos\phi, \text{ and } v = V\sin\phi \quad\quad (1)$$

Eliminating V, and writing p for $\tan\phi$,

we have $$\frac{v}{u} = \tan\phi = p; \quad\quad (2)$$

differentiating, $$dp = \frac{udv - vdu}{u^2} \quad\quad (3)$$

Again, squaring and adding equations (1),

$$V^2 = u^2 + v^2 = u^2(1 + p^2) \quad\quad (4)$$

The equations of motion are, in this case,

$$\frac{d^2x}{dt^2} = \frac{du}{dt} = -2b\,V^3\cos\phi \quad\quad (5)$$

and $$\frac{d^2y}{dt^2} = \frac{dv}{dt} = -2b\,V^3\sin\phi - g \quad\quad (6)$$

which may be written thus—

$$\frac{du}{dt} = -2b\,V^2u \quad\quad (7)$$

and $$\frac{dv}{dt} = -2b\,V^2v - g \quad\quad (8)$$

Eliminating V, $$\frac{udv - vdu}{dt} = -gu;$$

hence $$\frac{udv - vdu}{u^2} = -g\frac{dt}{u},$$

or [equation (3)] $$dp = -g\frac{dt}{u} \quad\quad (9)$$

Combining equations (7) and (4),

$$\frac{du}{dt} = -2b(1 + p^2)\,u^3 \quad\quad (10)$$

and, eliminating dt between (9) and (10),

$$\frac{du}{u^4} = \frac{2b}{g}(1 + p^2)\,dp.$$

This equation involves but two variables, and is readily integrated. Denoting by u_0 the value of u corresponding to $p = 0$, or in other words the velocity at the highest point of the curve, and integrating, we obtain

$$-\frac{1}{3u^3}\Big]_u^{u_0} = \frac{2b}{g}\left(p + \frac{p^3}{3}\right)\Big]_p^0,$$

or $$\tfrac{1}{3}\left(\frac{1}{u^3} - \frac{1}{u_0^3}\right) = -\frac{2b}{g}\left(p + \frac{p^3}{3}\right);$$

therefore $$\frac{1}{u} = \frac{1}{u_0}\left\{1 - \frac{2bu_0^3}{g}(3p + p^3)\right\}^{\frac{1}{3}} \quad\text{..........(11)}$$

Putting $\gamma = \dfrac{2bu_0^3}{g}$,

$$\frac{1}{u} = \frac{1}{u_0}\left\{1 - \gamma(3p + p^3)\right\}^{\frac{1}{3}}; \quad\text{............(12)}$$

but [equation (9)] $\dfrac{1}{u} = -\dfrac{dp}{gdt}$ ....(13)

therefore, eliminating u,

$$dt = -\frac{u_0}{g}\frac{dp}{\{1 - \gamma(3p + p^3)\}^{1/3}},$$

or $$t = -\frac{u_0}{g}\int_p^{p'}\frac{dp}{\{1 - \gamma(3p - p^3)\}^{1/3}} \quad\text{..........(14)}$$

Again, dividing equation (13) by the identity $u = \dfrac{dx}{dt}$, we obtain $\frac{1}{u^2} = -\frac{dp}{gdx}$, or $dx = -\frac{u^2}{g}\,dp$,

and, substituting the value of u^2 obtained from (12), and integrating, we have

$$x = -\frac{u_0^2}{g}\int_p^{p'} \frac{dp}{\{1-\gamma(3p+p^3)\}^{2/3}} \dots\dots\dots\dots (15)$$

Also, by means of the identity $dy = pdx$, we obtain from (15)

$$y = -\frac{u_0^2}{g}\int_p^{p'} \frac{pdp}{\{1-\gamma(3p+p^3)\}^{2/3}} \dots\dots\dots\dots (16)$$

The quantity $\frac{2bu_0^3}{g}$ for which γ is substituted in equation (12) may be written thus, $\frac{2bmu_0^3}{mg}$; the numerator denoting the resistance of the air at the vertex of the trajectory, and the denominator the weight of the shot.

Putting $\tan\phi = p$ and $\tan\phi' = p'$,
$dp = \sec^2\phi\, d\phi = (1+p^2)\, d\phi$; introducing this value of dp in equations (14), (15) and (16), and changing limits, we obtain

$$t = -\frac{u_0}{g}\int_\phi^{\phi'} \frac{(1+p^2)\,d\phi}{\{1-\gamma(3p+p^2)\}^{1/3}} = -\frac{u_0}{g}\,T_\gamma\Big]_\phi^{\phi'}; \qquad (a)$$

$$x = -\frac{u_0^2}{g}\int_\phi^{\phi'} \frac{(1+p^2)\,d\phi}{\{1-\gamma(3p+p^3)\}^{2/3}} = -\frac{u_0^2}{g}X_\gamma\Big]_\phi^{\phi'}; \qquad (b)$$

$$y = -\frac{u_0^2}{g}\int_\phi^{\phi'} \frac{(p+p^3)\,d\phi}{\{1-\gamma(3p+p^3)\}^{2/3}} = \frac{u_0^2}{g}Y_\gamma\Big]_\phi^{\phi'}. \qquad (c)$$

1745. Inasmuch as it is impossible to find the values of x y and t by direct integration, it has been necessary to compute by quadratures the values of X, Y and T for all practical values of $+\phi$ not greater than $60°$, and of $-\phi$ not less than $60°$ or $45°$, for values of $\gamma = 0.00$, 0.01, $0.02 ... 0.18$, 0.19, 0.2, 0.3, $0.4 ... 4.9$, 5.0. The value of $d\phi$ generally used was the circular measure of $1°$, but when $1 - \gamma(3p + p^3)$ became small, the successive values of $\frac{1}{1 - \gamma(3p + p^3)}$ were subject to rapid variation; in such cases intervals of $\frac{1}{5}°$ were used, and the results have been given in preliminary tables (see Appendix). By the ordinary rule of proportional parts, or, where great accuracy is required, by interpolation, it will not be difficult to find the values of X, Y, and T for values of γ and ϕ intermediate to those given in the tables.

Examples of the Methods of finding the Numerical Values of X, Y and T, γ being given.

From the tables, page 71, Appendix:

$$X_{0.7}\Big]_{5}^{10} = X_{0.7}\Big]_{0}^{10} - X_{0.7}\Big]_{0}^{5} = .20430 - .09348 = .11082,$$

$$Y_{0.7}\Big]_{10}^{4} = Y_{0.7}\Big]_{10}^{0} - Y_{0.7}\Big]_{4}^{0} = .013448 - .002299 = .011149,$$

$$T_{3.2}\Big]_{0}^{5} = .11027,\ T_{3.2}\Big]_{5}^{0} = .07836.$$

Suppose it was required to find the value of $Y_{3.2}\Big]_{3.}^{7.41}$,*

$$Y_{3.2}\Big]_{3}^{7.41} = Y_{3.2}\Big]_{3}^{7} + \left(Y_{3.2}\Big]_{0}^{8} - Y_{3.2}\Big]_{0}^{7}\right) \times 0.41,$$

$$= .004059 + (.006548 - .005196) \times 0.41$$

$$= .004059 + .001352 \times 0.41$$

$$= .004059 + .000554$$

$$= .004613.$$

In the same way $X_{3.2}\Big]_{3}^{7.41}$ and $T_{3.2}\Big]_{3}^{7.41}$ may be found.

* In this example both limits are negative.

1746. In order that the tables may be used for the solution of problems, we see from the above examples that γ must first be determined numerically* having found its value, we turn to the corresponding table, and obtain [see Fig. 369]

$$OM = \frac{u_0^2}{g} X_\gamma\Big]_0^a,\ MA = \frac{u_0^2}{g} Y_\gamma\Big]_0^a,$$

and the time in $OA = \frac{u_0}{g} T_\gamma\Big]_0^a$, for the *ascending* branch.

Now for the *descending* branch we have for the co-ordinates of the point P', where the direction of the curve is inclined at an angle β to the horizon, β being negative.

$$AN' = \frac{u_0^2}{g} X_{\gamma'}\Big]_0^\beta,\ N'P' = \frac{u_0^2}{g} Y_{\gamma'}\Big]_0^\beta,$$

and the time in $AP' = \frac{u_0}{g} T_{\gamma'}\Big]_0^\beta$.

To find the Range on a Horizontal Plane.

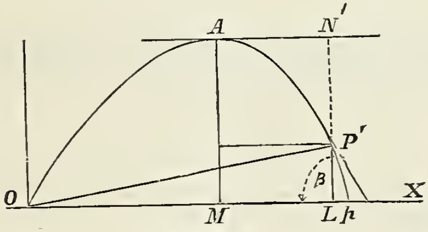


Fig. 369.

Having computed OM, we make $AM = N'P'$, whence

$$\frac{u_0^2}{g} Y_\gamma\Big]_a^0 = \frac{u_0^2}{g} Y_{\gamma'}\Big]_0^\beta \quad \text{or } Y_\gamma\Big]_a^0 = Y_{\gamma'}\Big]_0^\beta.$$

By the help of the tables β can be found, and this value of β must be used in calculating Mp.

Suppose it were required to find the height at which the shot would strike a vertical target placed at the distance OL, and the time of flight. Here we have

* See article 1748.

$$ML = LO - OM = \frac{u_0^2}{g} X_\gamma \Big]_0^\beta,$$

or

$$X_\gamma \Big]_0^\beta = (LO - OM)\frac{g}{u_0^2},$$

which gives β by the help of the tables. The value of β so found must be used to find $N'P'$, which subtracted from AM, computed by the formula on page 641, gives the required height. We must proceed in the same way if it be required to find where the shot will be at a given time.

u_0 may be obtained by putting $\phi = a$ in equation (19) below (a denoting the angle of projection); replacing ϕ, and substituting the value of u_0, we can obtain from the same equation the value of u_ϕ (ϕ being known or assumed).

1747. Functions belonging to the descending branch are usually distinguished from those belonging to the ascending branch by a prime; thus, ϕ' denotes the angle made by the descending branch of the curve with the horizontal plane.

The symbol *f-s* is sometimes used to denote feet per second.

The relation between the horizontal component of the velocity and the corresponding velocity in the curve is expressed thus:

$$v_\phi \cos\phi = u_\phi$$

and, consequently (a being the angle of projection, and V the initial velocity),

$$V \cos a = u.$$

1748. To DETERMINE γ.

We have $\gamma = \dfrac{2bu_0^3}{g}$ (by definition, page 639); . . . .(17)

Now, it is obvious that b must increase directly with the transverse section of the projectile, and inversely with its weight: that is, it must be proportional to $\frac{c^2}{w}$, c denoting the calibre of the projectile; we therefore put

$$2b = K.\frac{c^2}{w}.\left(\frac{1}{1000}\right)^3 \ldots\ldots\ldots\ldots\ldots\ldots (18)$$

in which K has been determined experimentally for such velocities as are likely to occur in practice; the factor $\frac{1}{(1000)^3}$ is introduced to save space in printing the tables.

From equations (11) and (18) we obtain by eliminating $2b$

$$\frac{1}{u_0^{\ 3}} = \frac{1}{u_\phi^{\ 3}} + \frac{Kc^2}{gw}.\frac{3\tan\phi + \tan^3\phi}{(1000)^3} \ldots\ldots\ldots (19)$$

or $$\left(\frac{1000}{u_0}\right)^3 = \left(\frac{1000}{u_\phi}\right)^3 + \frac{K}{g}.\frac{c^2}{w}(3\tan\phi + \tan^3\phi) \ldots\ldots\ldots (20)$$

and introducing the value of $u_0^{\ 3}$ from (20) in (12) and reducing, we have

$$\gamma = \frac{\frac{K}{g}.\frac{c^2}{w}}{\left(\frac{1000}{u_\phi}\right)^3 + \frac{K}{g}.\frac{c^2}{w}(3\tan\phi + \tan^3\phi)} \ldots\ldots\ldots (21)$$

Log $\frac{K}{g}$ is found in Tables I and II, and

Log $(3\tan\phi + \tan^3\phi) =$ Log P_ϕ, in Tables III and V.

EXAMPLES.

1749. A 16-pounder fires an ogival-headed shot 16 lbs. in weight and 3.54 in. in diameter, the angle of projection being 2°, and the initial velocity 1358 ft. per sec.; find the trajectory and time of flight.

Putting $N = \left(\frac{1000}{u_\phi}\right)^3$, and $P_\phi = (3\tan\phi + \tan^3\phi)$, (21) becomes

$$\gamma = \frac{\frac{K}{g} \cdot \frac{c^2}{w}}{N + \frac{K}{g} \cdot \frac{c^2}{w} . P_\phi} = \frac{\frac{Kc^2}{gw}}{\left(\frac{1000}{u_0}\right)^3} \quad \ldots\ldots\ldots\ldots (22)$$

$$u_\phi = u_2 = V \cos 2° = 1358 \cos 2°,$$
$$w = 16 \text{ lbs., and } c = 3.54 \text{ in.}$$

1.358 ar. co.		9.86710	
2°, sec		10.00026	
$\frac{1000}{u_2}$	Log	9.86736	
$\left(\frac{1000}{u_2}\right)^3 = 0.40002$	3 Log	9.60208	
$\frac{K}{g}$ $(v = 1358)$	Log	0.51793 (Table I.)	
$c = 3.54$	2 Log	1.09800	
$w = 16$	ar. co.	8.79588	
$\frac{K}{g} \cdot \frac{c^2}{w}$	Log	0.41181	Log 0.41181
P_2 (Table III.).....	Log	9.02038	
0.27051	Log	9.43219	
$\left(\frac{1000}{u_0}\right)^3$ 0.67053			Log 9.82642
$\gamma = 3.85$			Log 0.58539

The value of $\frac{K}{g}$ (for $v = 1358$), employed in the above computation, is too small; a more accurate result may be obtained by taking the value corresponding to the mean of the initial velocity (1358), and the value of u_0 obtained from Log $\left(\frac{1000}{u_0}\right)^3$ found above, thus:

$$\text{Log} \left(\frac{1000}{u_0}\right)^3 = 9{\cdot}82642,$$

whence $u_0 = 1143$; but $u_2 = 1357$

$$\therefore \tfrac{1}{2}(u_0 + u_2) = 1250;$$

corresponding correction of Log $\frac{K}{g} = +0.01077$.

$\frac{K}{g} \cdot \frac{c^2}{w}(1250)$ ....Log 0.42258

0.27730 ....Log 9.44296 *

$\left(\frac{1000}{u_2}\right)^3 = 0.40002$

0.67732 ....Log 9.83079

$\gamma = 3.91$ 0.59179

$$u_0 = 1139.$$

$$\therefore X_{3\cdot 9}\Big]_0^2 = 0.04118, \text{ and } x\Big]_0^2 = x' = \frac{u_0^2}{g} \cdot X_{3\cdot 9}\Big]_0^2 = 1659.7 \text{ ft.}$$

$$Y_{3\cdot 9}\Big]_0^2 = 0.00076, \text{ and } y\Big]_0^2 = y' = \frac{u_0^2}{g} Y_{3\cdot 9}\Big]_0^2 = 30.67 \text{ ft.}$$

$$T_{3\cdot 9}\Big]_0^2 = 0.03788, \text{ and } t\Big]_0^2 = t' = \frac{u_0}{g} T_{3\cdot 9}\Big]_0^2 = 1''.34.$$

1750. For the descending branch, suppose we wish to find the co-ordinates of the point at which the curve makes an angle of 2°.4 with the axis of x, and suppose that by a rough computation it has been found that the mean velocity is about 1080 ft. per sec.

From equation (22) we have

$$\gamma = \frac{K}{g} \cdot \frac{c^2}{w}\left(\frac{u_0}{1000}\right)^3$$

$\left(\frac{u_0}{1000}\right)^3$ ....3 Log 0.16921

c ....2 Log 1.09800

w ....ar. co. 8.79588

$\frac{K}{g}$ (1080) ....Log 0.50680

$\gamma = 3.714$ 0.56989

* Obtained by adding correction to 9.43219.

$$\therefore X\Big]_{3.7\ 2.4}^{0} = 0.03670, \quad x\Big]_{2.4}^{0} = x'' = 1479.2 \text{ ft.};$$

$$Y\Big]_{3.7\ 2.4}^{0} = -0.000737, \; y\Big]_{2.4}^{0} = y'' = 29.70 \text{ ft.};$$

$$T\Big]_{3.7\ 2.4}^{0} = 0.03920, \quad t\Big]_{2.4}^{0} = t'' = 1''.387.$$

$$u'_{2.4} = 1002.3 \ f\text{-}s.$$

The point of projection being the origin, and x and y the coordinates of the centre of gravity of the projectile, and t the time when it is moving in the descending branch of its trajectory in a direction inclined to the horizon at an angle of 2°.4, we have

$$x = x' + x'' = 3138.9 \text{ ft.}$$
$$y = y' + y'' = 0.97 \text{ ft.}$$
$$t = t' + t'' = 2''.727.$$

The velocity

$$= v'_{2.4} = u'_{2.4} \sec 2°.4 = 1002.3 \sec 2°.4 = 1003.2 \ f\text{-}s.$$

The range on the horizontal plane

$$= (3138.9 + 0.97 \cot 2°.4), \text{ nearly.}$$

1751. A projectile 3.24 in. in diameter is discharged from a 16-pdr. with a velocity of 1307 *f-s;* to find u_0, $u'_{2.4}$, $v'_{2.4}$, x, y, and t; the values of $\frac{K}{g}$ and x being the same as in the preceding example.

$$u_0 = 1136.5, \; u'_{2.4} = 1018.6, \; v'_{2.4} = 1019.5,$$

$$x = 3101, \qquad y = -1.09, \quad t = 2''.715.$$

A spherical shot 8.9 in. in diameter, and weighing 94 lbs., is discharged with an initial velocity of 1564 *f-s*, the angle of elevation being 5°; find u_0, u'_8, v'_8, x, y and t, the mean value of $\frac{K}{g}$ being, for the ascending branch that corresponding to a velocity of 1300 *f-s*, and for the descending branch that corresponding to 900 *f-s*.

$$u_0 = 920.5, \quad x_8 = 6343', \quad y_8 = 3'.3.$$

To find the Range on a Horizontal Plane.

ϕ denoting the angle of incidence, we have

$$y\Big]_a^0 = y\Big]_0^\phi \text{ or } Y_\gamma\Big]_a^0 = Y_{\gamma'}\Big]_0^\phi.$$

In the above example, $\gamma = 3.017$ and $\gamma' = 2.822$,

also $$Y_{3.017}\Big]_5^0 = 0.006910 = Y'_{2.822}\Big]_0^\phi,$$

but $$Y_{2.822}\Big]_0^9 - Y_{2.822}\Big]_0^8 = 0.008329 - 0.006788 = 0.001541,$$

and $$Y_{2.822}\Big]_0^\phi - Y_{2.822}\Big]_0^8 = 0.000122.$$

$$\therefore \qquad \phi = 8^\circ + \frac{122}{1541} = 8^\circ.079 \text{ the angle of incidence.}$$

$$Range = x\Big]_5^0 + x'\Big]_0^{8.079} = 3559.7 + 2804.9 = 6364.6.$$

In a similar manner we obtain time of flight $= 6''.58$.

1752. A more accurate solution of the problem may be obtained by dividing each branch of the trajectory into successive portions, and using a mean approximate value of K for each portion; the final values of x, y and t will each be equal to the algebraic sum of the corresponding partial values thus obtained. It will be convenient to change K at points of the curve where its direction is inclined to the horizon some entire number of degrees, because the values of X, Y, and T are given for all those cases in the tables.*

1753. It will be found sufficient for many practical purposes to neglect the effect of gravity, and treat the motion of a shot as if its path were a straight line; this will suffice for experimental purposes when it is desired to find the loss of velocity, or the time of flight for a limited space, the initial velocity being high. The less the shot is affected by the resistance of the air the more accurate will be the results; therefore this

* For an example of this method, see Professor Bashforth's Treatise.

method will apply better to pointed elongated shot than to spherical shot, and better to solid shot than to shell of the same external form.

The equation of motion for the cubic law of resistance is

$$\frac{d^2s}{dt^2} = \frac{dv}{dt} = -2bv^3 \dots\dots\dots\dots (1)$$

or

$$\frac{dv}{v^3} = -2b\,dt.$$

Suppose that $v = V$ when $t = 0$,

$$\text{then} \int_V^v \frac{dv}{v^3} = -2b\int_0^t dt,$$

integrating and substituting value of $2b$ (page 643),

$$\frac{1}{v^2} - \frac{1}{V^2} = 4bt = 2tK\frac{c^2}{w}\frac{1}{(1000)^3},$$

or

$$\frac{c^2}{w}t = \frac{500}{K}\left\{\left(\frac{1000}{v}\right)^2 - \left(\frac{1000}{V}\right)^2\right\} \dots\dots\dots (2)$$

which connects t and v.

Again, $\frac{d^2s}{dt^2} = \frac{dv}{dt}$, since $v = \frac{ds}{dt}$, or $\frac{1}{dt} = \frac{v}{ds}$

$$\therefore \quad \frac{dv}{dt} = \frac{vdv}{ds},$$

$$\therefore \quad \frac{d^2s}{dt^2} = \frac{vdv}{ds} = -2bv^3 \text{ [equation (1)]},$$

whence

$$\int_V^v \frac{dv}{v^2} = -2b\int_0^s ds,$$

and therefore

$$\frac{1}{v} - \frac{1}{V} = 2bs = sK\frac{c^2}{w}\frac{1}{(1000)^3},$$

or $$\frac{c^2}{w} s = \frac{(1000)^2}{K} \left\{ \left(\frac{1000}{v}\right) - \left(\frac{1000}{V}\right) \right\} \quad \ldots\ldots\ldots\ldots (3)$$

which connects s and v.

If in the equation $\frac{1}{v} - \frac{1}{V} = 2bs$, we substitute $\frac{dt}{ds}$ for $\frac{1}{v}$, we have

$$\frac{dt}{ds} = \frac{1}{V} + 2bs,$$

and integrating, we have

$$t = \frac{s}{V} + bs^2 \quad \ldots\ldots\ldots\ldots (4)$$

which connects t and s.

If we divide $$\frac{1}{v^2} - \frac{1}{V^2} = 4bt$$

by $$\frac{1}{v} - \frac{1}{V} = 2bs,$$

we obtain $$\frac{1}{v} + \frac{1}{V} = \frac{2t}{s} \quad \ldots\ldots\ldots\ldots (5)$$

which connects v, t, and s independently of $2b$, the coefficient of resistance.

1754. In determining the velocity of a shot it is usual to measure the time in which a given *short* range is described, and then, dividing the space in feet by the time in seconds, the result is adopted as the approximate velocity at the middle point. If the cubic law of the resistance of the air be supposed sufficiently near the truth, this may easily be shown to be strictly correct for any range, so long as the path of the shot may be considered to be a straight line.

We have seen that when V is the initial velocity and v the velocity at the distance s, then

$$\frac{1}{v} = \frac{1}{V} + 2bs,$$

or if v' be the velocity at the distance $\frac{s}{2}$, then

$$\frac{1}{v'} = \frac{1}{V} + bs.$$

Also $\dfrac{\text{space in feet}}{\text{time in seconds}} = \dfrac{s}{t} = \dfrac{s}{\dfrac{s}{V} + bs^2}$, by equation (4),

$$= \frac{1}{\dfrac{1}{V} + bs} = v',$$

the true velocity at the middle point of the range s.

1755. Inasmuch as the resistance of the air does not vary strictly as the cube of the velocity, when formulæ (2), (3), and (4) are used for considerable differences of V and v, it is necessary to use several numerical values of K. But as this would be a troublesome operation to perform in each case, general tables of the values of $\dfrac{500}{K}\left\{\left(\dfrac{1000}{v}\right)^2 - \left(\dfrac{1000}{V}\right)^2\right\}$ for spherical and ogival-headed shot [Tables IX and XI], and also of the values of $\dfrac{(1000)^2}{K}\left\{\dfrac{1000}{v} - \dfrac{1000}{V}\right\}$ for spherical and elongated shot [Tables VIII and X], have been computed. It is manifest that these quantities depend upon v and V, which are quite independent of the nature of the shot, while K is a coefficient dependent on the *form* of the projectile.

1756. Suppose the initial velocity to be V, and that the velocity falls from V to v_1, in space s_1, and in time t_1; from v_1 to v_2 in space s_2, and in time t_2; from v_2 to v_3 in space s_3, and in time t_3; . . . and from v_{n-1} to v_n, in space s_n, and in time t_n. Let K_1, K_2, K_3, . . . K_n be the particular values of K due to the mean of the velocities V and v_1, v_1 and v_2, v_2 and $v_3 \ldots v_{n-1}$ and v_n. Then we have from equation (2)

$$\frac{c^2}{w} t_1 = \frac{500}{K_1}\left\{\left(\frac{1000}{v_1}\right)^2 - \left(\frac{1000}{V}\right)^2\right\},$$

$$\frac{c^2}{w} t_2 = \frac{500}{K_2}\left\{\left(\frac{1000}{v_2}\right)^2 - \left(\frac{1000}{v_1}\right)^2\right\},$$

$$\frac{c^2}{w} t_3 = \frac{500}{K_3}\left\{\left(\frac{1000}{v_3}\right)^2 - \left(\frac{1000}{v_2}\right)^2\right\},$$

etc. etc.,

$$\frac{c^2}{w} t_n = \frac{500}{K_n} \left\{ \left(\frac{1000}{v_n}\right)^2 - \left(\frac{1000}{v_{n-1}}\right)^2 \right\}.$$

Adding these equations, we have

$$\frac{c^2}{w} \Sigma t_n = 500 \Sigma \frac{1}{K_n} \left\{ \left(\frac{1000}{v_n}\right)^2 - \left(\frac{1000}{v_{n-1}}\right)^2 \right\} \ldots\ldots\text{(I.)}$$

Proceeding in the same way with equation (3), we have

$$\frac{c^2}{w} s_1 = \frac{(1000)^2}{K_1} \left\{ \frac{1000}{v_1} - \frac{1000}{V} \right\},$$

$$\frac{c^2}{w} s_2 = \frac{(1000)^2}{K_2} \left\{ \frac{1000}{v_2} - \frac{1000}{v_1} \right\},$$

etc. etc.,

therefore $$\frac{c^2}{w} \Sigma s_n = (1000)^2 \Sigma \frac{1}{K_n} \left\{ \frac{1000}{v_n} - \frac{1000}{v_{n-1}} \right\} \ldots\ldots\text{(II.)}$$

In calculating the numerical values of the right-hand members of the above equations, V was taken (for elongated shot) $= 1700$ *f-s*; $v_1 = 1690$; $v_2 = 1680$; $v_3 = 1670$, etc., and K_1 the coefficient corresponding to the velocity 1695 *f-s*, K_2 to 1685, K_3 to 1675, etc. Tables of the values of $\frac{c^2}{w} t$ and $\frac{c^2}{w} s$ were thus formed corresponding to a loss of every ten feet in the velocity. By interpolation, the values of $\frac{c^2}{w} t$ and of $\frac{c^2}{w} s$ which have been given in the tables, were then found for every foot lost in velocity.

Examples of the use of Tables VIII, IX, X, and XI.

1757. (1) Let it be required to find in what range an 11.52-inch ogival-headed shot weighing 600 lbs. would have its velocity reduced from 1400 to 1300 *f-s*. Let s denote the required space, then

$$\frac{c^2}{w} . s = \frac{(11.52)^2}{600} s = 1865 - 1348 = 517,$$

$$\therefore \qquad s = \frac{517 \times 600}{(11.52)^2} = 2337 \text{ ft.}$$

517 is the difference of the ranges opposite 1400 and 1300 *f-s* in Table VIII.

(2) Let it be required to find in what *time* the velocity of the same shot would be reduced from 1400 to 1300 *f-s*.

Here $\frac{c^2}{w}t = 1''.258 - 0''.875 = 0''.383$, the difference of the times opposite 1400 and 1300 *f-s* in Table IX. Hence $t = 1''.732$.

(3) If, on the other hand, the initial velocity being given 1350 *f-s*, it was required to find what would be the loss of velocity in 1500 ft., we should have given

$$\frac{c^2}{w}s = \frac{(11.50)^2}{600} 1500 = 331.8,$$

the *reduced range*. Now opposite the initial velocity 1350 *f-s* in Table VIII we find 1599, to which must be added the reduced range 331.8, making 1930.8; and corresponding to this we find the velocity 1288.2 *f-s*, by the same table; hence the velocity of an 11.52-in. 600-lb. elongated shot would fall from 1350 to 1288.2 *f-s* in 1500 feet.

(4) In like manner, if it was required to find how much the velocity of the same shot would be reduced in half a second. its initial velocity being 1334 *f-s*, we must find the *reduced time*, $\frac{c^2}{w}t = .2212 \times 0''.5 = 0''.1106$; adding this to $1''.120$, the number opposite the velocity 1334 *f-s* in Table IX, we obtain $1''.2306$; and opposite $1''.2306$ we obtain by proportional parts 1306.6 *f-s*, which is the velocity the shot will retain at the end of half a second.

(5) Suppose a 15-in. spherical shot weighing 452 lbs. to be fired with an initial velocity of 1400 *f-s* at a target 500 yards off; to find the striking velocity. Here $c = 14.88$ in.; then

$$\frac{c^2}{w}s = \frac{(14\ 88)^2 \times 15}{45200} = 734.7,$$

the reduced range; opposite the velocity 1400 in Table X we find 1501, and adding 734.7 to this, we have 2235.7, opposite which, in the same table, we find the velocity 1215.8 *f-s*, which is the required striking velocity.

Table VIII was deduced from experiments made with ogival-headed shot struck with a radius of $1\frac{1}{2}$ diameters.

For high initial velocities and low angles of projection, tables VIII to XI may be used to find approximately the time of flight and trajectory of the shot; thus, suppose V the initial velocity, and v the velocity when the shot has described the space OP' (Fig. 369) in time t, the effect of gravity not being considered; then, by tables VIII to XI, it is possible to find OP' and t. If x, y be the co-ordinates of P' at time t, then

$$\left.\begin{aligned} x &= OP' \cos a \\ y &= OP' \sin a - \tfrac{1}{2}gt^2 \end{aligned}\right\}$$

become known because OP' and t are known approximately.

Table XII will be useful in finding the values of $\frac{1}{2}gt^2$.

The Law of Penetration of Projectiles.*

1758. A Commission, appointed by the French Minister of War, carried on experiments at Metz, in 1834 and 1835, with a view to determine the law of penetration of spherical shot into various kinds of wood, masonry, and earth. The conclusions arrived at were, first, that the resistance of the same substance to spherical shot of *different diameters* varied as the square of the diameter of the shot; and, secondly, that the resistance of *different substances* to the same shot varied as $a + \beta \times$ (velocity)^2, where a and β were constant for each substance. If, therefore, c be the diameter of the shot in inches, w its weight in pounds, and v its velocity in feet per second, then the resistance to the shot will be expressed by $\frac{1}{4}\pi c^2 (a + \beta v^2) = c^2 (\lambda + \mu v^2)$, and the retarding force by $\frac{g}{w} c^2 (\lambda + \mu v^2)$.

The following are the values of λ, μ, and $\frac{\lambda}{\mu}$ calculated from the values a and β, as given by Didion,† and adapted to English measures.

* Bashforth *On the Motion of Projectiles*, London, 1873, p. 74.
† Didion, *Traité*, pp. 301, 302, and 304.

Substances.	λ	μ	$u=\sqrt{\left(\frac{\lambda}{\mu}\right)}$
Oak, Beech, and Ash	2329.4	.004328	734
Elm	1787.5	.003322	734
Fir and Birch	1296.0	.002408	734
Poplar	1217.7	.002263	734
Sand, mixed with Gravel	486.0	.009031	232
Earth, mixed with Sand and Gravel	670.3	.012456	232
Clayey soil	1167.5	.003799	554
Earth from an old Parapet	782.0	.004360	424
Damp Clay	297.2	.002209	367
Moistened Clay	102.4	.000762	367
Masonry of good quality	6166.9	.008595	847
Masonry of medium quality	4915.7	.006851	847
Brickwork	3530.4	.004920	847

1759. Suppose that V is the striking velocity of a spherical shot, and that when it has penetrated a distance s, its velocity is v; let S denote the value of s when the shot comes to rest, that is, when $v=0$.

We have $\frac{d^2s}{dt^2}=\frac{vdv}{ds}=-\frac{gc^2}{w}(\lambda+\mu v^2)$;

$$\therefore \int_0^V \frac{vdv}{\lambda+\mu v^2}=-\frac{c^2g}{w}\int_S^0 ds,$$

or $$\frac{1}{2\mu}\log_\varepsilon(\lambda+\mu v^2)\Big]_0^V=\frac{c^2g}{w}S,$$

$$\therefore \quad S=\frac{w}{2\mu\, c^2g}\log_\varepsilon\left(1+\frac{\mu V^2}{\lambda}\right),$$

or $$S=\frac{w\log_\varepsilon 10}{2\mu\, c^2g}\log_{10}\left(1+\frac{\mu V^2}{\lambda}\right),$$

$$S=\frac{w}{2\mu\, c^2g\log_{10}\varepsilon}\log_{10}\left(1+\frac{\mu V^2}{\lambda}\right).$$

CHAPTER XII.

NAVAL OPERATIONS ON SHORE.*

Section I.—General Considerations.

1760. CONSIDERATIONS.—The application of a naval force to the purposes of littoral warfare can only be considered as incidental to the general purposes for which the navy is created, and the character of the operations is necessarily limited by the character and strength of the force. The squadrons which the navy might collect would seldom be able to land a sufficient number of men to cope successfully with the forts or troops of any civilized nation with whom we might be at war. When they have been employed by foreign nations against each other, or against us, the operations have been desultory and generally attended with deplorable results.

1761. The landing of seamen would rarely be resorted to when opposed by good infantry, or when the object to be attained would take them very far from their base of operations. It would be unwise, generally speaking, to expose them voluntarily to measure force in the field with disciplined infantry and cavalry. When necessity leads to such a measure, it should be based on the unquestioned superiority of the sailors and marines, both in numbers and appointments. Exceptional cases occur where the strength of a ship or squadron may be landed with important effect, as when the rights of the flag, of civilization, or of humanity require the use of a naval force for want of other means. The offences of savage nations or islanders, or of a piratical people, may be instanced as cases requiring punishment or intimidation.

1762. Should it be judged expedient, however, to prosecute this desultory kind of warfare, the commanders employed in it will do well to consider that a descent ought never to be hazarded

* Compiled by Lieutenant J. C. Soley, United States Navy.

into an enemy's country without having taken proper precautions to secure a retreat; that the severest discipline ought to be preserved during all the operations of the campaign; that a commander ought never to disembark but on a well-concerted plan, nor commence his military operations without some immediate point or object in view; that a re-embarkation ought never to be attempted, except from a clear, open beach, where the approach of an enemy may be seen and the forces covered by the fire from the ships.

1763. THE BASE.—In all naval operations on shore, the first point to consider and fix should be the base of operations. Whenever it is possible, this base should be the squadron; but when operating in shallow waters, the largest possible ship or ships, whose draught will admit of it, should accompany the boats and keep up a constant communication with the forces on shore, so as to be ready at all times to forward with dispatch supplies both of provisions and ammunition, and to send forward reinforcements if required.

1764. PREPARATIONS.—Before landing, many points must present themselves for the consideration of the commander-in-chief: the means of approach, the opportunities for landing, the nature of the ground, the possibility of maintaining communications with a suitable base, the character and numbers of the opposing force, the possibility and probability of accomplishing the objects of the expedition, and the safe withdrawal of the forces.

1765. Taking it for granted that all the preliminary drills have been thoroughly taught, and that the men are fully acquainted with the manual of the howitzer and with the skirmish drill, and have some knowledge of battalion drill, the first consideration is the means of approach. Every care should be taken to keep the men fresh for their work; and to this end, the boats containing the landing-force should be towed to the place of disembarkation by the steam launches and cutters of the fleet.

1766. The officer in command of the landing-force should be furnished with accurate information of the depth of water and the dangers of navigation. Care must be taken also to get as much knowledge as is possible of the character of the ground and the opportunities for landing. Generally speaking, an open beach which may be swept by the fire of the shipping and will offer a firm footing, should be selected. Judicious means, however, must be used to get the force landed without opposition; avoiding it either by keeping out of sight, or, if seen, by pulling rapidly to some point which may be more readily reached by the boats than by the party on shore, or by dividing the force and making false attacks upon different points.

1767. If, however, such attempts are unavailing, then it only remains to land promptly in the face of the enemy; and to this end, that part of the beach must be selected where the footing is most likely to be firm, the bank generally shelving, and the bottom freest from stones and mud, least exposed to the surf, and most especially where no cover of any kind for the enemy exists within some hundreds of yards from the shore. It is also of the utmost importance to keep up communication with the base, and for this purpose some vessels should be stationed to cover and protect the boats, and also to furnish assistance to the party on shore in whatever way it may be needed.

Section II.—Landing.

1768. Details.—Before landing, the station of each boat should be fixed, and every officer should be made acquainted with the details of the organization, and particularly with his position after landing.

The small-arm men should be formed into companies of forty men, with four petty officers, and armed with breech-loading rifles and bayonets; each company to be commanded by a lieutenant and two other officers. The howitzer crews should be composed of twenty-one men, each man being armed with a cutlass and breech-loading pistol.

1769. Each ship landing two companies should also furnish twelve pioneers: four with a saw and axe each, four with a pick-axe and spade each, four with small crowbars and sledge-hammers each, or such intrenching or other tools as the nature of the expedition may require; the men should be equipped with those tools to whose use they are most accustomed: carpenters with saws and axes, firemen with intrenching-tools. Vessels furnishing a smaller contingent of infantry should furnish a proportionate number of pioneers. An armorer, who will join the pioneers, should be sent with each landing-party, and furnished with cleaning-rods, screw-drivers, and gimlets. The ship's bugler and the drummer and fifer should be sent with the men.

1770. Every man in the command should have a canteen and haversack, and a blanket, folded and slung over his shoulder.

1771. Each division of boats should carry a distinguishing flag; scaling-ladders, intrenching-tools, and other implements should be carried by designated boats.

1772. If landing in a heavy surf, the ammunition should be put into small powder-tanks with the lids well screwed down, and the howitzers might be rafted on shore if they could not be carried safely in the boats.

Fig. 370.

1773. Landing.—Should the distance to the point of landing be considerable, the boats should be towed to within a suitable distance of the beach, being careful to keep out of range. On arriving opposite the place of disembarkation, the tow-ropes should be cast off and the line formed preparatory to landing. The boats containing the heavy howitzers should be on the extreme flanks, next the light howitzers which are to be landed, and the main body of infantry in the middle, with the skirmishers in the centre. There should be a reserve force of howitzers and infantry ready to be directed to either flank, or to reinforce any particular part of the line. The howitzer divisions should be formed in echelon, so as to deliver a cross-fire on that part of the beach where the landing is to be made. When all these dispositions have been made, the boats should pull in for the landing-place.

1774. It should be borne in mind that the force will be at the greatest disadvantage when disembarking in the face of a strong opposition; for in using all the celerity that is practicable with trained men, there must be a few minutes when the pieces to be put ashore must be inactive. Therefore it is necessary that, as soon as the howitzer fire has cleared the beach, a strong body of skirmishers and infantry should be landed, to engage the enemy during the disembarkation of the howitzers. No gun should be landed before there are at least forty men on the beach.

1775. Meanwhile the fire of the heavy howitzers should be discontinued, unless they can safely fire shell over the heads of the party on shore. The skirmishers should immediately advance and seize the nearest cover, while the main body of infantry will pull in and land, followed by the howitzers. Immediately the main body of infantry has landed they should be deployed into line of battle, with a strong skirmish line in advance, and they should take up the strongest position possible, the howitzers being brought into position as fast as they are landed. The line should be formed in such a manner that the flanks will if possible be protected by the nature of the ground, or by the fire from the ships.

1776. The Boats will always land a boat's length apart. Before leaving the ship, four boat-keepers should be appointed to each boat carrying a howitzer, and two for the others, with an officer in charge of each division of boats, who should on no account leave them. The boats should be hauled off to their anchors with a long scope of cable, and a man left in each boat to veer in, that the troops may be readily embarked. The officer left in charge of the boats should be careful to avoid being surprised, and, if circumstances will admit, should strengthen his position by cutting down trees and throwing up small breastworks a short distance in front. There should be at least one boat with a full crew left with him, to enable him to keep up communication with his base; he should also endeavor to keep up communication with the commander of the forces by means of signal-men.

Section III.—On the March.

1777. The Advance.—If the force has landed without opposition, the first duty will be to make a reconnaissance, in order to ascertain the position of the enemy, the situation of the nearest towns and villages, the direction of roads, streams, etc., and to obtain a general idea of the country. If it becomes necessary to advance into the country, the manner of advance must be determined by the commanding officer. If the country be open, or if no opposition be met with, the column may take up the march in close order.

1778. Advance-guards.—If, on the other hand, the line of march should pass over hilly country, or through woods, or if there are any indications of the presence of an enemy, every precaution should be taken against a surprise, by throwing out advance-guards, rear-guards, and flankers, as may be deemed necessary.

1779. The object of these guards is to give time for the column to make the necessary preparations for attack or retreat in case the enemy are discovered.

1780. The guards should each consist of at least one officer,

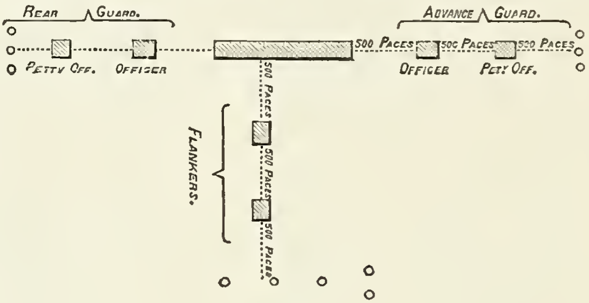


Fig. 371.

one petty officer, and twenty men, arranged as in the figure. Generally speaking, the advance-guard should be from one-fifth to one-tenth of the whole force, and should be accompanied by a detachment of signal-men and pioneers. The advance-guard may be increased or diminished at the discretion of the commanding officer.

1781. When the column halts, the advance-guard does the same, but the men at the head should occupy the neighboring heights, if there be any within four or five hundred yards. There should never be less than three men at the head, and different divisions should endeavor to keep their distance from the others. On coming to a wood, the men at the head should be reinforced, and some sent through, and others around it, the column halting until the wood has been patrolled. The same rule should be followed on coming to a village. They should never enter a defile without previously occupying the heights on either side by flanking-parties. At night the distances should be reduced, and communication kept up with a chain of men just far enough apart to see each other. Should the advance-guard be attacked, it should engage with spirit, and never fall back until absolutely obliged to do so, and then the retreat should be made on either side of the column, and never on the column itself.

1782. Rear-guards.—The object of rear-guards is to prevent the enemy from approaching the column unperceived, and the men composing it should be picked men. Should they be attacked, the men in rear should be reinforced by the other squads, and the enemy must be held in check. If they retire, the same rules apply to them as to the advance-guard. Whenever the

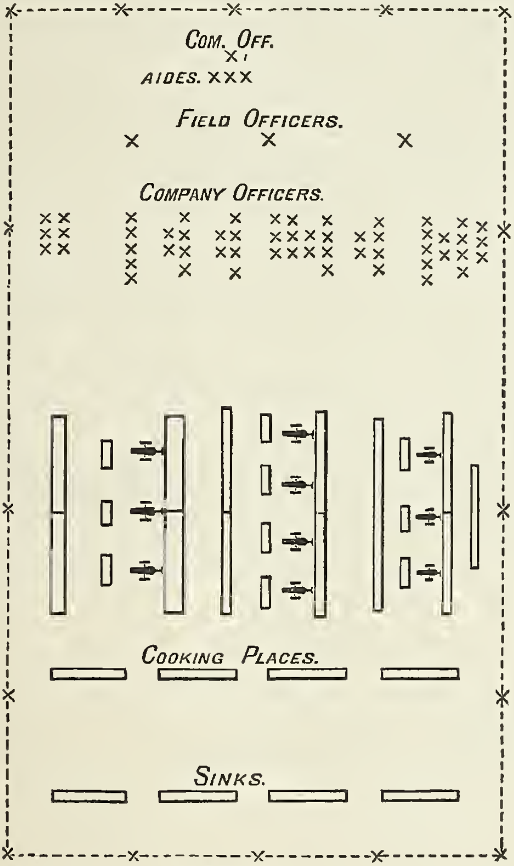


Fig. 372.

Bivouac of a force of
1 Comp. Pioneers....70
10 Howitzers.......220
12 Companies......1008
Officers...........54
} 1352 men.

column halts, the rear-guard should face to the rear. Flankers are placed as in the figure, on either or both flanks, as may be necessary, and their movements are governed by the same general rules as the other guards; all parties so thrown out should keep themselves concealed as much as possible.

1783. Bivouac.—In selecting a site for a bivouac, wood and water are the great requisites. In cold weather, woods are the warmest places, but in tropical climates it is better to bivouac in the open. Dry and sheltered positions should be chosen. If obliged to bivouac where one may have to engage, it is better to take a position in advance of the one which must be occupied in fighting. If obliged to bivouac near a marsh, there should be some rising ground between it and the position selected; this should be done if possible some time before the arrival of the column.

1784. On arriving on the ground selected, the infantry and howitzers should wheel into open column by divisions, crews of howitzers formed to the rear and the men mustered, absentees reported to the commanding officer, and arms stacked. The men should sleep where they stand in ranks, officers sleeping opposite the flanks. Cooking places should be made on the other flanks, and sinks dug some two hundred yards off. The camp-guard should be immediately posted, whose duty it is to prevent all persons from leaving, except officers and authorized persons. The advance-guard and rear-guard should be relieved in the afternoon, at the time of going into bivouac.

1785. Grand-guard.—Besides the regular camp-guard, which is charged with maintaining order and discipline in the camp, there should be a grand-guard thrown out in the direction of the

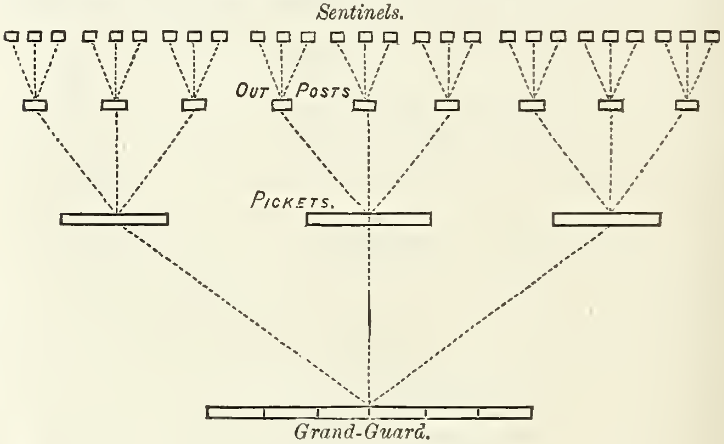


Fig. 373.

enemy. This should consist of one or two companies, according to the nature of the service and the ground to be covered. The first line is the grand-guard, one-half of whom may rest six hours, and the other half be awake and ready for duty six hours. This is the post from which the pickets, outposts, and sentinels radiate. The picket-guards compose the second line, and are relieved from the grand-guard every eight hours; one-half to be under arms half the time, the other half to rest half the time. The third line are the outposts, consisting of nine men, relieved from the pickets every two hours: these men should be always watchful. The fourth or front line of sentinels are to be relieved from the outposts every hour: they patrol constantly, and connect with one another.

1786. The officer commanding the grand-guard should be stationed at the first line, visiting the second every six hours, and generally supervising. The other officers should be stationed with the pickets, and should visit the outposts and sentinels frequently. The petty officers command the outposts. It is not necessary that the line should be straight, but the general principles should always be carried out. It is generally advisable to have some howitzers with the grand-guard, on the first line, posted so as to command the approaches.

1787. When attacked, the outposts forming as skirmishers move to the support of the sentinels; pickets may move forward to support the others, or all may retire skirmishing as the nature of the attack may suggest. Should the attack be so strong that the whole grand-guard is compelled to retire, then each line will retire fighting. When an attack commences, a message should be instantly sent to the commanding officer, detailing its nature and giving any necessary information.

Section IV.—Engaging.

1788. The Attack.—This operation must be considered under two phases: 1st. The column has halted within sufficiently easy distance of the enemy to make a march of from five to ten miles, with the intention of attacking as soon as it arrives. 2d. It has halted at too great a distance for that purpose, so it marches up to him, and bivouacs for the night to attack next morning.

1789. If the column has been closely pursuing the enemy, with the advance-guard continually in contact with the enemy's rear, it may happen that the retreating force may be suddenly found drawn up to receive battle. Under such circumstances, it would be better to act as in the second case, particularly if it occurs late in the day, in which case all preparations for attack should be made late in the night; but should the enemy be demoralized from previous defeats or other causes, he should be attacked when he turns to show fight, as in the first case.

1790. In either case, the nature of the country and its communications must determine the mode of the advance; but it should resemble closely the order in which it is intended to fight, covered by swarms of skirmishers as an advance-guard. If it is impossible to advance in line of battle, the double column is suggested as being the easiest to deploy. In any case, the column should be kept closed up and ready to be deployed into line, followed in the rear by the reserve.

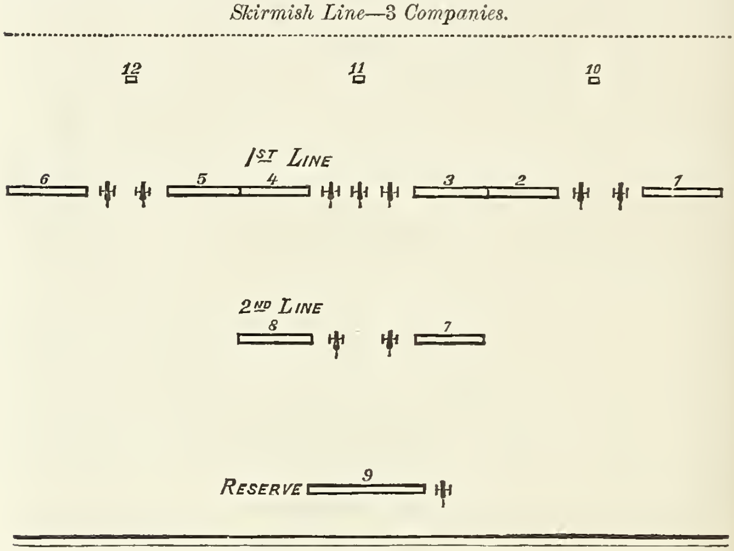


FIG. 374.—FORCE DEPLOYED, READY TO ATTACK.

Arrived within the fire of the enemy's guns, the position should be reconnoitred, and the column deployed into line and placed in position.

1791. These arrangements should be made under cover of the advanced line of skirmishers. Having decided on what part of the enemy's line to make his false and real attacks, the commanding officer should attack as soon as possible, if the chances are in his favor: delays in such cases are very dangerous. The artillery should be massed opposite that part of the enemy's line where the real attack is to be made. It is sometimes necessary to begin an action with all the guns available at the moment, in order to keep the enemy at a distance while the troops are getting into position.

1792. The commanding officer must decide whether the assault is to be made in line or in column. If in line, it must be remembered that the charge must occasion much disorder in the line, which, unless supported on the instant of its first success, is sure to be driven back by a counter-charge. For this reason, a second line should be formed and placed so as to cover the assault.

1793. Taking it for granted that it was decided to attack the enemy's left, the disposition would be as in the figure. Of

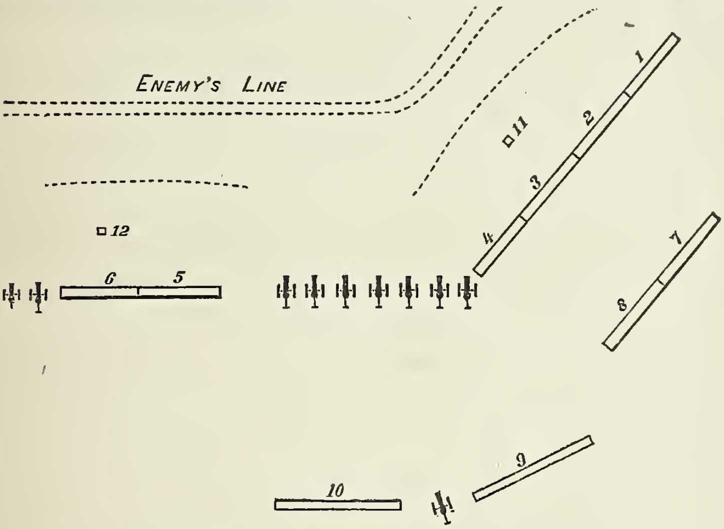


FIG. 375.—FORCE ATTACKING ENEMY'S LEFT FLANK.

course, before the advance, all the available guns should be brought to bear on the left. When it was considered that the artillery fire had told sufficiently, the attacking-party should advance. As soon as they become engaged a partial advance of the whole line should take place. The advance should be closely covered by skirmishers, who should push on as near to the enemy's lines as possible.

1794. If, however, during the march the enemy should be unexpectedly found in position, or when called upon to act as in the first case, more time will be required to deploy and to make arrangements for attacking. The advance-guard should take up some defensive position, and strengthen it if possible. The commander should hasten to the front and reconnoitre the ground. Having done so, orders must be sent to the commanders of the several divisions, telling them where to deploy, etc. These dispositions must depend entirely on whether it is intended to await the enemy's attack or to attack first, and in the latter case, on what part of the enemy's line the attack is to be made.

1795. THE SKIRMISHERS.—Specially instructed men are necessary for this work. In covering a line or a column advancing to attack an enemy, their numbers should be increased according as the nature of the ground to be moved over affords cover; every skirmisher of the enemy should be wiped out by them from the front of the attacking-line, and a continued fire maintained up to the last moment, as this will serve to screen the advance and to steady the men. They should move forward quickly as soon as the advance commences, keeping about 150 yards ahead, and under cover as much as they can, and press as close to the enemy's line as possible, even up to 150 yards. Too much care cannot be taken in guarding against a waste of ammunition: the firing should be deliberate and careful in the extreme, and not a shot thrown away. Random firing only encourages and gives confidence to the enemy, while it depletes one's own resources.

1796. THE INFANTRY.—In advancing the main body of the infantry to the attack, they should be distributed in two lines, as above shown (Fig. 375). The lines should advance together at a steady quick march to within 150 yards of the enemy, when the order will be given to the first line, "Prepare to charge." If the skirmishers have pushed up close to the enemy, they will lie down, and the first line passing over them will commence their charge as they do so. The second line should continue the movement in quick-step. At the order "Charge," let the men cheer with a will, and take up the run with their pieces at a trail, seizing them with the left hand as they close with the enemy.

1797. THE ARTILLERY.—The ground in the vicinity of the point to be attacked must be swept by a heavy cannonade before the attacking-force is launched forward. The heaviest possible fire should be maintained up to the last moment, and when the attacking-force has advanced into such a position as to impede the fire, the howitzers should, if possible, be advanced into such a position that they can reopen.

1798. After the charge commences, they should devote themselves to the other part of the line, or be placed in such a position as best to repel a counter-charge, or they may be used as circumstances dictate, being careful to keep some companies with them. The skirmishers, after the charge has commenced, should form on the artillery

1799. The guns should always be massed when it is possible, as the moral effect is much greater than when they are scattered, and their fire should be directed to the enemy's men rather than to his guns. They should always be supported by infantry on one or both flanks, but never in rear.

1800. The Defence.—Great care is necessary in the selection of a position where a defence is to be made. It should afford a depth of five or six hundred yards on which to manœuvre, with free communication from right to left, and with roads in rear by which to retreat. The protection of the flanks is a serious consideration; one at least ought to rest on some impassable obstacle. The general line of positions must either curve convexly or concavely towards the enemy, or there must be a mixture of both. If the flanks are strong and not easily approached or turned, the concave is the stronger. If, on the contrary, the spots where the flanks rest present no feature of strength, it is better to have them retired, thus forming a convex front to the enemy.

1801. An obstacle, not actually an impassable one, running somewhat parallel to the general line of the position and about two or three hundred yards in front of it, adds greatly to its strength; but such obstacles as high banks, hedges, etc., which would afford any cover, are most dangerous. Obstacles that cut up one's own lines are to be avoided, and also positions with wooded ground in front of them. If there is but one road to retreat by, it should run from near the centre.

1802. The Infantry.—In distributing the troops along a chosen position, some parts of it will require to be held by a much greater number than others, and the commander must decide which is the important point or key, and that point should be occupied in force, with the reserves near at hand. He should then set to work to strengthen himself artificially. The formation of the command into two lines instead of one has many advantages, as it keeps it more compact and renders it easier to support any particular point of the line; but the second line should be used very sparingly, and only when the necessity is urgent.

1803. The front of the infantry will always be covered by skirmishers, so that no fire can be delivered till they have been driven in: when the front has been cleared and the enemy is advancing, it is time for the infantry to open fire, kneeling and with volleys, *by word of command*. File-firing should not be used at such a time, as it is so difficult to stop it. It will be for the commander to decide when it shall stop, and then the order should be given, "Prepare to charge," and let them go in with a cheer. An advancing enemy should never be awaited in the open plain: in all such attacks there is a moment when the defendant must charge. Immediately after charging the men should be reformed and led back to their original position without being allowed to go too far in their broken state.

1804. The Artillery.—In defence, as in attack, it is the duty of the artillery to devote itself to the enemy's men, and it should be placed on that flank which occupies the strongest position. When neither flank has any natural supports, the guns should be massed in the centre. These rules can be adhered to when the front does not exceed 1200 yards; beyond that, batteries must occupy several parts of the position.

1805. Squares to resist cavalry should only be formed when absolutely necessary, as the square is a mark for every description of fire. In forming them, advantage should be taken of any favorable ground. If there is an obstacle, such as a small hedge, ditch, or fence, it is better to form at about twenty yards from it than to hug it closely.

Section V.—Field Fortification.

1806. Definitions.—When an armed force is constrained to act on the defensive, from disparity of numbers or strength, it should endeavor to counterbalance this disparity by selecting a position on which to receive battle which will afford every military advantage to itself and prove, in a corresponding degree, unfavorable to the assailant. Such a position should present natural obstructions to the advance of an assailant; it should screen the assailed from fire; it should command the ground over which the assailant must advance; it should command the lines of approach by a front and cross fire; it should offer no obstructions to the free movements of the assailed; it should have natural points of support both on the flanks and in the rear; and its lines of retreat should be ample and secure. As natural defensive positions may rarely possess the most essential of these advantages, their defects must be remedied by artificial means. These means are termed *fortifications.*

1807. *Fortification* may therefore be defined as the art of so arranging a position selected for defence that an inferior force shall be able to resist with advantage the assaults of one superior to it.

The covering mass is termed a *Parapet* when it shelters the assailed from the view and fire of the assailant, and affords a sweeping fire over the lines of approach.

1808. *The Profile* is the vertical section showing the thickness and height of the parapet and the slopes in front and rear.

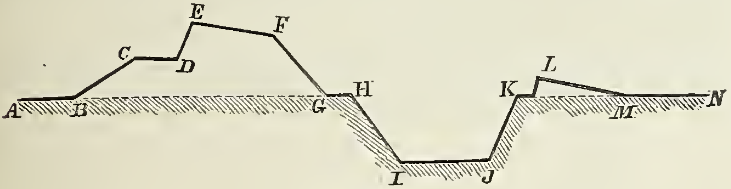


FIG. 375.

ABMN, Ground line.
BC, Banquette Slope.
CD, Banquette.
DE, Interior Slope.
EF, Superior Slope.
FG, Exterior Slope.
GH, Berm.
HI, Scarp.
JK, Counterscarp.
HIJK, Ditch.
LM, Glacis.

The most usual obstruction to impede the enemy's approach is the *Ditch*, which is placed in front of the parapet, for which it furnishes the material.

Any little ditch made behind a breastwork for the men to stand in for cover is called a *Trench*. The excavation of this also furnishes material for the parapet.

1809. *A Banquette* is a step on which men stand to fire over the parapet. It should generally be about 4 feet 6 inches below the top.

1810. *A Berm* is a narrow strip left between the parapet and the ditch to prevent the earth from falling into the ditch.

1811. The top of the parapet is termed the *Superior Slope;* the interior face, when arranged for infantry, is termed the *Interior Slope;* when for artillery, the *Genouillère;* the exterior face is the *Exterior Slope.*

1812. The side of the ditch adjacent to the parapet is called the *Scarp;* the side opposite, the *Counterscarp.*

1813. A mound of earth placed in front of the counterscarp, with a gentle slope outwards, is called a *Glacis.*

1814. *An Abattis* is an obstacle formed by felling trees and laying them side by side, with the branches pointed and turned towards the enemy.

1815. *A Traverse* is any mass which is interposed to protect the men from fire which comes in any direction except the front.

1816. *A Revetment* consists of a facing of stone, wood, or sods, or any other material to sustain an embankment when it receives a slope steeper than is natural. They are used only for the interior slope of the parapet, and for the scarp.

1817. *Relief* is the height of the crest of the parapet above the bottom of the ditch.

1818. *Command* is its height above the level of the surrounding country.

1819. In order to establish mutual defensive relations between all the parts, certain parts may be thrown forward towards the enemy, and they are denominated *advanced parts;* other portions, denominated *retired parts*, are withdrawn from the enemy and protected from their fire by the advanced parts.

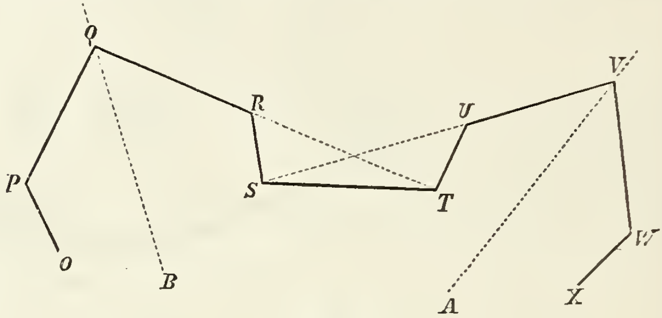


FIG. 376.

PQR and UVW, Advanced Parts.
RSTU, Retired Parts.
PQ, QR, UV, VW, Faces.
RS, TU, Flanks.
ST, Curtain.
QT, SV. Lines of Defence.
PQR, UVW, Salient Angles.
RST, STU, Re-entering Angles.
VA, QB, Capitals.

1820. This arrangement naturally indicates that the general outline of the plan must present an angular system—some of the angular points, denominated *salients*, being towards the enemy, and others, called *re-enterings*, being towards the assailed. When such a disposition is made it is termed a flank disposition, because the enemy's flank is attained by the fire of the retired parts when he is advancing upon the salients. No salient

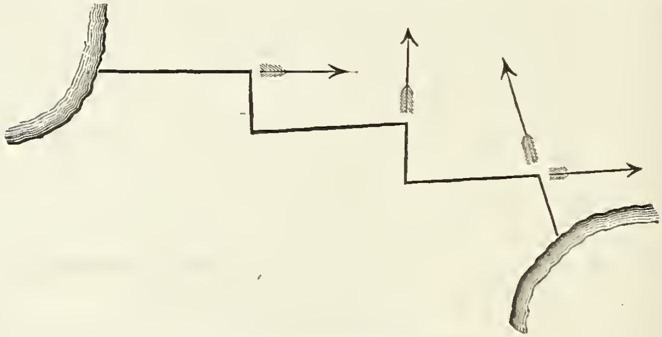


FIG. 377.—INDENTED LINE.

should be less than 60°. A *line of defence* should not exceed 300 yards.

1821. PLANS.—The simplest line that can be used, where the front to be defended is of limited extent and the flanks and rear are secure, is a *right line.* But from this line only a direct fire can be obtained; and for extended forms a combination of front and flank fire may be obtained by using the *indented line.* (Fig. 377.)

1822. The plan of works for positions which have the rear secure, but are assailable in the front and on the flanks, admits of great variety. The simplest is a work of two faces only, the salient being towards the enemy's line of approach. This is termed a *Redan* (Fig. 378). Its faces should receive such a direction as to sweep the approaches to the flanks; from the angular point, however, only a single line of direct fire can be brought to bear on the section in advance of it; to remedy this a portion of the salient is filled in so as to form a short defensive line, perpendicular to the capital. This is termed a *Pan-coupée.*

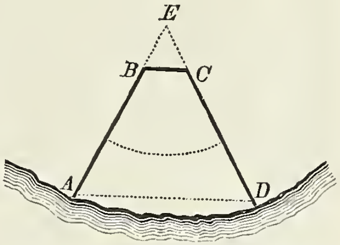


FIG. 378.—PLAN OF THE REDAN.
AB, CD, Faces. *AD,* Gorge.
BC, Pan-coupée.

1823. When the faces of the redan cannot be placed so as to sweep the flank approaches without making the salient angle too acute, the plan may be what is termed a *Priest-cap* or *Swallow-tail* (Fig. 379), in which the two main faces sweep the flank approaches, and instead of the pan-coupée, a broken line forming a re-entering angle is placed in the salient, and affords a cross-fire on the ground in front.

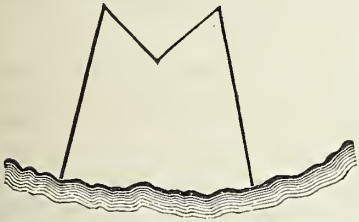


FIG. 379.—PLAN OF THE PRIEST-CAP.

1824. When the flank approaches extend to the rear, a flank (Fig. 380) is added to each face of the redan, and receives such a direction as to sweep that

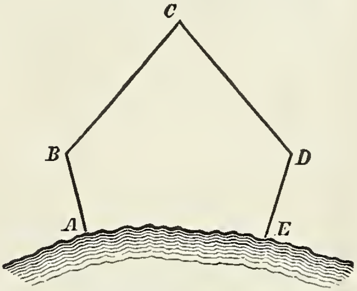


FIG. 380.—PLAN OF THE LUNETTE.
BC, CD, Faces. *AB, DE,* Flanks.

portion of the flank approach which cannot be reached by the faces except by a very oblique fire. This is termed a *Lunette.*

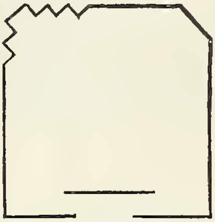


Fig. 381.

Plan of a Square Redoubt, with one angle indented and the other arranged with a pan-coupée.

1825. Such works as are assailable on all sides must present an unbroken line to the assault, and are termed *enclosed works.* They are generally of three classes: redoubts, star forts, and bastioned forts.

1826. A *Redoubt* may be a polygonal figure of any number of sides (Fig. 381). That most usually taken is the square.

1827. A *Star Fort* consists of a polygon having alternate salients and re-enterings (Fig. 382). It is generally planned by placing redans on the middle of the faces of a square redoubt. The star fort is but little, if at all, superior to the square redoubt, as its flanking dispositions are imperfect, and it presents a much longer line to be defended. It would only be useful on broken ground or irregular sites.

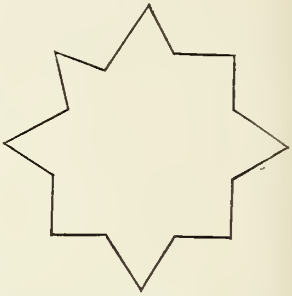


Fig. 382.

Plan of a Star Fort, with the faces of two redans prolonged inwards.

1828. The *Bastioned Fort* has been designed to remedy the defects in the two preceding classes. It may consist of a polygon of any number of sides, but for field forts the square and pentagon are generally preferred. To plan a work of this kind, a square or pentagon is first laid out (Fig. 383), and the sides bisected by perpendiculars, HI; a distance, GI, of one-eighth of a side in a square (one-seventh in a pentagon) is set off on the perpendiculars; from the angular points of the polygon, lines DA, CF, are drawn through the points thus set off: these lines give the direction of the lines of defence; from the salients of the polygon, distances equal to two-sevenths of a side are set off on the directions of the lines of defence, which give the faces; from the extremities of the

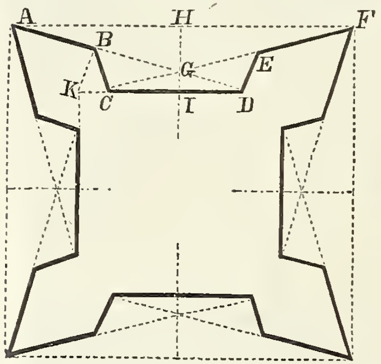


Fig. 383.—Plan of a Bastioned Fort constructed on a square.

faces the flanks are drawn perpendicular to, or making an angle of 110° with, the lines of defence; the extremities of the flanks are connected by curtains, CD.

1829. In deciding on the general plan to be carried out, the following considerations require attention: the object the work is expected to fulfil, and its situation with respect to the enemy; whether it is likely to be attacked by overwhelming forces; whether artillery is likely to be brought against it, or infantry; and whether it can be surrounded; the number of men there will be for its defence, observing that it is better to have a force concentrated, and that it is therefore injudicious to make works of a greater extent than can be well manned and vigorously defended. Another consideration that must not be omitted is the number of men that can be collected for working, whether they are one's own men or inhabitants, and whether there are tools enough and time enough to do it.

1830. PROFILES.—Having decided on what is the best plan of the works, the next consideration is the profile. This will also depend on much the same considerations as the general plan, particularly on the time in which the work is to be done and the number of men there are for work. A general idea may be formed of the quantity of work that may be performed in a given time, and of the proportion of cover that may be obtained in that time, by adopting different sections and referring to the annexed figures and corresponding estimates.

1831. In ordinary soils, a man can excavate one cubic yard per hour for 8 hours; in stiff clay, he would only do half as much; and in dry, light soils, three times as much. Each man should have 6 feet in length to execute, which distance enables him to use his tools with freedom; but when only improving the natural advantages offered by banks, fences, etc., the working-parties might be distributed at much wider intervals than 6 feet; for instance, a man might convert 20 or 30 feet of hedge into a good breastwork in three hours, when he could not execute 6 feet in length equally defensible on a level field.

1832. Fig. 384 represents the section of a small trench and the parapet that has been formed by throwing the earth up in front. The trench is 2½ feet deep and the same width, having a rough step 1 foot broad in rear. The earth thrown out will make a parapet of a height nearly equal to the

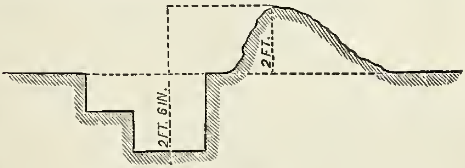


FIG. 384.

depth of the trench without taking any precautions to make it stand at a steeper slope than is natural; we will assume that is 2 feet high, which will make a total of $4\frac{1}{2}$ feet from the bottom of the trench. A man, therefore, though he can fire over the parapet, has to stoop to be concealed by it, and it therefore affords about the least amount of protection that should be considered. The solid contents of the excavation, from which the probable time to execute it may be determined, is found by multiplying the depth and breadth of the trench together, and that product by the length each man has to do—

Trench, $2\frac{1}{2} \times 2\frac{1}{2} \times 6 = 37\frac{1}{2}$ c. feet.
Step, $1 \times 1 \times 6 = 6$ "
Earth to be removed $= 43\frac{1}{2}$ "

Divide this sum by the amount excavated in one hour by one man, 27 c. feet, and it will be found that it will take a little over one hour and a half to throw up this parapet on level ground.

1833. Fig. 385 affords more cover, for the top of the parapet

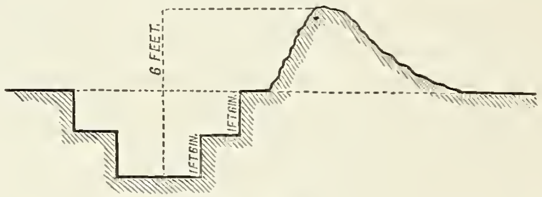


Fig. 385.

is 6 feet from the bottom of the trench. The best way to execute it would be to sink a trench 3 feet deep and 3 feet wide, and to throw the earth about 2 feet in front of it: so that, in the progress of the work, when the trench became too deep to stand in and fire over the parapet, a little step might be cut out of the solid left in front for a banquette; another step in the rear would complete it. The steps might be 18 inches wide and deep. To find the time it will take to execute

The Trench, $3 \times 3 \times 6 = 54$ c. feet.
Steps, $1\frac{1}{2} \times 1\frac{1}{2} \times 2 \times 6 = 27$ "
C. feet removed by one man per hour, 27) 81 "

It will require 3 hours.

But it offers no impediment to an enemy, and men could only be drawn up in single file for its defence.

1834. A trench of the dimensions shown in Fig. 386 might be completed in five hours on the presumed data, and being roomy enough to dispose men in double files for its defence, and high

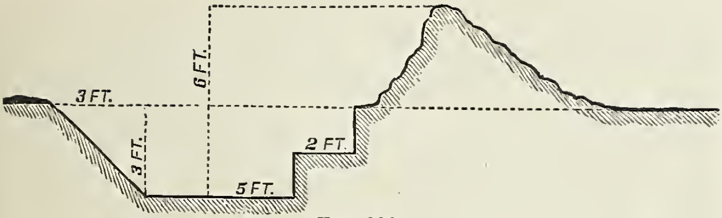


FIG. 386.

enough to screen and cover them, may be considered as large as is necessary for merely fulfilling these conditions.

1835. Fig. 387 is a form of breastwork that might be adopted

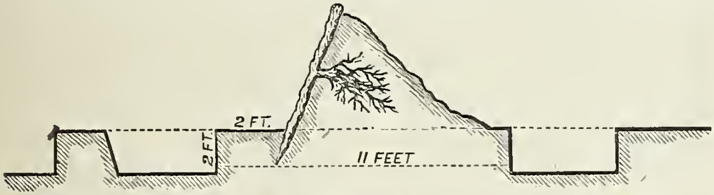


FIG. 387.—PROFILE OF REVETTED PARAPET FOR ROCKY OR MARSHY SOILS.

for obtaining cover in rocky or marshy situations, where a ditch or trench could not be made deeper than two feet; the men might be set to work in two lines, the interior slope revetted by stakes or sods, and it could be accomplished in from two to three hours.

1836. If more time could be devoted to strengthening a post, or if other circumstances were favorable, it would become a consideration whether some other profile of a different form could not be substituted with advantage for such as only afford cover without opposing an obstacle to the advance of an hostile force, and this would properly be accomplished by excavating a ditch in front of the parapet instead of making a trench in rear.

1837. Fig. 388 shows the general profile which such a work

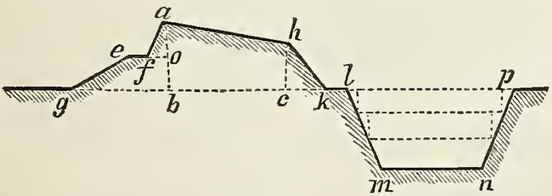


FIG. 388.

might have. The dimensions of the parapet are determined by the following considerations: The height, *ab*, by the cover required, and the position of the enemy; the thickness, *bc*, by the penetrating power of the projectiles likely to be brought against it. For field artillery, 15 feet is required; for rifles, 4 feet. The banquette, *ef*, should be 3 feet wide, if for single rank; $4\frac{1}{2}$ feet for double rank. In *eg*, the banquette slope, the height is equal to half the base; the interior slope, *af*, is $4\frac{1}{2}$ feet and steeply revetted; the superior slope, *ah*, is sufficiently sloped to enable the fire over it to defend the edge of the counterscarp; the exterior slope, *hk*, is left at the natural slope at which unrammed earth will support itself; the berm, *kl*, is made sufficiently wide to prevent the earth of the parapet from slipping into the ditch; the counterscarp, *pn*, is made as steep as the soil will permit, and from 6 to 12 feet deep; the scarp, *lm*, is not made so steep because it has to support the weight of the parapet: but both should be as steep as possible to resist *escalade*. The ditch is first excavated in steps, as represented in the figure, which are subsequently cut away. The breadth of the ditch is thus determined by calculation:

1838. If $ab = 8$ feet; $bc = 15$ feet; $ef = 3$ feet; in the slope *eg*, the base = height × 2; in slope *af*, the base $= \frac{\text{height}}{3}$; in slope *hk*, the base = height; in the scarp *lm*, the base $= \frac{\text{height}}{2}$; in the counterscarp, *pn*, the base $= \frac{\text{height}}{3}$; and if the ditch is to be 10 feet deep,

$$\text{the area,}\quad gefob, = \frac{4\frac{1}{2} + 11\frac{1}{2}}{2} \times 3\frac{1}{2} = 28 \text{ sq. feet.}$$

$$aof = \frac{4\frac{1}{2} \times 1\frac{1}{2}}{2} = 3\tfrac{3}{8} \quad \text{"}$$

$$abch = \frac{8 + 5\frac{1}{2}}{2} \times 15 = 101\tfrac{1}{4} \quad \text{"}$$

$$hck = \frac{5\frac{1}{2} \times 5\frac{1}{2}}{2} = 15\tfrac{1}{8} \quad \text{"}$$

$$\text{Area of profile of parapet or ditch} = 147\tfrac{3}{4} \quad \text{"}$$

Mean breadth of ditch $= \frac{147\frac{3}{4}}{10} = 14.775$ feet. Breadth at top or bottom of ditch $= 14.775 \pm \frac{\frac{10}{2} + \frac{10}{3}}{2} = 18.9$ or 10.6 feet.

Time required to execute $\frac{147\frac{3}{4}}{27} \times 6 =$ nearly 33 hours. To throw up a length of parapet of 100 yards would require a working-party of 100 men: 50 diggers, 34 shovellers, 16 rammers.

1839. Having selected a position on which a field-work is to be thrown up, and determined its dimensions, it is to be remembered that the salient angles should be directed towards points that are difficult of access; the faces of the work are then marked out by small pickets, and traced with a piece of tape and the angles set off. To guide the workmen in the construction, right profiles (Fig. 389), made with slips of board, are constructed along every face, about 10 yards apart.

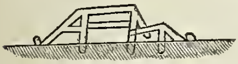


FIG. 389.

1840. Experience has shown that, in ordinary soils, a man with a pick can furnish employment to two men with shovels, and that, not to be in each other's way, they should be from $4\frac{1}{2}$ to 6 feet apart, and, finally, that a shovelful of earth can be pitched by a man 12 feet horizontally or 6 feet vertically.

1841. To distribute the workmen, the counterscarp crest is divided into lengths of 12 feet and the scarp crest into lengths of 9 feet, the points being marked by pickets. In each area thus marked out, a working-party is arranged, consisting of a pick with two shovels near the counterscarp, two shovels near the scarp, and one man to spread and one to ram the earth for two parties. The pick commences by breaking ground so far from the counterscarp crest, that by digging vertically 3 feet, he will arrive at the position of the counterscarp. This is carried on at the same depth of 3 feet advancing towards the scarp, where the same precaution is observed. The earth is thrown forward and evenly spread and rammed. If the ditch is deeper than 6 feet, an offset, about 4 feet broad, should be left at the scarp at mid-depth of the ditch, to place a relay of shovels. When the ditch has been excavated to the bottom, the offsets are cut away, and the proper slope given to the sides. The earth furnished by the offsets, if not required to complete the parapet, may be formed into a small glacis. Care should be taken not to have any pebbles on top of the parapet, and also to have a drain to take the water off without letting it run down the scarp.

1842. ARTILLERY IN FIELD-WORKS.—The proper positions for artillery are on the flanks and salients of a work, and the guns should be collected at these points in batteries of several pieces. The term *battery* is used of a collection of several guns, and it is named according as the parapet is arranged for firing over or through it: in firing over, it is called a *barbette battery;* in firing through, an *embrasure battery.*

1843. The barbette consists of a mound of earth thrown up against the interior slope; the upper surface is level and 1 foot 8 inches below the interior crest; the earth at the sides and rear receives the natural slope. To ascend the barbette a construction termed a *ramp* is made of earth; it should be 5 feet wide on top, and the slope is 6 feet of base to 1 of perpendicular. It should be at some convenient point in rear, and take up as little room as possible.

1844. An embrasure is an opening made in the parapet for a gun to fire through. The bottom of the embrasure is termed the *sole*, and should be 1 foot 8 inches above the ground, and should slope outward. The interior opening is termed the *mouth;* it should be 18 inches wide. The embrasure opens outwards; the sides of it are called *cheeks.*

1845. Defence of Walls.—Walls are readily made available for purposes of defence by loop-holing them, the mode of doing it varying with their height and situation. It is a general rule that

a. Fig. 390.—Defence of Walls. *b.*

loop-holes must be so placed that an enemy, if he succeeds in rushing up, shall not be able to make use of them. To prevent this they should be 8 or 9 feet above the ground on the outside (Fig. 390, *a*), but on the inside (Fig. 390, *b*) the banquette from which the defenders are to fire should not be more than about 4 feet 6 inches below them. A portion of the wall not less than 18 inches high should be left above the loop-holes to screen the men's heads when firing.

1846. These points are attainable in several ways; if the walls are high, the loop-holes may be made near the top, and a temporary stage or earthen banquette might be placed inside; if the wall is not over 6 feet high, the loop-holes may be made at 4 feet 6 inches above the inside level, and a ditch made outside. The quickest way of making a loop-hole is to break the wall down from the top for about 2 feet (Fig. 390, *a*), and then to fill it up at the top with a stone or sand-bag. If the wall should be low, a piece of timber supported on a couple of stones would be a ready expedient. If exposed to the fire of artillery, a wall will not afford good cover, but it may be improved by sinking a trench in rear and throwing the earth against the wall, or by digging a ditch in front and throwing the earth over the wall.

1847. DEFENCE OF A BUILDING.—The great art of making a defensible post out of a building and the adjoining outhouses and walls, consists in selecting from all the objects in view only what will be useful in strengthening the work, and in sacrificing everything else, making use of the materials for fortifying.

1848. A building proper for defensive purposes should be in a commanding position; it should be substantial, and of a nature to furnish materials for placing it in a state of defence; it should be of an extent proportioned to the number of defenders, and only require the time and means that can be devoted to completing it; it should have walls and projections that mutually flank each other; it should be difficult of access, and yet have a safe retreat; and the walls should be of moderate thickness. Brick houses or walls are to be preferred to those of stone or wood.

1849. The number of men necessary for defence may be roughly estimated by allowing 1 man to every 4 feet on the lower floor, 1 to every 6 on the next, and 1 to every 8 on the next.

1850. To put a building in condition to rep l an immediate attack, certain points would naturally claim primary attention, and they should be attended to in the order in which they are given.

1st. To collect material and barricade the doors and windows on the ground floor, to make loop-holes in them, and to level any obstruction outside that would give cover to an enemy. 2d. To sink ditches opposite the doors on the outside, and to arrange loop-holes in the windows of the upper story. 3d. To loop-hole the walls, generally attending first to the most exposed parts, and to make communications through all the walls. 4th. To place abattis or any feasible obstructions on the outside. 5th. To place out-buildings and garden walls in a state of defence, and to establish communications between them

1851. DEFENCE OF A VILLAGE.—In arranging the general plan, some substantial buildings within musket-range of each other should be selected for the prominent or salient points of the line. These, with the intervening walls, hedges, or open spaces, will be prepared for defence as has been already explained, so as to completely enclose the position. Care should be taken not

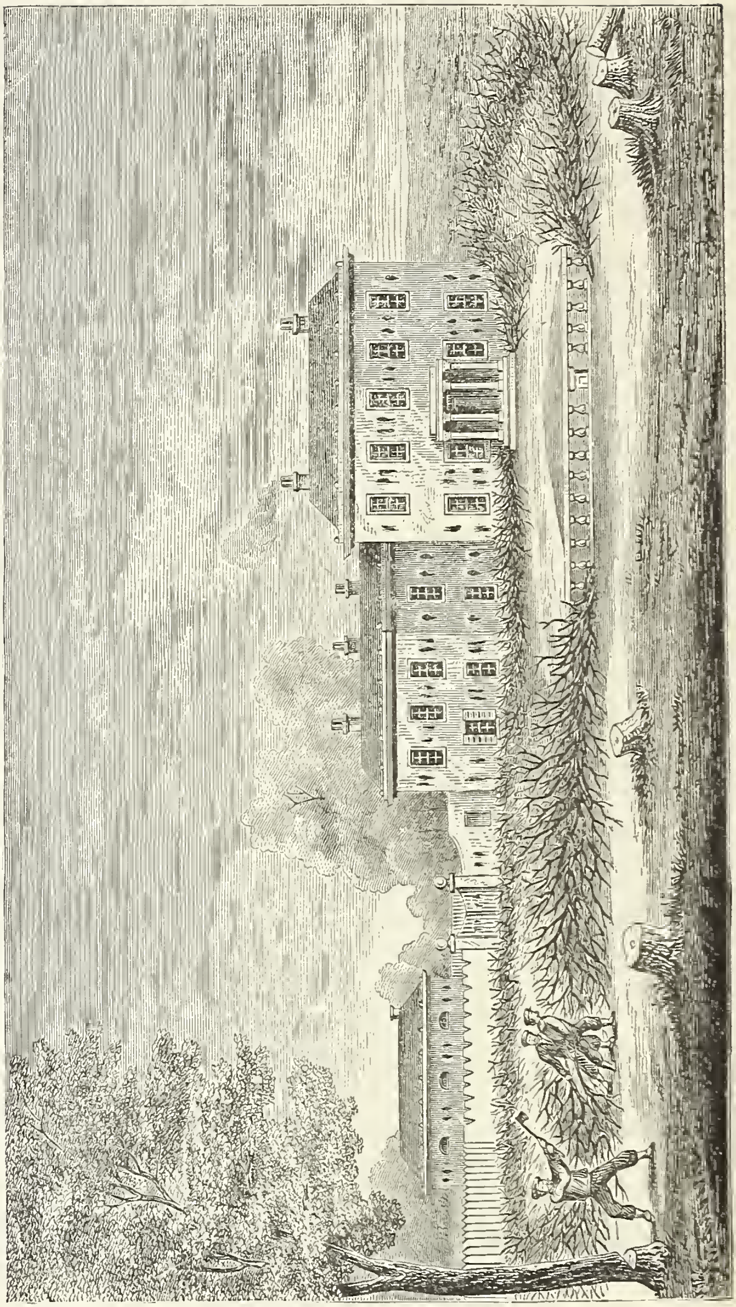


Fig. 391.—The Defence of a Building.

to attempt to enclose a larger space than can be manned and defended by the available force. Anything which would afford cover to an enemy outside of the lines should be destroyed, burning houses, filling ditches, throwing down fences, etc. The roads by which an enemy can approach should be cut across by trenches. All obstructions on the inside which are perpendicular to the line of defence should be removed so as to admit of manœuvring. All streets and roads open to attack should be

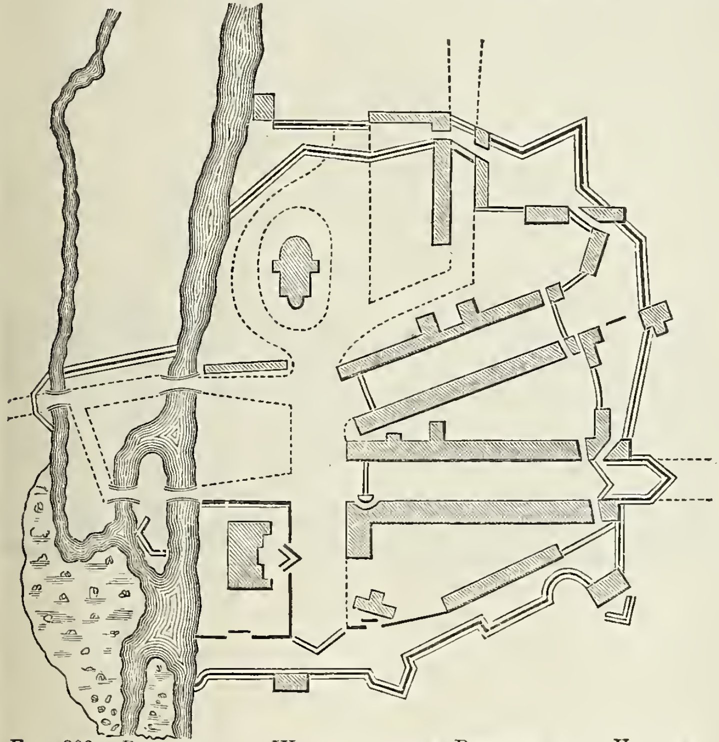


FIG. 392.—PLAN OF THE WORKS FOR THE DEFENCE OF A VILLAGE.

barricaded, or breastworks should be thrown up. If several barricades are to be disputed in succession, the means of retreat through them must be preserved, and communications should be made from house to house on each side of the street.

1852. Some strong building or buildings should be selected in a central position, commanding the principal roads and streets, which should be strengthened and made to serve as rallying-points in case the assailants penetrate the outer defences. A reserve force should always be kept ready to reinforce any part of the walls.

1853. Defence of a Bridge.—If a body of troops had to retire over a bridge in the presence of a superior force, works would naturally be thrown up in front of it for covering the retreat and ensuring its being held until the passage was effected, and others might be placed in rear for giving support and prolonging the resistance. If the protection of the bridge were the object, the same plan would be followed; but if it were merely for disputing the passage in order to cover a line of operations

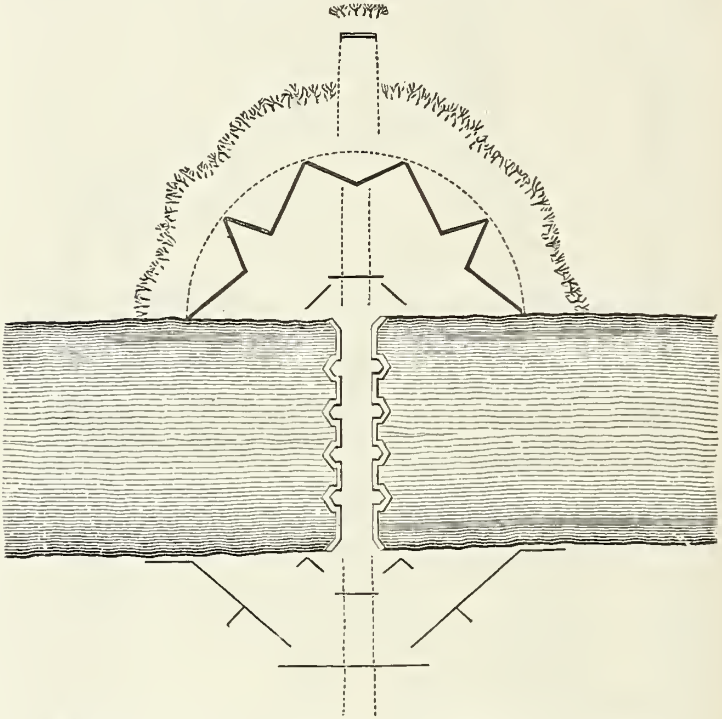


Fig. 393.—Plan of Works for the Defence of a Bridge.

or a flank march, works might be placed in rear, which is the proper position for defensive purposes. The annexed Fig. (393) may serve as an example of temporary works in front as well as in rear of a bridge for guarding and disputing the passage with a force of 600 men available for work and defence. The first consideration should be the distribution of the men. Three-fourths of them should be placed in advance, and one-fourth as a reserve in rear, and a small proportion of the former number as a support close to the front of the bridge. A file of men should be allowed to every yard of parapet in front, and the main reserve in other works in rear, which should be large enough to receive two-thirds of the whole number, if the force is obliged to fall back.

1854. This arrangement would give 400 men on the outer line in front, 50 men in rear of the outer line as a support, and 150 men partially occupying the works in rear as a reserve. This would require 200 yards on the outer line, 25 yards for the support: in all, 225 yards in front.

1855. The next point to decide would be the plan; and a simple and serviceable one would be the one shown in Fig. 393, a priest-cap with a redan on each face. A ready way of laying this out would be, first of all, to trace a rough semicircle with pickets about one-sixth less in running length than the required breastwork. This could be done with a radius of 64 yards. The salient angles being fixed in the outline of the work so traced, and their lengths being disposed within the semicircle so as to flank each other, the total length, though it may vary with the figure adopted, will be near enough the required extent for practice.

In rear of the bridge about 200 yards more would be required, but so disposed as to protect the men from enfilade.

1856. At a convenient distance in front, varying from 20 to 50 yards, an abattis or other obstruction should be placed parallel to the general contour of the works, and extending to the river on either side. This arrangement of the works would require 212 men to throw up the parapet; the rest might be employed in making the abattis, in throwing down the parapet walls of the bridge, blocking up the roads, etc.

1857. If the force be very much smaller the works should be executed of an extent to correspond; a good breastwork with an abattis before it might be made across the front of the bridge, a barricade in the middle, and another one in rear flanked by strong breastworks.

1858. Attack of Works.—Having considered the various means of putting positions in a state of defence, it is in order to consider the various methods of attacking and defending such posts. An attack should either be by surprise or by open force.

1859. Surprise.—In the first case the strictest secrecy should be observed as to the intent: the enemy should be deceived by false manœuvres, and the troops should be kept in ignorance of the movement until they are assembled for the attack. The most favorable moment for a surprise is about two hours before daylight. The troops should be divided into a storming-party and reserve, and the storming-party should consist of an advance-party and a support. Several columns of attack should be formed, some for false and some for real attack, but the columns formed for false attack should be strong enough to take advantage of any success.

1860. Pioneers should accompany each storming-party to remove obstacles, and they should be provided with bags of powder with fuses attached for blowing down gates, doors, or other obstructions. All operations should be carried on with despatch and in silence. The advance-party should be provided with ladders, planks, brush, or anything which would be serviceable in filling up ditches or crossing them, and the charges should generally be made in column through whatever force was formed for the defence of the parapet. A strong reserve should be kept ready to follow up any successful attack.

1861. Open Attack.—The general arrangements for an open assault comprehend the operations to gain possession of the works, the measures for maintaining possession, and the precautions to be observed in case of repulse. The troops should be drawn up in a sheltered position out of range of the assailed, and a heavy fire opened from the howitzers in the most favorable positions to enfilade the faces and destroy all visible obstacles. When the fire of the works is silenced, the troops are thrown forward and demonstrations made on several points, to divert the attention of the assailed from the true point of attack, and to prevent him from concentrating his forces there.

1862. The disposition of the troops making an assault will depend very much on circumstances; generally, the parties should be arranged as in the preceding case; the troops to support and, if necessary, to reinforce the storming-parties, should advance in one or two lines, with the artillery on the flanks, disposed to repel sorties. When the assailed are driven from their main works the storming-party should press them closely, and endeavor to enter the interior works with them, leaving to the troops which follow the duty of retaining possession of the works already gained. If the storming-party has to retreat, its retreat should be covered by a strong body of infantry and artillery.

1863. Defence.—The essential point in defence is to have every part of the works guarded by a sufficient number of troops to resist an attack on all sides; this is of importance, not only in isolated works, but in continued lines. At least two ranks should be drawn up on the banquette throughout the entire extent of the line, with supports and a reserve proportioned to the importance of the work. The strictest vigilance should be exerted to guard against a surprise; sentries should be posted on all the commanding points of the works, and on the outside patrols should be posted to watch the enemy's movements, and to give notice of his approach.

1864. At night the number of sentries should be increased, and redoubled vigilance should be used, especially after midnight. The reserve should be posted in the most convenient position to afford prompt assistance to any point in danger of being forced. If the enemy opens his attack by a warm cannonade, the men should not be exposed to it if they can be sheltered at the posts they are to occupy when the columns of attack approach. The men should be instructed to reserve their fire until the enemy arrives at certain points marked in front, which should not be more than 400 yards from the parapet. Should the enemy succeed in forcing his way in, the reserve should attack with the bayonet before he has time to form; but the only well-grounded prospect that the assailed can have of repelling the assault, when the enemy has gained the top of the scarp, is to meet him offensively with bayonet on top of the parapet. Large stones, heavy round logs, and hand-grenades should be in readiness to roll over on the enemy when he is in the ditch.

1865. Sorties.—If it should seem desirable, and the garrison is sufficiently strong to make a sortie, it is essential that it should be well timed and vigorously executed, and be in sufficient force to make some impression, either as a diversion in favor of the defenders of the parapet, or to drive the assailants back beyond the obstacles they may have already surmounted. The party should be selected from the reserve, leaving the parapets fully manned. The men for the sortie should be drawn up at the point where they are to go out, and at the critical moment when the speed of the assailants has been checked by the opposition they have met with in front, a furious onset with the bayonet should be made on one or both flanks, and when the object is effected, the troops should immediately retire within the works. The firing from the defences should cease when they come out, and be resumed the moment the front is clear again.

Section VI.—The Retreat.

1866. Rear-guards.—After having accomplished the objects of the expedition, or if the forces have been defeated or repulsed, it becomes necessary to get them on board ship as quickly as possible. If the forces are at a considerable distance from the boats, the retreat will be a matter requiring great care and judgment, particularly if the rear is closely pressed by the enemy in force. In this case, everything will depend on the rear-guard, which should be formed from the freshest men, and should number at least one-fifth or one-sixth of the whole force, including some howitzers.

1867. The great art of rear-guards is that of being able constantly to force an enemy to deploy and to attack, and then to get away safely without any serious fighting: its purpose is more fulfilled by threatening to fight than by fighting. If the pursuing enemy should become reckless and push on to attack with an insufficient force, it will then be for the rear-guard to pounce suddenly on him with all his available force, and having struck a severe blow, to at once resume the retreat.

1868. The officer commanding the main body should, from time to time, send to the commander of the rear-guard information as to the condition of the road, bridges, etc., to be passed, and every position suitable for the rear-guard to defend itself in should be especially noted.

1869. The distance that the rear-guard should be from the main body depends upon the nature of the country, its numbers, and the manner in which the pursuit is conducted. It should not be more than a few hours' march, and under all circumstances communication should be kept up with the main body. The actual rear of the rear-guard should be a line of skirmishers.

1870. All villages on the line of retreat and all supplies of provision should be destroyed; everything, in fact, on which the pursuers might subsist. If the country is so enclosed that the pursuers must travel on the roads, every thing should be done to retard their progress; setting fire to houses or villages on the line of march, felling trees across the road, destroying bridges, should never be omitted when it can be done.

1871. Destruction of Bridges.—Bridges may be destroyed by burning, if there is time; if not, it would be sufficient to bore a hole in the main braces or lower chords of truss-bridges and put in a charge of powder with a fuze. To destroy a bridge of masonry, sink a shaft in the roadway near the centre arch, down to the haunch, with a short gallery ending in a chamber, so as to lodge the powder in the middle of the width of the bridge under the roadway. Five or six hours' labor and a charge of from 50 to 100 lbs. will probably be sufficient. If there is not time to sink a deep shaft, a hole may be sunk across the crown of the arch, and a charge of 250 or 300 lbs. of powder, placed over the crown and covered with stones, will answer the purpose.

1872. Passage of a Defile.—In case it becomes necessary for the retreating forces to pass through a defile, troops from the main body should be posted on the heights on either side and deployed as skirmishers while the main body is passing through. As soon as the rear-guard is in position and the enemy has deployed, the supports should enter the defile, and the rear-guard should fall back, maintaining a heavy fire along the line. The skirmish-line of the rear-guard should, if possible, retire along the heights as well as by the defile; if that is not possible, they should dispute every inch of ground in the defile while the line of battle is being formed on the other side, howitzers being posted so as to enfilade the pass, and troops ready to attack the advance of the enemy as they emerge. After having given the enemy a serious check, the line of march should be resumed, the rear-guard resuming their original duties.

1873. The Embarkation.—On arriving at the boats, if there is no enemy present or near, the troops and howitzers might all be embarked at once, and return to their ships. But if the enemy is pressing closely, the breastworks which have been prepared by the officer in charge of the boats should be manned, retaining some howitzers to keep the enemy at a distance. The main portion of the howitzers should be embarked, and the boats hauled into such a position that, by their cross-fire, they can sweep the approaches and cover the embarkation of the infantry, which should be proceeded with as expeditiously as possible, being careful to get all the howitzers embarked while there is still a large number of infantry on shore. The last who are on the beach should retire in skirmishing order, keeping up a vigorous fire until the last moment, when they should lose no time in getting to their boats, the howitzers, boats, and vessels keeping up a continuous fire to prevent the enemy from making a sudden rush and capturing them.

APPENDIX I.

TABLES.

I. COEFFICIENTS FOR THE CUBIC LAW OF RESISTANCE.

ELONGATED PROJECTILES WITH OGIVAL HEADS.

Reprinted from Professor FRANCIS BASHFORTH'S *Motion of Projectiles.*

v	K_v	$\frac{K_v}{g}$	$\text{Log}\,\frac{K_v}{g}$	v	K_v	$\frac{K_v}{g}$	$\text{Log}\,\frac{K_v}{g}$
f-s				f-s			
900	64.4	2.001	.3012	1300	107.9	3.352	.5253
910	64.8	2.014	.3041	1310	107.7	3.345	.5244
920	65.3	2.029	.3073	1320	107.4	3.337	.5234
930	65.9	2.047	.3111	1330	107.1	3.328	.5222
940	66.6	2.069	.3158	1340	106.8	3.317	.5207
950	67.4	2.094	.3210	1350	106.4	3.305	.5192
960	68.4	2.125	.3274	1360	106.0	3.293	.5176
970	69.6	2.162	.3349	1370	105.6	3.280	.5159
980	71.0	2.206	.3436	1380	105.1	3.265	.5139
990	72.8	2.262	.3545	1390	104.6	3.249	.5118
1000	75.0	2.330	.3674	1400	104.0	3.231	.5093
1010	77.5	2.408	.3817	1410	103.4	3.212	.5068
1020	80.4	2.498	.3976	1420	102.8	3.193	.5042
1030	83.9	2.606	.4160	1430	102.2	3.175	.5017
1040	88.2	2.740	.4378	1440	101.6	3.155	.4990
1050	92.8	2.883	.4598	1450	100.9	3.134	.4961
1060	97.2	3.019	.4799	1460	100.2	3.112	.4930
1070	100.8	3.131	.4957	1470	99.4	3.089	.4898
1080	103.4	3.212	.5068	1480	98.7	3.065	.4864
1090	105.1	3.265	.5139	1490	97.9	3.041	.4830
1100	106.0	3.293	.5176	1500	97.2	3.018	.4797
1110	106.6	3.312	.5201	1510	96.4	2.994	.4763
1120	107.1	3.327	.5221	1520	95.5	2.968	.4725
1130	107.5	3.339	.5236	1530	94.7	2.942	.4686
1140	107.9	3.351	.5252	1540	93.8	2.915	.4646
1150	108.2	3.361	.5265	1550	93.0	2.889	.4607
1160	108.5	3.371	.5278	1560	92.2	2.864	.4570
1170	108.7	3.377	.5285	1570	91.4	2.839	.4532
1180	108 9	3.381	.5290	1580	90.6	2.814	.4493
1190	108.9	3.383	.5293	1590	89.8	2.790	.4456
1200	108.9	3.383	.5293	1600	89.0	2.765	.4417
1210	108.9	3.383	.5293	1610	88.2	2.740	.4378
1220	108.9	3.382	.5292	1620	87.4	2.715	.4338
1230	108.8	3.381	.5290	1630	86.7	2.693	.4302
1240	108.8	3.380	.5289	1640	86.0	2.672	.4268
1250	108.7	3.378	.5287	1650	85.4	2.654	.4239
1260	108.6	3.375	.5283	1660	85.0	2.640	.4216
1270	108.5	3.370	.5276	1670	84.6	2.628	.4196
1280	108.3	3.364	.5269	1680	84.3	2.619	.4181
1290	108.1	3.358	.5261	1690	84.1	2.613	.4171
1300	107.9	3.352	.5253	1700	83.9	2.606	.4160

II. COEFFICIENTS FOR THE CUBIC LAW OF RESISTANCE.

SPHERICAL PROJECTILES.

v	K_v	$\frac{K_v}{g}$	Log $\frac{K_v}{g}$	v	K_v	$\frac{K_v}{g}$	Log $\frac{K_v}{g}$
f-s				f-s			
850	138.4	4.299	.6334	1250	151.1	4.694	.6715
860	138.3	4.296	.6331	1260	150.5	4.674	.6697
870	138.3	4.294	.6329	1270	149.8	4.654	.6678
880	138.2	4.293	.6328	1280	149.1	4.632	.6659
890	138.2	4.293	.6328	1290	148.4	4.611	.6638
900	138.2	4.294	.6329	1300	147.8	4.591	.6619
910	138.3	4.296	.6331	1310	147.2	4.572	.6601
920	138.4	4.299	.6334	1320	146.5	4.552	.6582
930	138.5	4.302	.6337	1330	145.9	4.533	.6564
940	138.6	4.306	.6341	1340	145.3	4.514	.6546
950	138.8	4.312	.6347	1350	144.7	4.495	.6527
960	139.1	4.322	.6357	1360	144.1	4.475	.6508
970	139.5	4.334	.6369	1370	143.4	4.455	.6489
980	139.9	4.346	.6381	1380	142.7	4.433	.6467
990	140.4	4.362	.6397	1390	142.0	4.410	.6444
1000	141.1	4.383	.6418	1400	141.3	4.388	.6423
1010	141.9	4.408	.6442	1410	140.6	4.366	.6401
1020	142.8	4.436	.6470	1420	139.8	4.343	.6378
1030	143.8	4.467	.6500	1430	139.1	4.320	.6355
1040	144.9	4.501	.6533	1440	138.4	4.299	.6334
1050	146.1	4.539	.6570	1450	137.7	4.277	.6311
1060	147.3	4.576	.6605	1460	137.0	4.254	.6288
1070	148.5	4.613	.6640	1470	136.2	4.231	.6264
1080	149.6	4.647	.6672	1480	135.5	4.209	.6242
1090	150.6	4.677	.6700	1490	134.8	4.188	.6220
1100	151.4	4.703	.6724	1500	134.1	4.166	.6197
1110	152.1	4.725	.6744	1510	133.5	4.146	.6176
1120	152.7	4.744	.6762	1520	132.8	4.125	.6154
1130	153.1	4.757	.6773	1530	132.1	4.105	.6133
1140	153.4	4.766	.6782	1540	131.5	4.085	.6112
1150	153.6	4.772	.6787	1550	130.8	4.064	.6090
1160	153.7	4.774	.6789	1560	130.1	4.043	.6067
1170	153.7	4.775	.6790	1570	129.5	4.023	.6046
1180	153.7	4.774	.6789	1580	128.8	4.003	.6024
1190	153.6	4.771	.6786	1590	128.2	3.983	.6002
1200	153.4	4.765	.6781	1600	127.5	3.961	.5978
1210	153.1	4.756	.6772	1610	126.8	3.940	.5955
1220	152.7	4.744	.6762	1620	126.2	3.920	.5933
1230	152.2	4.728	.6747	1630	125.5	3.899	.5910
1240	151.7	4.712	.6732	1640	124.8	3.877	.5885
1250	151.1	4.694	.6715	1650	124.1	3.856	.5861

v	K_v	$\frac{K_v}{g}$	Log $\frac{K_v}{g}$	v	K_v	$\frac{K_v}{g}$	Log $\frac{K_v}{g}$
f-s				f-s			
1650	124.1	3.856	.5861	1900	108.7	3.377	.5285
1660	123.5	3.836	.5839	1910	108.2	3.361	.5265
1670	122.8	3.815	.5815	1920	107.7	3.346	.5245
1680	122.1	3.793	.5790	1930	107.3	3.332	.5227
1690	121.4	3.772	.5766	1940	106.8	3.317	.5208
1700	120.8	3.752	.5743	1950	106.3	3.302	.5188
1710	120.1	3.731	.5718	1960	105.8	3.287	.5168
1720	119.4	3.710	.5694	1970	105.3	3.272	.5148
1730	118.8	3.689	.5669	1980	104.9	3.258	.5130
1740	118.1	3.669	.5646	1990	104.4	3.243	.5110
1750	117.4	3.648	.5621	2000	103.9	3.228	.5089
1760	116.8	3.628	.5597	2010	103.4	3.212	.5068
1770	116.1	3.608	.5573	2020	102.9	3.197	.5047
1780	115.5	3.588	.5549	2030	102.5	3.183	.5028
1790	114.9	3.568	.5524	2040	102.0	3.169	.5009
1800	114.2	3.548	.5500	2050	101.5	3.154	.4989
1810	113.6	3.529	.5477	2060	101.1	3.140	.4969
1820	113.0	3.511	.5454	2070	100.6	3.125	.4949
1830	112.5	3.494	.5433	2080	100.1	3.110	.4928
1840	111.9	3.476	.5411	2090	99.7	3.096	.4908
1850	111.3	3.459	.5390	2100	99.2	3.081	.4887
1860	110.8	3.442	.5368	2110	98.7	3.066	.4866
1870	110.3	3.425	.5347	2120	98.3	3.053	.4847
1880	109.7	3.408	.5325	2130	97.8	3.039	.4827
1890	109.2	3.392	.5305	2140	97.4	3.025	.4807
1900	108.7	3.377	.5285	2150	96.9	3.010	.4786

III. $\text{Log } P_\varphi = \text{Log}(3 \tan \varphi + \tan^3 \varphi)$.

φ	Log P_φ	φ	Log P_φ	φ	Log P_φ	φ	Log P_φ
0		0		0		0	
1	8.71909	16	9.94636	31	0.30525	46	0.62501
2	9.02038	17	9.97579	32	0.32605	47	0.64839
3	9.19691	18	0.00392	33	0.34676	48	0.67226
4	9.32247	19	0.03093	34	0.36743	49	0.69666
5	9.42018	20	0.05695	35	0.38809	50	0.72164
6	9.50034	21	0.08212	36	0.40877	51	0.74725
7	9.56844	22	0.10654	37	0.42952	52	0.77355
8	9.62777	23	0.13030	38	0.45037	53	0.80059
9	9.68045	24	0.15349	39	0.47135	54	0.82844
10	9.72792	25	0.17618	40	0.49250	55	0.85717
11	9.77121	26	0.19844	41	0.51385	56	0.88685
12	9.81109	27	0.22033	42	0.53545	57	0.91755
13	9.84813	28	0.24191	43	0.55732	58	0.94937
14	9.88280	29	0.26322	44	0.57951	59	0.98239
15	9.91545	30	0.28432	45	0.60206	60	1.01671

IV. VALUES OF X, Y & T FOR INTERVALS OF 0°.2.

$\gamma = 0.00$				$\gamma = 0.01$			
φ	X	Y	T	φ	X	Y	T
° 60.0	1.73205	1.50000	1.73205	° 60.0	1.77949	1.55885	1.75552
59.8	1.71818	1.47606	1.71818	59.8	1.76457	1.53311	1.74112
59.6	1.70446	1.45259	1.70446	59.6	1.74984	1.50791	1.72691
59.4	1.69091	1.42959	1.69091	59.4	1.73530	1.48323	1.71288
59.2	1.67752	1.40703	1.67752	59.2	1.72096	1.45906	1.69902
59.0	1.66428	1.38492	1.66428	59.0	1.70679	1.43539	1.68533
58.8	1.65120	1.36322	1.65120	58.8	1.69281	1.41221	1.67180
58.6	1.63826	1.34195	1.63826	58.6	1.67899	1.38949	1.65843
58.4	1.62548	1.32109	1.62548	58.4	1.66535	1.36723	1.64523
58.2	1.61283	1.30062	1.61283	58.2	1.65188	1.34542	1.63218
58.0	1.60033	1.28054	1.60033	58.0	1.63857	1.32404	1.61928
57.8	1.58797	1.26083	1.58797	57.8	1.62543	1.30308	1.60653
57.6	1.57575	1.24149	1.57575	57.6	1.61244	1.28253	1.59393
57.4	1.56366	1.22251	1.56366	57.4	1.59960	1.26238	1.58147
57.2	1.55170	1.20388	1.55170	57.2	1.58691	1.24262	1.56915
57.0	1.53987	1.18559	1.53987	57.0	1.57437	1.22324	1.55697
56.8	1.52816	1.16764	1.52816	56.8	1.56198	1.20423	1.54493
56.6	1.51658	1.15001	1.51658	56.6	1.54973	1.18558	1.53302
56.4	1.50512	1.13270	1.50512	56.4	1.53762	1.16728	1.52124
56.2	1.49378	1.11569	1.49378	56.2	1.52564	1.14932	1.50958
56.0	1.48256	1.09899	1.48256	56.0	1.51380	1.13170	1.49806
55.8	1.47146	1.08259	1.47146	55.8	1.50209	1.11440	1.48665
55.6	1.46046	1.06648	1.46046	55.6	1.49051	1.09742	1.47537
55.4	1.44958	1.05065	1.44958	55.4	1.47905	1.08075	1.46420
55.2	1.43881	1.03509	1.43881	55.2	1.46772	1.06438	1.45315
55.0	1.42815	1.01980	1.42815	55.0	1.45651	1.04831	1.44222
54.8	1.41759	1.00478	1.41759	54.8	1.44541	1.03253	1.43140
54.6	1.40714	.99002	1.40714	54.6	1.43444	1.01703	1.42068
54.4	1.39679	.97550	1.39679	54.4	1.42357	1.00180	1.41008
54.2	1.38653	.96124	1.38653	54.2	1.41282	.98684	1.39958
54.0	1.37638	.94722	1.37638	54.0	1.40219	.97214	1.38919
53.8	1.36633	.93343	1.36633	53.8	1.39165	.95770	1.37890
53.6	1.35637	.91987	1.35637	53.6	1.38123	.94351	1.36871
53.4	1.34650	.90653	1.34650	53.4	1.37091	.92956	1.35862
53.2	1.33673	.89342	1.33673	53.2	1.36069	.91585	1.34863
53.0	1.32704	.88052	1.32704	53.0	1.35058	.90238	1.33873
52.8	1.31745	.86783	1.31745	52.8	1.34056	.88914	1.32891
52.6	1.30795	.85536	1.30795	52.6	1.33064	.87612	1.31921
52.4	1.29853	.84309	1.29853	52.4	1.32071	.86332	1.30959
52.2	1.28919	.83102	1.28919	52.2	1.31108	.85073	1.30007
52.0	1.27994	.81913	1.27994	52.0	1.30144	.83834	1.29063
51.8	1.27077	.80743	1.27077	51.8	1.29189	.82616	1.28127
51.6	1.26169	.79592	1.26169	51.6	1.28243	.81418	1.27200
51.4	1.25268	.78460	1.25268	51.4	1.27306	.80240	1.26282
51.2	1.24375	.77346	1.24375	51.2	1.26378	.79081	1.25371

$\gamma = 0.02$				$\gamma = 0.03$			
φ	X	Y	T	φ	X	Y	T
60.0°	1.83254	1.62567	1.78117	60.0°	1.89266	1.70264	1.80950
59.8	1.81636	1.59774	1.76618	59.8	1.87490	1.67200	1.79380
59.6	1.80041	1.57045	1.75139	59.6	1.85743	1.64211	1.77832
59.4	1.78468	1.54376	1.73680	59.4	1.84025	1.61294	1.76306
59.2	1.76919	1.51766	1.72239	59.2	1.82334	1.58447	1.74802
59.0	1.75391	1.49213	1.70817	59.0	1.80671	1.55667	1.73318
58.8	1.73885	1.46716	1.69413	58.8	1.79033	1.52952	1.71854
58.6	1.72399	1.44273	1.68027	58.6	1.77421	1.50301	1.70410
58.4	1.70934	1.41882	1.66658	58.4	1.75833	1.47710	1.68985
58.2	1.69488	1.39541	1.65306	58.2	1.74270	1.45178	1.67579
58.0	1.68062	1.37250	1.63971	58.0	1.72729	1.42703	1.66191
57.8	1.66655	1.35007	1.62652	57.8	1.71211	1.40283	1.64822
57.6	1.65266	1.32810	1.61349	57.6	1.69716	1.37917	1.63469
57.4	1.63896	1.30658	1.60062	57.4	1.68241	1.35603	1.62134
57.2	1.62542	1.28550	1.58790	57.2	1.66788	1.33339	1.60815
57.0	1.61206	1.26485	1.57533	57.0	1.65355	1.31123	1.59513
56.8	1.59887	1.24461	1.56290	56.8	1.63941	1.28955	1.58227
56.6	1.58584	1.22478	1.55062	56.6	1.62547	1.26833	1.56956
56.4	1.67298	1.20534	1.53847	56.4	1.61172	1.24755	1.55701
56.2	1.56027	1.18628	1.52647	56.2	1.59815	1.22721	1.54461
56.0	1.54771	1.16759	1.51460	56.0	1.58476	1.20728	1.53235
55.8	1.53530	1.14927	1.50286	55.8	1.57154	1.18776	1.52023
55.6	1.52304	1.13130	1.49125	55.6	1.55850	1.16864	1.50826
55.4	1.51093	1.11367	1.47977	55.4	1.54562	1.14690	1.49642
55.2	1.49895	1.09638	1.46841	55.2	1.53291	1.13154	1.48472
55.0	1.48712	1.07941	1.45718	55.0	1.52035	1.11354	1.47315
54.8	1.47542	1.06276	1.44607	54.8	1.50795	1.09589	1.46171
54.6	1.46385	1.04642	1.43507	54.6	1.49570	1.07859	1.45039
54.4	1.45241	1.03038	1.42419	54.4	1.48360	1.06163	1.43920
54.2	1.44109	1.01464	1.41342	54.2	1.47164	1.04499	1.42813
54.0	1.42991	.99918	1.40276	54.0	1.45983	1.02867	1.41718
53.8	1.41884	.98401	1.39221	53.8	1.44815	1.01266	1.40634
53.6	1.40785	.96911	1.38177	53.6	1.43661	.99694	1.39562
53.4	1.39706	.95447	1.37143	53.4	1.42521	.98153	1.38501
53.2	1.38635	.94010	1.36120	53.2	1.41393	.96640	1.37452
53.0	1.37575	.92598	1.35107	53.0	1.40278	.95155	1.36413
52.8	1.36526	.91211	1.34104	52.8	1.39175	.93697	1.35385
52.6	1.35488	.89848	1.33111	52.6	1.38085	.92266	1.34367
52.4	1.34460	.88509	1.32127	52.4	1.37007	.90860	1.33359
52.2	1.33442	.87192	1.31152	52.2	1.35940	.89480	1.32361
52.0	1.32435	.85898	1.30187	52.0	1.34885	.88125	1.31372
51.8	1.31438	.84627	1.29231	51.8	1.33841	.86794	1.30393
51.6	1.30451	.83378	1.28284	51.6	1.32808	.85486	1.29424
51.4	1.29474	.82149	1.27346	51.4	1.31786	.84201	1.28465
51.2	1.28506	.80941	1.26416	51.2	1.30774	.82938	1.27515
51.0	1.27548	.79753	1.25494	51.0	1.29773	.81697	1.26574
50.8	1.26598	.78585	1.24581	50.8	1.28782	.80477	1.25642
50.6	1.25658	.77436	1.23676	50.6	1.27801	.79278	1.24718

$\gamma = 0.04$				$\gamma = 0.05$			
φ	X	Y	T	φ	X	Y	T
0				0			
60.0	1.96194	1.79302	1.84116	60.0	2.04361	1.90178	1.87718
59.8	1.94216	1.75889	1.82459	59.8	2.02112	1.86297	1.85951
59.6	1.92275	1.72568	1.80828	59.6	1.99913	1.82535	1.84215
59.4	1.90372	1.69336	1.79222	59.4	1.97764	1.78886	1.82509
59.2	1.88503	1.66189	1.77640	59.2	1.95662	1.75346	1.80831
59.0	1.86669	1.63124	1.76082	59.0	1.93605	1.71908	1.79181
58.8	1.84867	1.60138	1.74546	58.8	1.91591	1.68569	1.77557
58.6	1.83097	1.57227	1.73033	58.6	1.89618	1.65325	1.75960
58.4	1.81358	1.54388	1.71542	58.4	1.87685	1.62170	1.74388
58.2	1.79648	1.51620	1.70072	58.2	1.85790	1.59102	1.72840
58.0	1.77967	1.48920	1.68623	58.0	1.83932	1.56116	1.71316
57.8	1.76314	1.46284	1.67193	57.8	1.82108	1.53210	1.69814
57.6	1.74688	1.43712	1.65783	57.6	1.70619	1.50379	1.68336
57.4	1.73088	1.41201	1.64392	57.4	1.78563	1.47622	1.66878
57.2	1.71513	1.38748	1.63020	57.2	1.76838	1.44935	1.65442
57.0	1.69963	1.36351	1.61666	57.0	1.75143	1.42316	1.64026
56.8	1.68437	1.34010	1.60329	56.8	1.73478	1.39762	1.62630
56.6	1.66933	1.31721	1.59010	56.6	1.71842	1.37270	1.61253
56.4	1.65453	1.29484	1.57707	56.4	1.70233	1.34839	1.59895
56.2	1.63994	1.27292	1.56421	56.2	1.68650	1.32466	1.58556
56.0	1.62556	1.25157	1.55151	56.0	1.67003	1.30150	1.57234
55.8	1.61139	1.23064	1.53897	55.8	1.65562	1.27887	1.55930
55.6	1.59742	1.21017	1.52657	55.6	1.64054	1.25677	1.54643
55.4	1.58365	1.19013	1.51433	55.4	1.62570	1.23517	1.53372
55.2	1.57007	1.17051	1.50224	55.2	1.61108	1.21407	1.52117
55.0	1.55667	1.15130	1.49029	55.0	1.59669	1.19344	1.50878
54.8	1.54346	1.13250	1.47847	54.8	1.58251	1.17326	1.49655
54.6	1.53042	1.11408	1.46680	54.6	1.56854	1.15353	1.48446
54.4	1.51755	1.09604	1.45526	54.4	1.55477	1.13423	1.47253
54.2	1.50485	1.07837	1.44385	54.2	1.54120	1.11534	1.46073
54.0	1.49231	1.06105	1.43256	54.0	1.52782	1.09686	1.44908
53.8	1.47994	1.04408	1.42141	53.8	1.51463	1.07877	1.43756
53.6	1.46772	1.02744	1.41038	53.6	1.50162	1.06105	1.42617
53.4	1.45565	1.01113	1.39946	53.4	1.48878	1.04370	1.41492
53.2	1.44373	.99514	1.38867	53.2	1.47612	1.02671	1.40380
53.0	1.43195	.97945	1.37799	53.0	1.46362	1.01007	1.39280
52.8	1.42032	.96406	1.36743	52.8	1.45129	.99376	1.38192
52.6	1.40882	.94897	1.35698	52.6	1.43911	.97778	1.37116
52.4	1.39746	.93417	1.34664	52.4	1.42709	.96212	1.36052
52.2	1.38624	.91965	1.33640	52.2	1.41522	.94676	1.34999
52.0	1.37514	.90540	1.32626	52.0	1.40351	.93171	1.33958
51.8	1.36417	.89141	1.31623	51.8	1.39194	.91695	1.32928
51.6	1.35332	.87768	1.30630	51.6	1.38051	.90247	1.31909
51.4	1.34260	.86420	1.29647	51.4	1.36921	.88827	1.30901
51.2	1.33199	.85095	1.28674	51.2	1.35804	.87434	1.29903
51.0	1.32150	.83795	1.27711	51.0	1.34701	.86067	1.28914
50.8	1.31112	.82518	1.26757	50.8	1.33611	.84726	1.27935
50.6	1.30085	.81264	1.25812	50.6	1.32533	.83410	1.26966

$\gamma = 0.06$				$\gamma = 0.07$			
φ	X	Y	T	φ	X	Y	T
°				°			
60.0	2.14308	2.03739	1.91913	60.0	2.27039	2.21597	1.96977
59.8	2.11669	1.99187	1.89999	59.8	2.23783	2.15980	1.94851
59.6	2.09106	1.94799	1.88124	59.6	2.20652	2.10621	1.92779
59.4	2.06613	1.90568	1.86386	59.4	2.17634	2.05498	1.90757
59.2	2.04187	1.86482	1.84484	59.2	2.14722	2.00594	1.88782
59.0	2.01825	1.82534	1.82716	59.0	2.11908	1.95891	1.86852
58.8	1.99522	1.78717	1.80980	58.8	2.09184	1.91376	1.84964
58.6	1.97276	1.75023	1.79276	58.6	2.06545	1.87036	1.83117
58.4	1.95084	1.71445	1.77601	58.4	2.03986	1.82859	1.81308
58.2	1.92943	1.67979	1.75956	58.2	2.01501	1.78835	1.79535
58.0	1.90851	1.64619	1.74339	58.0	1.99085	1.74955	1.77798
57.8	1.88806	1.61359	1.72749	57.8	1.96736	1.71209	1.76093
57.6	1.86806	1.58194	1.71186	57.6	1.94448	1.67591	1.74421
57.4	1.84848	1.55121	1.69647	57.4	1.92220	1.64092	1.72780
57.2	1.82931	1.52135	1.68133	57.2	1.90046	1.60707	1.71167
57.0	1.81053	1.49233	1.66642	57.0	1.87926	1.57430	1.69584
56.8	1.79213	1.46410	1.65175	56.8	1.85856	1.54254	1.68027
56.6	1.77409	1.43663	1.63729	56.6	1.83833	1.51175	1.66497
56.4	1.75639	1.40990	1.62306	56.4	1.81857	1.48188	1.64991
56.2	1.73903	1.38386	1.60902	56.2	1.79923	1.45289	1.63511
56.0	1.72199	1.35850	1.59520	56.0	1.78031	1.42473	1.62054
55.8	1.70526	1.33379	1.58156	55.8	1.76179	1.39738	1.60620
55.6	1.68883	1.30970	1.56812	55.6	1.74365	1.37078	1.59207
55.4	1.67268	1.28621	1.55487	55.4	1.72587	1.34491	1.57816
55.2	1.65682	1.26330	1.54180	55.2	1.70844	1.31974	1.56446
55.0	1.64122	1.24094	1.52890	55.0	1.69135	1.29524	1.55096
54.8	1.62588	1.21911	1.51617	54.8	1.67458	1.27133	1.53766
54.6	1.61079	1.19780	1.50361	54.6	1.65812	1.24813	1.52454
54.4	1.59595	1.17699	1.49122	54.4	1.64196	1.22548	1.51161
54.2	1.58134	1.15666	1.47898	54.2	1.62609	1.20339	1.49885
54.0	1.56696	1.13679	1.46690	54.0	1.61049	1.18185	1.48627
53.8	1.55280	1.11738	1.45496	53.8	1.59517	1.16083	1.47386
53.6	1.53885	1.09839	1.44318	53.6	1.58010	1.14032	1.46161
53.4	1.52512	1.07983	1.43154	53.4	1.56529	1.12030	1.44952
53.1	1.51158	1.06167	1.42004	53.2	1.55071	1.10075	1.43758
53.0	1.49824	1.04390	1.40867	53.0	1.53638	1.08165	1.42580
52.8	1.48509	1.02652	1.39744	52.8	1.52227	1.06299	1.41417
52.6	1.47213	1.00950	1.38634	52.6	1.50838	1.04475	1.40268
52.4	1.45935	.99284	1.37537	52.4	1.49470	1.02691	1.39133
52.2	1.44674	.97653	1.36452	52.2	1.48122	1.00948	1.38011
52.0	1.43431	.96056	1.35379	52.0	1.46794	.99244	1.36902
51.8	1.42204	.94491	1.34318	51.8	1.45486	.97577	1.35807
51.6	1.40993	.92958	1.33269	51.6	1.44197	.95945	1.34725
51.4	1.39798	.91455	1.32232	51.4	1.42926	.94348	1.33655
51.2	1.38619	.89983	1.31206	51.2	1.41674	.92784	1.32597
51.0	1.37454	.88540	1.30191	51.0	1.40439	.91252	1.31552
50.8	1.36304	.87125	1.29186	50.8	1.39220	.89752	1.30519
50.6	1.35168	.85737	1.28192	50.6	1.38018	.88284	1.29497

$\gamma = 0.08$				$\gamma = 0.09$			
φ	X	Y	T	φ	X	Y	T
60.0°	2.44854	2.47491	2.03488	59.0°	2.43774	2.40308	1.98477
59.8	2.40421	2.39843	2.01008	58.8	2.38974	2.32351	1.95971
59.6	2.36247	2.32699	1.98615	58.6	2.34500	2.24992	1.93565
59.4	2.32298	2.25995	1.96302	58.4	2.30304	2.18144	1.91249
59.2	2.28550	2.19682	1.94061	58.2	2.26349	2.11740	1.89013
59.0	2.24980	2.13716	1.91887	58.0	2.22605	2.05726	1.86850
58.8	2.21570	2.08063	1.89775	57.8	2.19049	2.00056	1.84753
58.6	2.18304	2.02693	1.87720	57.6	2.15659	1.94694	1.82718
58.4	2.15171	1.97579	1.86719	57.4	2.12420	1.89609	1.80738
58.2	2.12158	1.92700	1.83767	57.2	2.09316	1.84775	1.78812
58.0	2.09255	1.88037	1.81862	57.0	2.06336	1.80168	1.76934
57.8	2.06455	1.83573	1.80002	56.8	2.03470	1.75770	1.75102
57.6	2.03749	1.79292	1.78183	56.6	2.00707	1.71564	1.73314
57.4	2.01131	1.75182	1.76404	56.4	1.98040	1.67535	1.71566
57.2	1.98594	1.71231	1.74662	56.2	1.95462	1.63670	1.69856
57.0	1.96134	1.67428	1.72956	56.0	1.92967	1.59956	1.68182
56.8	1.93745	1.63764	1.71284	55.8	1.90548	1.56384	1.66544
56.6	1.91424	1.60230	1.69644	55.6	1.88202	1.52944	1.64938
56.4	1.89166	1.56818	1.68036	55.4	1.85923	1.49628	1.63363
56.2	1.86968	1.53522	1.66457	55.2	1.83707	1.46428	1.61818
56.0	1.84826	1.50334	1.64906	55.0	1.81551	1.43338	1.60302
55.8	1.82737	1.47249	1.63383	54.8	1.79451	1.40350	1.58813
55.6	1.80699	1.44261	1.61887	54.6	1.77405	1.37460	1.57350
55.4	1.78709	1.41366	1.60415	54.4	1.75409	1.34661	1.55913
55.2	1.76765	1.38559	1.58968	54.2	1.73461	1.31950	1.54500
55.0	1.74864	1.35834	1.57545	54.0	1.71558	1.29321	1.53110
54.8	1.73006	1.33189	1.56144	53.8	1.69698	1.26771	1.51742
54.6	1.71187	1.30620	1.54765	53.6	1.67880	1.24295	1.50397
54.4	1.69406	1.28123	1.53407	53.4	1.66101	1.21891	1.49072
54.2	1.67661	1.25695	1.52069	53.2	1.64359	1.19554	1.47767
54.0	1.65951	1.23333	1.50752	53.0	1.62653	1.17283	1.46482
53.8	1.64275	1.21034	1.49454	52.8	1.60982	1.15073	1.45216
53.6	1.62630	1.18796	1.48174	52.6	1.59344	1.12922	1.43968
53.4	1.61017	1.16615	1.46912	52.4	1.57737	1.10828	1.42738
53.2	1.59433	1.14491	1.45668	52.2	1.56161	1.08789	1.41525
53.0	1.57878	1.12419	1.44441	52.0	1.54614	1.06802	1.40328
52.8	1.56351	1.10399	1.43230	51.8	1.53095	1.04865	1.39147
52.6	1.54850	1.08429	1.42036	51.6	1.51603	1.02976	1.37982
52.4	1.53375	1.06507	1.40858	51.4	1.50137	1.01133	1.36834
52.2	1.51924	1.04630	1.39694	51.2	1.48696	.99335	1.35700
52.0	1.50497	1.02797	1.38545	51.0	1.47280	.97579	1.34581
51.8	1.49094	1.01007	1.37410	50.8	1.45887	.95865	1.33476
51.6	1.47713	.99258	1.36290	50.6	1.44517	.94191	1.32385
51.4	1.46354	.97549	1.35183	50.4	1.43169	.92556	1.31307
51.2	1.45015	.95878	1.34090	50.2	1.41842	.90957	1.30241
51.0	1.43696	.94244	1.33010	50.0	1.40535	.89393	1.29186
50.8	1.42397	.92646	1.31943	49.8	1.39248	.87865	1.28144
50.6	1.41118	.91083	1.30888	49.6	1.37980	.86370	1.27115

$\gamma = 0.10$				$\gamma = 0.11$			
φ	X	Y	T	φ	X	Y	T
°				°			
58.0	2.42326	2.32865	1.93480	57.0	2.40402	2.25049	1.88501
57.8	2.37144	2.24604	1.90955	56.8	2.34841	2.16518	1.85950
57.6	2.32368	2.17049	1.88543	56.6	2.29779	2.08810	1.83528
57.4	2.27931	2.10084	1.86226	56.4	2.25119	2.01771	1.81218
57.2	2.23780	2.03618	1.83998	56.2	2.20795	1.95286	1.79004
57.0	2.19876	1.97583	1.81849	56.0	2.16753	1.89271	1.76874
56.8	2.16188	1.91925	1.79772	55.8	2.12955	1.83660	1.74820
56.6	2.12689	1.86598	1.77758	55.6	2.09367	1.78402	1.72835
56.4	2.09358	1.81566	1.75805	55.4	2.05966	1.73453	1.70911
56.2	2.06179	1.76799	1.73906	55.2	2.02730	1.68779	1.69044
56.0	2.03136	1.72270	1.72059	55.0	1.99642	1.64352	1.67229
55.8	2.00217	1.67958	1.70258	54.8	1.96687	1.60147	1.65463
55.6	1.97411	1.63844	1.68502	54.6	1.93852	1.56144	1.63742
55.4	1.94708	1.59911	1.66787	54.4	1.91128	1.52324	1.62062
55.2	1.92100	1.56146	1.65111	54.2	1.88504	1.48673	1.60422
55.0	1.89581	1.52534	1.63472	54.0	1.85974	1.45177	1.58819
54.8	1.87143	1.49066	1.61868	53.8	1.83529	1.41824	1.57252
54.6	1.84782	1.45730	1.60297	53.6	1.81163	1.38603	1.55717
54.4	1.82491	1.42519	1.58757	53.4	1.78872	1.35506	1.54213
54.2	1.80268	1.39424	1.57247	53.2	1.76649	1.32525	1.52739
54.0	1.78106	1.36438	1.55766	53.0	1.74491	1.29650	1.51294
53.8	1.76003	1.33555	1.54312	52.8	1.72394	1.26877	1.49875
53.6	1.73956	1.30768	1.52884	52.6	1.70353	1.24199	1.48482
53.4	1.71961	1.28071	1.51481	52.4	1.68367	1.21609	1.47114
53.2	1.70015	1.25461	1.50102	52.2	1.66431	1.19104	1.45770
53.0	1.68116	1.22932	1.48746	52.0	1.64542	1.16679	1.44448
52.8	1.66262	1.20480	1.47412	51.8	1.62699	1.14328	1.43149
52.6	1.64450	1.18101	1.46100	51.6	1.60900	1.12050	1.41870
52.4	1.62678	1.15792	1.44808	51.4	1.59141	1.09839	1.40611
52.2	1.60945	1.13550	1.43536	51.2	1.57422	1.07692	1.39372
52.0	1.59249	1.11371	1.42283	51.0	1.55739	1.05607	1.38151
51.8	1.57587	1.09252	1.41049	50.8	1.54092	1.03580	1.36949
51.6	1.55959	1.07191	1.39832	50.6	1.52479	1.01610	1.35765
51.4	1.54363	1.05185	1.38633	50.4	1.50898	.99692	1.34597
51.2	1.52798	1.03232	1.37451	50.2	1.49349	.97826	1.33445
51.0	1.51262	1.01330	1.36286	50.0	1.47829	.96008	1.32310
50.8	1.49755	.99476	1.35136	49.8	1.46338	.94238	1.31190
50.6	1.48276	.97669	1.34001	49.6	1.44875	.92512	1.30085
50.4	1.46823	.95906	1.32881	49.4	1.43438	.90829	1.28994
50.2	1.45396	.94186	1.31776	49.2	1.42026	.89188	1.27917
50.0	1.43993	.92508	1.30685	49.0	1.40639	.87587	1.26855
49.8	1.42613	.90870	1.29608	48.8	1.39275	.86024	1.25806
49.6	1.41256	.89270	1.28544	48.6	1.37934	.84498	1.24770
49.4	1.39921	.87707	1.27493	48.4	1.36616	.83007	1.23746
49.2	1.38607	.86180	1.26454	48.2	1.35319	.81551	1.22734
49.0	1.37315	.84687	1.25428	48.0	1.34042	.80128	1.21734
48.8	1.36042	.83227	1.24414	47.8	1.32785	.78737	1.20746
48.6	1.34788	.81800	1.23412	47.6	1.31547	.77377	1.19769

$\gamma = 0.12$				$\gamma = 0.13$			
φ	X	Y	T	φ	X	Y	T
0				0			
56.0	2.37888	2.16734	1.83487	55.0	2.34664	2.07817	1.78424
55.8	2.31979	2.08005	1.80925	54.8	2.28474	1.99009	1.75868
55.6	2.26665	2.00215	1.78508	54.6	2.22971	1.91236	1.73470
55.4	2.21820	1.93166	1.76213	54.4	2.17996	1.84260	1.71201
55.2	2.17357	1.86719	1.74020	54.2	2.13441	1.77922	1.69040
55.0	2.13210	1.80775	1.71917	54.0	2.09231	1.72105	1.66973
54.8	2.09331	1.75256	1.69894	53.8	2.05309	1.66727	1.64987
54.6	2.05683	1.70103	1.67941	53.6	2.01633	1.61722	1.63074
54.4	2.02237	1.65271	1.66052	53.4	1.98169	1.57041	1.61225
54.2	1.98967	1.60720	1.64221	53.2	1.94891	1.52643	1.59435
54.0	1.95854	1.56419	1.62444	53.0	1.91777	1.48495	1.57699
53.8	1.92882	1.52344	1.60715	52.8	1.88809	1.44571	1.56011
53.6	1.90037	1.48471	1.59032	52.6	1.85972	1.40846	1.54369
53.4	1.87307	1.44781	1.57390	52.4	1.83253	1.37303	1.52769
53.2	1.84682	1.41260	1.55789	52.2	1.80642	1.33925	1.51208
53.0	1.82153	1.37892	1.54224	52.0	1.78130	1.30698	1.49683
52.8	1.79714	1.34666	1.52694	51.8	1.75708	1.27609	1.48193
52.6	1.77356	1.31570	1.51197	51.6	1.73370	1.24648	1.46735
52.4	1.75074	1.28596	1.49731	51.4	1.71108	1.21805	1.45308
52.2	1.72862	1.25735	1.48294	51.2	1.68918	1.19071	1.43909
52.0	1.70717	1.22979	1.46886	51.0	1.66795	1.16439	1.42538
51.8	1.68634	1.20322	1.45504	50.8	1.64734	1.13903	1.41194
51.6	1.66608	1.17757	1.44147	50.6	1.62731	1.11457	1.39874
51.4	1.64637	1.15279	1.42814	50.4	1.60783	1.09094	1.38577
51.2	1.62717	1.12883	1.41505	50.2	1.58887	1.06810	1.37304
51.0	1.60846	1.10564	1.40218	50.0	1.57040	1.04600	1.36052
50.8	1.59021	1.08318	1.38953	49.8	1.55238	1.02460	1.34821
50.6	1.57239	1.06142	1.37707	49.6	1.53480	1.00387	1.33609
50.4	1.55499	1.04030	1.36482	49.4	1.51763	.98377	1.32417
50.2	1.53798	1.01981	1.35276	49.2	1.50085	.96426	1.31244
50.0	1.52134	.99992	1.34088	49.0	1.48445	.94533	1.30088
49.8	1.50506	.98058	1.32917	48.8	1.46840	.92693	1.28950
49.6	1.48912	.96179	1.31764	48.6	1.45269	.90905	1.27828
49.4	1.47351	.94351	1.30627	48.4	1.43731	.89166	1.26722
49.2	1.45820	.92571	1.29507	48.2	1.42223	.87473	1.25631
49.0	1.44320	.90839	1.28401	48.0	1.40745	.85826	1.24556
48.8	1.42848	.89152	1.27310	47.8	1.39295	.84222	1.23495
48.6	1.41403	.87508	1.26234	47.6	1.37873	.82659	1.22448
48.4	1.39985	.85905	1.25172	47.4	1.36477	.81136	1.21415
48.2	1.38593	.84342	1.24124	47.2	1.35106	.79650	1.20395
48.0	1.37225	.82817	1.23090	47.0	1.33759	.78200	1.19387
47.8	1.35880	.81329	1.22069	46.8	1.32435	.76785	1.18392
47.6	1.34558	.79876	1.21060	46.6	1.31134	.75404	1.17409
47.4	1.33258	.78457	1.20063	46.4	1.29855	.74056	1.16438
47.2	1.31979	.77071	1.19077	46.2	1.28597	.72739	1.15478
47.0	1.30720	.75716	1.18103	46.0	1.27358	.71452	1.14530
46.8	1.29481	.74392	1.17140	45.8	1.26139	.70194	1.13593
46.6	1.28261	.73097	1.16188	45.6	1.24939	.68964	1.12666

γ = 0,14				γ = 0.15			
φ	X	Y	T	φ	X	Y	T
0				0			
54.0	2.30632	1.98239	1.73297	53.0	2.25742	1.88017	1.68106
53.8	2.24268	1.89511	1.70768	52.8	2.19343	1.79555	1.65629
53.6	2.18662	1.81878	1.68405	52.6	2.13738	1.72197	1.63321
53.4	2.13627	1.75073	1.66177	52.4	2.09724	1.65662	1.61148
53.2	2.09040	1.68919	1.64059	52.2	2.04169	1.59768	1.59086
53.0	2.04816	1.63293	1.62037	52.0	1.99983	1.54391	1.57118
52.8	2.00893	1.58106	1.60097	51.8	1.96103	1.49442	1.55232
52.6	1.97224	1.53290	1.58230	51.6	1.92480	1.44854	1.53417
52.4	1.93775	1.48795	1.56427	51.4	1.89076	1.40575	1.51667
52.2	1.90516	1.44578	1.54683	51.2	1.85864	1.36565	1.49973
52.0	1.87425	1.40607	1.52992	51.0	1.82819	1.32791	1.48331
51.8	1.84482	1.36853	1.51350	50.8	1.79922	1.29226	1.46737
51.6	1.81672	1.33295	1.49752	50.6	1.77157	1.25849	1.45186
51.4	1.78982	1.29913	1.48195	50.4	1.74512	1.22640	1.43675
51.2	1.76400	1.26691	1.46677	50.2	1.71975	1.19584	1.42202
51.0	1.73918	1.23615	1.45195	50.0	1.69536	1.16667	1.40764
50.8	1.71527	1.20672	1.43746	49.8	1.67187	1.13877	1.39358
50.6	1.69219	1.17852	1.42329	49.6	1.64921	1.11205	1.37983
50.4	1.66988	1.15146	1.40941	49.4	1.62731	1.08641	1.36636
50.2	1.64829	1.12545	1.39582	49.2	1.60612	1.06177	1.35317
50.0	1.62737	1.10043	1.38250	49.0	1.58558	1.03806	1.34024
49.8	1.60706	1.07632	1.36943	48.8	1.56566	1.01522	1.32756
49.6	1.58734	1.05306	1.35660	48.6	1.54631	.99320	1.31511
49.4	1.56816	1.03060	1.34400	48.4	1.52750	.97194	1.30288
49.2	1.54950	1.00890	1.33163	48.2	1.50919	.95139	1.29086
49.0	1.53132	.98792	1.31946	48.0	1.49136	.93151	1.27905
48.8	1.51359	.96760	1.30749	47.8	1.47397	.91228	1.26743
48.6	1.49630	.94791	1.29572	47.6	1.45702	.89364	1.25599
48.4	1.47941	.92883	1.28414	47.4	1.44046	.87557	1.24474
48.2	1.46292	.91031	1.27273	47.2	1.42428	.85804	1.23366
48.0	1.44679	.89233	1.26149	47.0	1.40847	.84102	1.22275
47.8	1.43101	.87487	1.25042	46.8	1.39300	.82449	1.21199
47.6	1.41557	.85790	1.23952	46.6	1.37786	.80843	1.20139
47.4	1.40045	.84140	1.22876	46.4	1.36303	.79280	1.19094
47.2	1.38563	.82534	1.21816	46.2	1.34851	.77760	1.18064
47.0	1.37111	.80971	1.20770	46.0	1.33427	.76281	1.17047
46.8	1.35688	.79449	1.19738	45.8	1.32030	.74839	1.16044
46.6	1.34292	.77966	1.18719	45.6	1.30660	.73435	1.15053
46.4	1.32920	.76520	1.17713	45.4	1.29315	.72067	1.14076
46.2	1.31572	.75110	1.16720	45.2	1.27995	.70732	1.13110
46.0	1.30247	.73736	1.15741	45.0	1.26697	.69430	1.12157
45.8	1.28945	.72394	1.14774	44.8	1.25421	.68159	1.11216
45.6	1.27666	.71084	1.13818	44.6	1.24167	.66918	1.10286
45.4	1.26409	.69805	1.12873	44.4	1.22935	.65707	1.09366
45.2	1.25173	.68556	1.11939	44.2	1.21723	.64524	1.08457
45.0	1.23959	.67336	1.11015	44.0	1.20531	.63368	1.07558
44.8	1.22765	.66143	1.10102	43.8	1.19358	.62238	1.06669
44.6	1.21588	.64976	1.09200	43.6	1.18203	.61133	1.05790

$\gamma = 0.16$				$\gamma = 0.17$			
φ	X	Y	T	φ	X	Y	T
0				0			
52.0	2.20019	1.77260	1.62859	51.0	2.13564	1.66158	1.57577
51.8	2.13736	1.69247	1.60460	50.8	2.07535	1.58739	1.55277
51.6	2.08241	1.62287	1.58225	50.6	2.02246	1.52276	1.53132
51.4	2.03328	1.56111	1.56122	50.4	1.97508	1.46529	1.51111
51.2	1.98869	1.50545	1.54127	50.2	1.93201	1.41340	1.49191
51.0	1.94773	1.45469	1.52223	50.0	1.89240	1.36603	1.47358
50.8	1.90978	1.40798	1.50398	49.8	1.85566	1.32239	1.45600
50.6	1.87434	1.36468	1.48642	49.6	1.82133	1.28191	1.43908
50.4	1.84107	1.32431	1.46947	49.4	1.78907	1.24414	1.42274
50.2	1.80966	1.28648	1.45308	49.2	1.75860	1.20872	1.40692
50.0	1.77989	1.25088	1.43719	49.0	1.72971	1.17536	1.39159
49.8	1.75158	1.21725	1.42176	48.8	1.70222	1.14385	1.37668
49.6	1.72456	1.18539	1.40674	48.6	1.67597	1.11397	1.36218
49.4	1.69871	1.15512	1.39211	48.4	1.65085	1.08557	1.34805
49.2	1.67391	1.12629	1.37785	48.2	1.62674	1.05852	1.33426
49.0	1.65007	1.09878	1.36392	48.0	1.60356	1.03268	1.32079
48.8	1.62712	1.07246	1.35030	47.8	1.58123	1.00797	1.30762
48.6	1.60497	1.04725	1.33698	47.6	1.55968	.98428	1.29473
48.4	1.58356	1.02305	1.32393	47.4	1.53885	.96155	1.28211
48.2	1.56285	.99981	1.31115	47.2	1.51868	.93970	1.26974
48.0	1.54278	.97743	1.29862	47.0	1.49914	.91866	1.25760
47.8	1.52331	.95588	1.28632	46.8	1.48017	.89840	1.24570
47.6	1.50439	.93510	1.27424	46.6	1.46175	.87884	1.23400
47.4	1.48600	.91503	1.26238	46.4	1.44383	.85996	1.22251
47.2	1.46810	.89563	1.25073	46.2	1.42639	.84171	1.21122
47.0	1.45067	.87687	1.23927	46.0	1.40939	.82405	1.20011
46.8	1.43367	.85871	1.22800	45.8	1.39282	.80695	1.18918
46.6	1.41709	.84111	1.21690	45.6	1.37665	.79038	1.17843
46.4	1.40090	.82405	1.20598	45.4	1.36086	.77431	1.16783
46.2	1.38508	.80749	1.19523	45.2	1.34543	.75872	1.15740
46.0	1.36962	.79142	1.18463	45.0	1.33034	.74358	1.14712
45.8	1.35449	.77581	1.17419	44.8	1.31558	.72887	1.13698
45.6	1.33968	.76064	1.16389	44.6	1.30113	.71457	1.12699
45.4	1.32518	.74588	1.15374	44.4	1.28698	.70066	1.11714
45.2	1.31097	.73152	1.14373	44.2	1.27311	.68712	1.10741
45.0	1.29703	.71754	1.13385	44.0	1.25950	.67394	1.09782
44.8	1.28335	.70392	1.12410	43.8	1.24616	.66110	1.08835
44.6	1.26993	.69065	1.11447	43.6	1.23307	.64858	1.07900
44.4	1.25677	.67772	1.10497	43.4	1.22021	.63638	1.06976
44.2	1.24386	.66511	1.09559	43.2	1.20758	.62449	1.06064
44.0	1.23118	.65280	1.08632	43.0	1.19518	.61288	1.05163
43.8	1.21872	.64079	1.07716	42.8	1.18299	.60155	1.04272
43.6	1.20646	.62907	1.06811	42.6	1.17100	.59048	1.03392
43.4	1.19439	.61763	1.05916	42.4	1.15920	.57968	1.02522
43.2	1.18251	.60644	1.05031	42.2	1.14760	.56912	1.01661
43.0	1.17082	.59551	1.04157	42.0	1.13618	.55880	1.00811
42.8	1.15931	.58483	1.03292	41.8	1.12494	.54872	.99969
42.6	1.14798	.57439	1.02437	41.6	1.11387	.53885	.99136

γ = 0.18				γ = 0.19			
φ	X	Y	T	φ	X	Y	T
°				°			
50.0	2.06533	1.54956	1.52292	49.0	1.99111	1.43884	1.47035
49.8	2.00860	1.48218	1.50107	48.8	1.93855	1.37858	1.44975
49.6	1.95852	1.42312	1.48063	48.6	1.89175	1.32530	1.43038
49.4	1.91346	1.37036	1.46132	48.4	1.84937	1.27740	1.41203
49.2	1.87235	1.32256	1.44295	48.2	1.81053	1.23380	1.39452
49.0	1.83445	1.27881	1.42538	48.0	1.77459	1.19374	1.37775
48.8	1.79921	1.23841	1.40851	47.8	1.74107	1.15665	1.36162
48.6	1.76624	1.20087	1.39226	47.6	1.70963	1.12209	1.34605
48.4	1.73520	1.16579	1.37655	47.4	1.67997	1.08972	1.33099
48.2	1.70586	1.13285	1.36134	47.2	1.65187	1.05928	1.31639
48.0	1.67800	1.10181	1.34657	47.0	1.62516	1.03053	1.30220
47.8	1.65146	1.07244	1.33221	46.8	1.59969	1.00330	1.28840
47.6	1.62611	1.04457	1.31824	46.6	1.57531	.97744	1.27495
47.4	1.60182	1.01806	1.30461	46.4	1.55194	.95281	1.26183
47.2	1.57850	.99279	1.29130	46.2	1.52948	.92931	1.24902
47.0	1.55606	.96864	1.27830	46.0	1.50785	.90683	1.23648
46.8	1.53443	.94553	1.26559	45.8	1.48698	.88529	1.22422
46.6	1.51355	.92337	1.25314	45.6	1.46682	.86463	1.21221
46.4	1.49335	.90209	1.24094	45.4	1.44730	.84477	1.20043
46.2	1.47379	.88162	1.22898	45.2	1.42839	.82566	1.18888
46.0	1.45483	.86191	1.21724	45.0	1.41005	.80725	1.17754
45.8	1.43642	.84291	1.20572	44.8	1.39223	.78949	1.16641
45.6	1.41852	.82457	1.19441	44.6	1.37490	.77235	1.15547
45.4	1.40112	.80686	1.18329	44.4	1.35804	.75577	1.14471
45.2	1.38417	.78973	1.17235	44.2	1.34161	.73974	1.13413
45.0	1.36765	.77315	1.16160	44.0	1.32559	.72422	1.12372
44.8	1.35153	.75710	1.15101	43.8	1.30996	.70918	1.11347
44.6	1.33581	.74153	1.14058	43.6	1.29470	.69459	1.10337
44.4	1.32044	.72644	1.13032	43.4	1.27978	.68044	1.09342
44.2	1.30543	.71178	1.12020	43.2	1.26520	.66670	1.08362
44.0	1.29074	.69755	1.11023	43.0	1.25093	.65335	1.07396
43.8	1.27637	.68372	1.10040	42.8	1.23697	.64037	1.06442
43.6	1.26230	.67027	1.09071	42.6	1.22328	.62774	1.05502
43.4	1.24851	.65718	1.08114	42.4	1.20988	.61546	1.04574
43.2	1.23499	.64445	1.07170	42.2	1.19673	.60350	1.03658
43.0	1.22173	.63204	1.06239	42.0	1.18384	.59185	1.02754
42.8	1.20872	.61994	1.05320	41.8	1.17118	.58049	1.01861
42.6	1.19595	.60815	1.04412	41.6	1.15875	.56942	1.00979
42.4	1.18342	.59666	1.03515	41.4	1.14655	.55862	1.00107
42.2	1.17111	.58547	1.02628	41.2	1.13456	.54808	.99246
42.0	1.15901	.57455	1.01751	41.0	1.12277	.53780	.98395
41.8	1.14711	.56388	1.00885	40.8	1.11118	.52776	.97554
41.6	1.13541	.55346	1.00029	40.6	1.09978	.51796	.96722
41.4	1.12390	.54328	.99183	40.4	1.08856	.50838	.95899
41.2	1.11258	.53333	.98346	40.2	1.07752	.49901	.95085
41.0	1.10143	.52360	.97518	40.0	1.06665	.48986	.94279
40.8	1.09045	.51409	.96699	39.8	1.05595	.48091	.93482
40.6	1.07964	.50479	.95889	39.6	1.04541	.47215	.92693

$\gamma = 0.20$				$\gamma = 0.3$			
φ	X	Y	T	φ	X	Y	T
°				°			
48.0	1.91475	1.33144	1.41840	40.0	1.47905	.776117	1.08479
47.8	1.86658	1.27812	1.39905	39.8	1.44479	.747469	1.07054
47.6	1.82326	1.23051	1.38078	39.6	1.41331	.721330	1.05691
47.4	1.78375	1.18740	1.36340	39.4	1.38411	.697262	1.04383
47.2	1.74734	1.14794	1.34678	39.2	1.35684	.674936	1.03122
47.0	1.71350	1.11151	1.33081	39.0	1.33120	.654103	1.01903
46.8	1.68182	1.07766	1.31542	38.8	1.30699	.634565	1.00722
46.6	1.65202	1.04603	1.30055	38.6	1.28402	.616164	.99574
46.4	1.62383	1.01633	1.28614	38.4	1.26216	.598772	.98458
46.2	1.59708	.988332	1.27215	38.2	1.24127	.582280	.97370
46.0	1.57159	.961847	1.25855	38.0	1.22128	.566599	.96308
45.8	1.54724	.936718	1.24530	37.8	1.20208	.551653	.95271
45.6	1.52391	.912812	1.23238	37.6	1.18361	.537377	.94256
45.4	1.50151	.890016	1.21977	37.4	1.16580	.523714	.93262
45.2	1.47995	.868234	1.20743	37.2	1.14861	.510615	.92289
45.0	1.45917	.847381	1.19537	37.0	1.13198	.498037	.91333
44.8	1.43911	.827384	1.18355	36.8	1.11587	.485942	.90396
44.6	1.41970	.808178	1.17197	36.6	1.10025	.474297	.89474
44.4	1.40090	.789706	1.16062	36.4	1.08507	.463071	.88569
44.2	1.38267	.771917	1.14947	36.2	1.07033	.452236	.87679
44.0	1.36498	.754766	1.13853	36.0	1.05597	.441769	.86803
43.8	1.34777	.738212	1.12777	35.8	1.04199	.431647	.85940
43.6	1.33104	.722218	1.11720	35.6	1.02836	.421851	.85091
43.4	1.31474	.706751	1.10680	35.4	1.01506	.412363	.84254
43.2	1.29885	.691780	1.09657	35.2	1.00207	.403166	.83429
43.0	1.28336	.677277	1.08650	35.0	.98937	.394244	.82615
42.8	1.26823	.663218	1.07658	34.8	.97696	.385584	.81813
42.6	1.25345	.649579	1.06680	34.6	.96481	.377172	.81021
42.4	1.23900	.636339	1.05717	34.4	.95291	.368996	.80239
42.2	1.22486	.623479	1.04767	34.2	.94126	.361046	.79467
42.0	1.21103	.610979	1.03830	34.0	.92984	.353312	.78704
41.8	1.19748	.598823	1.02906	33.8	.91863	.345784	.77951
41.6	1.18420	.586996	1.01995	33.6	.90764	.338453	.77206
41.4	1.17119	.575483	1.01095	33.4	.89685	.331311	.76470
41.2	1.15843	.564270	1.00206	33.2	.88625	.324350	.75743
41.0	1.14590	.553344	.99328	33.0	.87584	.317563	.75023
40.8	1.13361	.542692	.98462	32.8	.86561	.310942	.74311
40.6	1.12153	.532304	.97605	32.6	.85555	.304481	.73607
40.4	1.10966	.522170	.96759	32.4	.84565	.298174	.72910
40.2	1.09800	.512280	.95922	32.2	.83591	.292015	.72220
40.0	1.08653	.502625	.95095	32.0	.82632	.286000	.71537
39.8	1.07526	.493196	.94278	31.8	.81688	.280124	.70861
39.6	1.06416	.483984	.93469	31.6	.80758	.274381	.70191
39.4	1.05324	.474982	.92668	31.4	.79842	.268767	.69528
39.2	1.04249	.466182	.91877	31.2	.78939	.263277	.68871
39.0	1.03190	.457578	.91093	31.0	.78049	.257908	.68220
38.8	1.02147	.449162	.90318	30.8	.77171	.252656	.67575
38.6	1.01119	.440928	.89551	30.6	.76305	.247516	.66936

$\gamma = 0.4$				$\gamma = 0.5$			
φ	X	Y	T	φ	X	Y	T
°				°			
34.2	1.24777	.536087	.89410	29.6	1.06591	.384666	.75459
34.0	1.21572	.514384	.88133	29.4	1.03607	.367783	.74287
33.8	1.18649	.494743	.86916	29.2	1.00900	.352587	.73172
33.6	1.15954	.476774	.85750	29.0	.98413	.338743	.72106
33.4	1.13449	.460188	.84629	28.8	.96107	.326013	.71081
33.2	1.11103	.444779	.83546	28.6	.93953	.314219	.70093
33.0	1.08894	.430379	.82498	28.4	.91928	.303226	.69136
32.8	1.06805	.416859	.81481	28.2	.90015	.292927	.68208
32.6	1.04819	.404114	.80492	28.0	.88201	.283238	.67306
32.4	1.02927	.392057	.79528	27.8	.86473	.274088	.66427
32.2	1.01117	.380618	.78588	27.6	.84822	.265421	.65570
32.0	.99383	.369734	.77669	27.4	.83240	.257188	.64732
31.8	.97715	.359357	.76770	27.2	.81722	.249348	.63913
31.6	.96110	.349440	.75891	27.0	.80260	.241866	.63110
31.4	.94561	.339947	.75028	26.8	.78850	.234713	.62323
31.2	.93063	.330844	.74182	26.6	.77488	.227862	.61552
31.0	.91614	.322101	.73351	26.4	.76170	.221289	.60794
30.8	.90209	.313693	.72535	26.2	.74892	.214976	.60049
30.6	.88846	.305596	.71733	26.0	.73653	.208903	.59316
30.4	.87521	.297791	.70944	25.8	.72448	.203055	.58595
30.2	.86232	.290258	.70167	25.6	.71277	.197418	.57886
30.0	.84976	.282981	.69402	25.4	.70136	.191977	.57187
29.8	.83753	.275945	.68648	25.2	.69025	.186722	.56498
29.6	.82559	.269136	.67905	25.0	.67940	.181643	.55818
29.4	.81393	.262542	.67172	24.8	.66882	.176728	.55148
29.2	.80255	.256152	.66449	24.6	.65847	.171970	.54487
29.0	.79141	.249954	.65735	24.4	.64836	.167361	.53834
28.8	.78052	.243939	.65031	24.2	.63846	.162892	.53189
28.6	.76985	.238098	.64335	24.0	.62877	.158557	.52552
28.4	.75940	.232424	.63648	23.8	.61928	.154350	.51922
28.2	.74916	.226908	.62969	23.6	.60997	.150265	.51300
28.0	.73911	.221543	.62298	23.4	.60084	.146297	.50684
27.8	.72925	.216323	.61634	23.2	.59189	.142440	.50075
27.6	.71957	.211242	.60977	23.0	.58309	.138689	.49473
27.4	.71007	.206294	.60328	22.8	.57446	.135040	.48877
27.2	.70073	.201473	.59686	22.6	.56597	.131490	.48287
27.0	.69155	.196775	.59050	22.4	.55763	.128034	.47703
26.8	.68252	.192195	.58420	22.2	.54942	.124668	.47124
26.6	.67364	.187728	.57797	22.0	.54135	.121190	.46551
26.4	.66489	.183370	.57180	21.8	.53341	.118396	.45983
26.2	.65629	.179117	.56568	21.6	.52559	.115083	.45420
26.0	.64781	.174966	.55963	21.4	.51788	.112048	.44862
25.8	.63946	.170913	.55363	21.2	.51028	.109088	.44310
25.6	.63124	.166954	.54768	21.0	.50280	.106200	.43763
25.4	.62313	.163086	.54178	20.8	.49542	.103384	.43220
25.2	.61514	.159307	.53594	20.6	.48815	.100636	.42682
25.0	.60726	.155615	.53015	20.4	.48097	.097954	.42148
24.8	.59948	.152005	.52440	20.2	.47389	.095336	.41618

$\gamma = 0.6$				$\gamma = 0.7$			
φ	X	Y	T	φ	X	Y	T
0				0			
26.0	.93344	.290751	.65330	23.0	.81319	.220114	.56922
25.8	.90438	.276640	.64211	22.8	.78636	.208780	.55871
25.6	.87825	.264063	.63151	22.6	.76226	.198698	.54877
25.4	.85442	.252696	.62141	22.4	.74029	.189597	.53929
25.2	.83245	.242310	.61172	22.2	.72004	.181290	.53020
25.0	.81202	.232737	.60239	22.0	.70121	.173643	.52145
24.8	.79288	.223854	.59338	21.8	.68358	.166554	.51300
24.6	.77486	.215563	.58465	21.6	.66697	.159945	.50480
24.4	.75780	.207789	.57617	21.4	.65126	.153754	.49684
24.2	.74159	.200470	.56792	21.2	.63632	.147930	.48909
24.0	.72613	.193554	.55987	21.0	.62208	.142434	.48153
23.8	.71134	.187002	.55201	20.8	.60845	.137231	.47415
23.6	.69716	.180776	.54433	20.6	.59539	.132293	.46693
23.4	.68352	.174848	.53681	20.4	.58282	.127596	.45986
23.2	.67039	.169191	.52943	20.2	.57072	.123118	.45293
23.0	.65771	.163786	.52220	20.0	.55903	.118842	.44613
22.8	.64545	.158605	.51510	19.8	.54774	.114752	.43945
22.6	.63358	.153639	.50812	19.6	.53679	.110835	.43289
22.4	.62207	.148871	.50126	19.4	.52618	.107077	.42643
22.2	.61089	.144286	.49451	19.2	.51588	.103468	.42008
22.0	.60003	.139873	.48786	19.0	.50586	.099998	.41382
21.8	.58945	.135622	.48131	18.8	.49611	.096659	.40765
21.6	.57915	.131522	.47486	18.6	.48660	.093443	.40157
21.4	.56910	.127564	.46849	18.4	.47733	.090343	.39557
21.2	.55929	.123741	.46221	18.2	.46829	.087352	.38966
21.0	.54972	.120045	.45602	18.0	.45945	.084464	.38381
20.8	.54035	.116470	.44990	17.8	.45081	.081674	.37804
20.6	.53119	.113009	.44385	17.6	.44236	.078976	.37234
20.4	.52223	.109657	.43788	17.4	.43409	.076368	.36671
20.2	.51345	.106409	.43198	17.2	.42598	.073843	.36113
20.0	.50484	.103259	.42614	17.0	.41804	.071399	.35562
19.8	.49640	.100204	.42037	16.2	.41025	.069031	.35017
19.6	.48812	.097238	.41466	16.6	.40260	.066738	.34478
19.4	.47999	.094360	.40901	16.4	.39509	.064514	.33944
19.2	.47201	.091563	.40342	16.2	.38772	.062358	.33416
19.0	.46416	.088847	.39788	16.0	.38047	.060267	.32892
18.8	.45645	.086206	.39239	15.8	.37335	.058237	.32374
18.6	.44887	.083639	.38696	15.6	.36634	.056268	.31860
18.4	.44141	.081143	.38158	15.4	.35945	.054356	.31351
18.2	.43406	.078715	.37625	15.2	.35266	.052500	.30847
18.0	.42683	.076352	.37096	15.0	.34598	.050697	.30346
17.8	.41971	.074053	.36572	14.8	.33940	.048946	.29850
17.6	.41270	.071815	.36053	14.6	.33292	.047245	.29358
17.4	.40579	.069636	.35538	14.4	.32653	.045592	.28870
17.2	.39897	.067513	.35027	14.2	.32023	.043985	.28386
17.0	.39225	.065444	.34520	14.0	.31401	.042424	.27906
16.8	.38562	.063430	.34017	13.8	.30788	.040907	.27429
16.6	.37908	.061468	.33518	13.6	.30183	.039432	.26956

γ = 0.8				γ = 0.9			
φ	X	Y	T	φ	X	Y	T
20.6°	.72328	.173439	.50514	18.6°	.64747	.138865	.45242
20.4	.69753	.163809	.49502	18.4	.62289	.130637	.44265
20.2	.67451	.155295	.48546	18.2	.60098	.123395	.43344
20.0	.65361	.147646	.47637	18.0	.58115	.116911	.42469
19.8	.63440	.140692	.46766	17.8	.56295	.111033	.41631
19.6	.61658	.134310	.45928	17.6	.54609	.105653	.40826
19.4	.59992	.128411	.45119	17.4	.53035	.100690	.40049
19.2	.58426	.122924	.44335	17.2	.51556	.096084	.39297
19.0	.56945	.117797	.43575	17.0	.50159	.091787	.38566
18.8	.55539	.112984	.42834	16.8	.48834	.087761	.37855
18.6	.54200	.108450	.42112	16.6	.47573	.083976	.37162
18.4	.52920	.104167	.41407	16.4	.46367	.080405	.36486
18.2	.51693	.100109	.40718	16.2	.45212	.077027	.35824
18.0	.50514	.096255	.40043	16.0	.44103	.073825	.35177
17.8	.49378	.092587	.39382	15.8	.43035	.070782	.34542
17.6	.48283	.089091	.38733	15.6	.42005	.067886	.33919
17.4	.47224	.085752	.38095	15.4	.41009	.065125	.33307
17.2	.46199	.082559	.37468	15.2	.40045	.062488	.32706
17.0	.45205	.079501	.36852	15.0	.39111	.059967	.32114
16.8	.44240	.076569	.36246	14.8	.38204	.057554	.31532
16.6	.43302	.073754	.35648	14.6	.37323	.055242	.30958
16.4	.42389	.071050	.35060	14.4	.36465	.053024	.30393
16.2	.41499	.068450	.34479	14.2	.35630	.050894	.29836
16.0	.40632	.065947	.33906	14.0	.34815	.048848	.29286
15.8	.39786	.063537	.33341	13.8	.34020	.046881	.28743
15.6	.38960	.061213	.32783	13.6	.33244	.044989	.28208
15.4	.38152	.058972	.32232	13.4	.32485	.043167	.27678
15.2	.37361	.056810	.31688	13.2	.31743	.041412	.27155
15.0	.36587	.054722	.31149	13.0	.31016	.039721	.26638
14.8	.35829	.052705	.30617	12.8	.30305	.038091	.26127
14.6	.35087	.050756	.30091	12.6	.29607	.036518	.25621
14.4	.34358	.048872	.29570	12.4	.28923	.035001	.25120
14.2	.33643	.047050	.29054	12.2	.28251	.033537	.24625
14.0	.32942	.045287	.28544	12.0	.27592	.032124	.24134
13.8	.32252	.043581	.28039	11.8	.26945	.030760	.23648
13.6	.31575	.041929	.27538	11.6	.26308	.029442	.23167
13.4	.30909	.040330	.27042	11.4	.25683	.028170	.22690
13.2	.30254	.038782	.26551	11.2	.25068	.026940	.22218
13.0	.29609	.037282	.26064	11.0	.24462	.025753	.21749
12.8	.28974	.035829	.25581	10.8	.23866	.024606	.21285
12.6	.28349	.034421	.25102	10.6	.23279	.023497	.20825
12.4	.27734	.033057	.24627	10.4	.22701	.022426	.20368
12.2	.27128	.031735	.24156	10.2	.22132	.021391	.19914
12.0	.26531	.030454	.23690	10.0	.21571	.020391	.19464
11.8	.25942	.029213	.23227	9.8	.21018	.019425	.19018
11.6	.25361	.028010	.22767	9.6	.20472	.018492	.18575
11.4	.24788	.026844	.22310	9.4	.19934	.017591	.18135
11.2	.24222	.025713	.21856	9.2	.19403	.016721	.17699

$\gamma = 1.0$				$\gamma = 1.1$			
φ	X	Y	T	φ	X	Y	T
°				°			
17.0	.59414	.116140	.41265	15.4	.51899	.090241	.36756
16.8	.56934	.108606	.40293	15.2	.49780	.084445	.35864
16.6	.54752	.102059	.39382	15.0	.47885	.079331	.35022
16.4	.52792	.096251	.38519	14.8	.46163	.074748	.34219
16.2	.51004	.091024	.37696	14.6	.44578	.070591	.33451
16.0	.49357	.086268	.36907	14.4	.43108	.066788	.32711
15.8	.47824	.081903	.36147	14.2	.41732	.063282	.31996
15.6	.46389	.077869	.35412	14.0	.40438	.060032	.31302
15.4	.45037	.074119	.34699	13.8	.39215	.057004	.30629
15.2	.43758	.070618	.34006	13.6	.38053	.054171	.29974
15.0	42541	.067336	.33331	13.4	.36945	.051512	.29334
14.8	.41381	.064249	.32672	13.2	.35886	.049008	.28709
14.6	.40271	.061337	.32029	13.0	.34871	.046645	.28098
14.4	.39206	.058582	.31399	12.8	.33895	.044409	.27499
14.2	.38182	.055972	.30782	12.6	.32954	.042291	.26912
14.0	.37195	.053493	.30177	12.4	.32047	.040279	.26336
13.8	.36242	.051134	.29583	12.2	.31169	.038366	.25769
13.6	.35320	.048887	.28999	12.0	.30320	.036544	.25212
13.4	.34427	.046744	.28425	11.8	.29496	.034807	.24664
13.2	.33561	.044696	.27860	11.6	.28695	.033150	.24124
13.0	.32720	.042738	.27303	11.4	.27917	.031567	.23592
12.8	.31902	.040864	.26755	11.2	.27160	.030053	.23068
12.6	.31105	.039069	.26214	11.0	.26422	.028605	.22551
12.4	.30329	.037348	.25681	10.8	.25702	.027219	.22040
12.2	.29571	.035696	.25155	10.6	.24999	.025891	.21536
12.0	.28832	.034111	.24635	10.4	.24313	.024618	.21039
11.8	.28109	.032588	.24122	10.2	.23641	.023398	.20547
11.6	.27403	.031125	.23615	10.0	.22985	.022228	.20060
11.4	.26711	.029718	.23113	9.8	.22341	.021105	.19579
11.2	.26034	.028365	.22618	9.6	.21711	.020028	.19103
11.0	.25371	.027063	.22127	9.4	.21093	.018994	.18632
10.8	.24720	.025811	.21642	9.2	.20487	.018001	.18166
10.6	.24082	.024605	.21162	9.0	.19892	.017049	.17704
10.4	.23456	.023444	.20686	8.8	.19308	.016134	.17247
10.2	.22841	.022326	.20215	8.6	.18734	.015255	.16794
10.0	.22236	.021249	.19749	8.4	.18170	.014412	.16346
9.8	.21642	.020212	.19286	8.2	.17615	.013603	.15901
9.6	.21058	.019213	.18828	8.0	.17069	.012826	.15460
9.4	.20483	.018252	.18374	7.8	.16532	.012080	.15023
9.2	.19918	.017325	.17924	7.6	.16003	.011365	.14589
9.0	.19361	.016433	.17477	7.4	.15482	.010680	.14159
8.8	.18812	.015574	.17034	7.2	.14969	.010022	.13733
8.6	.18271	.014747	.16594	7.0	.14463	.009392	.13309
8.4	.17738	.013951	.16158	6.8	.13965	.008788	.12888
8.2	.17213	.013185	.15726	6.6	.13473	.008210	.12471
8.0	.16696	.012447	.15297	6.4	.12988	.007657	.12057
7.8	.16185	.011738	.14871	6.2	.12509	.007129	.11646
7.6	.15681	.011056	.14448	6.0	.12037	.006625	.11238

$\gamma = 1.2$				$\gamma = 1.3$			
φ	X	Y	T	φ	X	Y	T
0				0			
14.6	.52776	.089263	.35707	13.4	.46665	.071208	.32266
14.4	.49953	.081960	.34683	13.2	.44277	.065561	.31329
14.2	.47586	.075927	.33745	13.0	.42223	.060781	.30459
14.0	.45528	.070755	.32871	12.8	.40407	.056621	.29643
13.8	.43694	.066215	.32047	12.6	.38770	.052932	.28868
13.6	.42031	.062161	.31263	12.4	.37274	.049614	.28128
13.4	.40505	.058497	.30512	12.2	.35892	.046600	.27417
13.2	.39091	.055153	.29790	12.0	.34604	.043839	.26731
13.0	.37770	.052079	.29093	11.8	.33396	.041294	.26068
12.8	.36528	.049236	.28418	11.6	.32258	.038936	.25424
12.6	.35355	.046592	.27762	11.4	.31178	.036740	.24797
12.4	.34242	.044125	.27123	11.2	.30152	.034688	.24187
12.2	.33182	.041813	.26501	11.0	.29172	.032765	.23591
12.0	.32169	.039641	.25892	10.8	.28233	.030958	.23008
11.8	.31198	.037595	.25297	10.6	.27333	.029256	.22438
11.6	.30265	.035663	.24715	10.4	.26466	.027650	.21878
11.4	.29367	.033835	.24143	10.2	.25630	.026131	.21329
11.2	.28500	.032103	.23582	10.0	.24823	.024693	.20790
11.0	.27662	.030459	.23031	9.8	.24041	.023329	.20260
10.8	.26851	.028897	.22489	9.6	.23284	.022034	.19738
10.6	.26065	.027411	.21956	9.4	.22549	.020804	.19224
10.4	.25301	.025995	.21431	9.2	.21835	.019635	.18718
10.2	.24559	.024646	.20913	9.0	.21141	.018522	.18220
10.0	.23836	.023359	.20403	8.8	.20464	.017462	.17728
9.8	.23132	.022130	.19900	8.6	.19804	.016453	.17242
9.6	.22446	.020957	.19404	8.4	.19160	.015491	.16763
9.4	.21776	.019836	.18913	8.2	.18532	.014573	.16290
9.2	.21121	.018764	.18429	8.0	.17917	.013699	.15822
9.0	.20481	.017738	.17950	7.8	.17316	.012865	.15359
8.8	.19855	.016758	.17477	7.6	.16728	.012069	.14902
8.6	.19242	.015819	.17009	7.4	.16151	.011310	.14449
8.4	.18641	.014922	.16546	7.2	.15586	.010586	.14002
8.2	.18052	.014062	.16088	7.0	.15032	.009896	.13558
8.0	.17474	.013240	.15635	6.8	.14489	.009238	.13120
7.8	.16908	.012454	.15186	6.6	.13955	.008611	.12685
7.6	.16351	.011701	.14741	6.4	.13430	.008013	.12254
7.4	.15804	.010981	.14300	6.2	.12915	.007444	.11828
7.2	.15267	.010293	.13864	6.0	.12408	.006903	.11405
7.0	.14738	.009634	.13431	5.8	.11910	.006387	.10985
6.8	.14218	.009005	.13002	5.6	.11419	.005898	.10570
6.6	.13706	.008404	.12576	5.4	.10937	.005433	.10157
6.4	.13203	.007830	.12154	5.2	.10461	.004992	.09748
6.2	.12706	.007282	.11735	5.0	.09993	.004574	.09342
6.0	.12218	.006760	.11320	4.8	.09532	.004178	.08939
5.8	.11736	.006262	.10908	4.6	.09077	.003804	08539
5.6	.11261	.005788	.10499	4.4	.08628	.003451	.08142
5.4	.10793	.005337	.10093	4.2	.08185	.003118	.07748
5.2	.10331	.004908	.09689	4.0	.07748	.002805	.07357

$\gamma = 1.4$				$\gamma = 1.5$			
φ	X	Y	T	φ	X	Y	T
°				°			
12.2	.40049	.054244	.28670	11.4	.37183	.046879	.26693
12.0	.38169	.050213	.27842	11.2	.35357	.043229	.25879
11.8	.36495	.046685	.27061	11.0	.33734	.040046	.25112
11.6	.34979	.043544	.26318	10.8	.32267	.037220	.24384
11.4	.33588	.040714	.25607	10.6	.30923	.034679	.23687
11.2	.32299	.038138	.24923	10.4	.29678	.032373	.23016
11.0	.31095	.035777	.24262	10.2	.28517	.030263	.22369
10.8	.29964	.033599	.23623	10.0	.27427	.028320	.21743
10.6	.28896	.031580	.23001	9.8	.26398	.026524	.21134
10.4	.27882	.029701	.22396	9.6	.25421	.024855	.20542
10.2	.26917	.027946	.21806	9.4	.24492	.023299	.19964
10.0	.25994	.026303	.21230	9.2	.23604	.021845	.19400
9.8	.25110	.024760	.20666	9.0	.22753	.020482	.18848
9.6	.24260	.023307	.20113	8.8	.21936	.019202	.18308
9.4	.23442	.021938	.19572	8.6	.21149	.017998	.17777
9.2	.22653	.020646	.19040	8.4	.20390	.016864	.17257
9.0	.21890	.019424	.18517	8.2	.19657	.015794	.16746
8.8	.21152	.018267	.18003	8.0	.18946	.014783	.16243
8.6	.20435	.017171	.17497	7.8	.18258	.013827	.15748
8.4	.19740	.016131	.16999	7.6	.17590	.012924	.15260
8.2	.19064	.015145	.16508	7.4	.16940	.012068	.14780
8.0	.18405	.014209	.16024	7.2	.16308	.011258	.14306
7.8	.17764	.013319	.15546	7.0	.15692	.010491	.13839
7.6	.17139	.012474	.15075	6.8	.15091	.009764	.13378
7.4	.16529	.011670	.14610	6.6	.14505	.009075	.12922
7.2	.15933	.010906	.14150	6.4	.13932	.008422	.12472
7.0	.15350	.010180	.13695	6.2	.13372	.007803	.12028
6.8	.14779	.009489	.13246	6.0	.12824	.007218	.11588
6.6	.14221	.008833	.12801	5.8	.12288	.006663	.11153
6.4	.13673	.008209	.12361	5.6	.11762	.006139	.10722
6.2	.13137	.007617	.11926	5.4	.11247	.005642	.10296
6.0	.12610	.007054	.11495	5.2	.10741	.005173	.09874
5.8	.12094	.006520	.11068	5.0	.10245	.004731	.09457
5.6	.11586	.006014	.10645	4.8	.09758	.004313	.09043
5.4	.11088	.005534	.10226	4.6	.09279	.003919	.08633
5.2	.10598	.005080	.09810	4.4	.08809	.003549	.08226
5.0	.10116	.004650	.09399	4.2	.08347	.003201	.07823
4.8	.09642	.004244	.08990	4.0	.07891	.002875	.07423
4.6	.09176	.003860	.08585	3.8	.07443	.002569	.07027
4.4	.08716	.003499	.08184	3.6	.07002	.002284	.06634
4.2	.08264	.003158	.07785	3.4	.06568	.002018	.06244
4.0	.07818	.002839	.07390	3.2	.06139	.001771	.05856
3.8	.07379	.002539	.06997	3.0	.05717	.001543	.05472
3.6	.06946	.002259	.06607	2.8	.05301	.001332	.05090
3.4	.06519	.001998	.06220	2.6	.04891	.001138	.04711
3.2	.06098	.001755	.05836	2.4	.04487	.000961	.04335
3.0	.05681	.001530	.05455	2.2	.04088	.000801	.03962
2.8	.05270	.001322	.05076	2.0	.03693	.000657	.03591

$\gamma = 1.6$				$\gamma = 1.7$			
φ	X	Y	T	φ	X	Y	T
0				0			
10.8	.35727	.042866	.25411	10.2	.33774	.038251	.23987
10.6	.33811	.039244	.24577	10.0	.31860	.034841	.23157
10.4	.32135	.036137	.23799	9.8	.30198	.031938	.22384
10.2	.30635	.033411	.23064	9.6	.28718	.029407	.21655
10.0	.29272	.030982	.22363	9.4	.27377	.027162	.20961
9.8	.28018	.028793	.21691	9.2	.26146	.025147	.20297
9.6	.26853	.026803	.21045	9.0	.25006	.023321	.19658
9.4	.25764	.024980	.20419	8.8	.23942	.021653	.19041
9.2	.24740	.023302	.19813	8.6	.22941	.020122	.18444
9.0	.23770	.021749	.19224	8.4	.21996	.018710	.17863
8.8	.22850	.020307	.18650	8.2	.21099	.017401	.17297
8.6	.21972	.018964	.18091	8.0	.20245	.016185	.16746
8.4	.21133	.017709	.17543	7.8	.19429	.015052	.16207
8.2	.20328	.016535	.17008	7.6	.18646	.013994	.15679
8.0	.19554	.015433	.16483	7.4	.17894	.013004	.15163
7.8	.18808	.014398	.15968	7.2	.17170	.012077	.14656
7.6	.18088	.013425	.15462	7.0	.16472	.011206	.14158
7.4	.17392	.012509	.14965	6.8	.15796	.010389	.13669
7.2	.16718	.011645	.14475	6.6	.15142	.009621	.13188
7.0	.16064	.010830	.13994	6.4	.14508	.008898	.12715
6.8	.15428	.010061	.13519	6.2	.13892	.008218	.12248
6.6	.14811	.009336	.13052	6.0	.13294	.007578	.11788
6.4	.14209	.008650	.12590	5.8	.12711	.006976	.11335
6.2	.13623	.008003	.12135	5.6	.12143	.006409	.10887
6.0	.13051	.007392	.11686	5.4	.11590	.005876	.10446
5.8	.12493	.006815	.11242	5.2	.11049	.005374	.10010
5.6	.11947	.006270	.10803	5.0	.10521	.004903	.09579
5.4	.11413	.005756	.10370	4.8	.10004	.004460	.09152
5.2	.10891	.005271	.09941	4.6	.09499	.004044	.08731
5.0	.10380	.004815	.09517	4.4	.09004	.003655	.08314
4.8	.09878	.004385	.09097	4.2	.08519	.003290	.07901
4.6	.09387	.003981	.08681	4.0	.08043	.002949	.07493
4.4	.08904	.003601	.08270	3.8	.07577	.002631	.07088
4.2	.08431	.003245	.07862	3.6	.07119	.002335	.06687
4.0	.07966	.002912	.07458	3.4	.06669	.002060	.06290
3.8	.07509	.002600	.07058	3.2	.06227	.001805	.05897
3.6	.07060	.002310	.06661	3.0	.05793	.001570	.05507
3.4	.06618	.002039	.06267	2.8	.05366	.001354	.05120
3.2	.06183	.001789	.05877	2.6	.04945	.001156	.04737
3.0	.05755	.001557	.05490	2.4	.04532	.000975	.04357
2.8	.05333	.001343	.05106	2.2	.04124	.000811	.03979
2.6	.04918	.001147	.04725	2.0	.03723	.000664	.03605
2.4	.04509	.000969	.04346	1.8	.03327	.000533	.03233
2.2	.04106	.000807	.03971	1.6	.02937	.000417	.02864
2.0	.03708	.000661	.03598	1.4	.02553	.000316	.02497
1.8	.03316	.000530	.03227	1.2	.02174	.000230	.02133
1.6	.02929	.000415	.02859	1.0	.01800	.000159	.01772
1.4	.02547	.000315	.02494	0.8	.01431	.000101	.01413

γ = 1.8				γ = 1.9			
φ	X	Y	T	φ	X	Y	T
0				0			
9.6	.31398	.033273	.22453	9.0	.28737	.028267	.20836
9.4	.29579	.030230	.21645	8.8	.27075	.025664	.20065
9.2	.27994	.027634	.20891	8.6	.25612	.023425	.19342
9.0	.26580	.025369	.20180	8.4	.24299	.021461	.18658
8.8	.25298	.023361	.19503	8.2	.23101	.019714	.18004
8.6	.24120	.021558	.18854	8.0	.21997	.018142	.17377
8.4	.23028	.019926	.18230	7.8	.20969	.016716	.16773
8.2	.22008	.018437	.17627	7.6	.20007	.015415	.16188
8.0	.21048	.017071	.17042	7.4	.19100	.014221	.15620
7.8	.20141	.015813	.16474	7.2	.18242	.013121	.15068
7.6	.19281	.014649	.15921	7.0	.17426	.012104	.14531
7.4	.18460	.013569	.15382	6.8	.16647	.011162	.14005
7.2	.17676	.012564	.14854	6.6	.15902	.010287	.13492
7.0	.16925	.011628	.14338	6.4	.15187	.009472	.12989
6.8	.16202	.010754	.13832	6.2	.14499	.008712	.12496
6.6	.15506	.009936	.13336	6.0	.13836	.008003	.12012
6.4	.14834	.009171	.12848	5.8	.13195	.007341	.11537
6.2	.14185	.008453	.12369	5.6	.12575	.006722	.11069
6.0	.13556	.007781	.11897	5.4	.11975	.006144	.10609
5.8	.12946	.007151	.11434	5.2	.11392	.005603	.10157
5.6	.12354	.006559	.10977	5.0	.10826	.005098	.09710
5.4	.11778	.006005	.10526	4.8	.10275	.004625	.09270
5.2	.11217	.005484	.10082	4.6	.09739	.004184	.08836
5.0	.10670	.004997	.09643	4.4	.09216	.003773	.08408
4.8	.10137	.004540	.09210	4.2	.08706	.003389	.07984
4.6	.09617	.004112	.08783	4.0	.08207	.003032	.07566
4.4	.09108	.003712	.08360	3.8	.07720	.002700	.07153
4.2	.08611	.003338	.07942	3.6	.07244	.002391	.06744
4.0	.08125	.002989	.07529	3.4	.06777	.002106	.06340
3.8	.07648	.002664	.07120	3.2	.06320	.001842	.05940
3.6	.07181	.002362	.06716	3.0	.05872	.001600	.05544
3.4	.06723	.002082	.06315	2.8	.05433	.001377	.05152
3.2	.06274	.001823	.05918	2.6	.05002	.001174	.04763
3.0	.05833	.001585	.05525	2.4	.04578	.000989	.04379
2.8	.05400	.001365	.05136	2.2	.04162	.000822	.03997
2.6	.04974	.001164	.04750	2.0	.03753	.000672	.03619
2.4	.04555	.000982	.04368	1.8	.03352	.000538	.03245
2.2	.04144	.000816	.03989	1.6	.02956	.000421	.02873
2.0	.03739	.000668	.03612	1.4	.02567	.000319	.02504
1.8	.03340	.000536	.03239	1.2	.02184	.000232	.02139
1.6	.02947	.000419	.02869	1.0	.01807	.000160	.01776
1.4	.02560	.000318	.02501	0.8	.01435	.000102	.01416
1.2	.02179	.000231	.02136	0.6	.01069	.000057	.01058
1.0	.01803	.000159	.01774	0.4	.00708	.000025	.00703
0.8	.01433	.000101	.01415	+.2	.00352	.000006	.00350
0.6	.01068	.000056	.01058	0.0	.00000	.000000	.00000
0.4	.00708	.000024	.00703	—.2	.00347	.000006	.00348
0.2	.00352	.000006	.00350	0.4	.00689	.000024	.00694

$\gamma = 2.0$				$\gamma = 2.1$			
φ	X	Y	T	φ	X	Y	T
8.6°	.27661	.026059	.19960	8.2°	.26354	.023652	.19018
8.4	.25962	.023518	.19182	8.0	.24666	.021250	.18243
8.2	.24482	.021358	.18455	7.8	.23203	.019219	.17522
8.0	.23162	.019478	.17769	7.6	.21901	.017459	.16842
7.8	.21964	.017816	.17117	7.4	.20724	.015908	.16195
7.6	.20864	.016328	.16491	7.2	.19644	.014525	.15576
7.4	.19843	.014985	.15889	7.0	.18644	.013279	.14981
7.2	.18890	.013763	.15308	6.8	.17711	.012149	.14406
7.0	.17994	.012646	.14744	6.6	.16834	.011119	.13849
6.8	.17146	.011621	.14196	6.4	.16005	.010175	.13308
6.6	.16342	.010676	.13663	6.2	.15220	.009308	.12781
6.4	.15575	.009802	.13142	6.0	.14471	.008508	.12267
6.2	.14843	.008993	.12633	5.8	.13756	.007769	.11764
6.0	.14140	.008242	.12135	5.6	.13071	.007085	.11273
5.8	.13465	.007544	.11647	5.4	.12412	.006451	.10791
5.6	.12815	.006895	.11168	5.2	.11778	.005862	.10319
5.4	.12187	.006291	.10698	5.0	.11167	.005316	.09855
5.2	.11580	.005727	.10236	4.8	.10575	.004809	.09399
5.0	.10992	.005203	.09781	4.6	.10002	.004338	.08950
4.8	.10422	.004714	.09333	4.4	.09447	.003901	.08508
4.6	.09868	.004259	.08892	4.2	.08908	.003496	.08073
4.4	.09329	.003835	.08457	4.0	.08383	.003120	.07645
4.2	.08805	.003441	.08028	3.8	.07873	.002772	.07222
4.0	.08294	.003074	.07605	3.6	.07376	.002450	.06804
3.8	.07796	.002734	.07187	3.4	.06891	.002153	.06392
3.6	.07309	.002420	.06774	3.2	.06418	.001880	.05985
3.4	.06834	.002129	.06366	3.0	.05955	.001630	.05582
3.2	.06369	.001861	.05962	2.8	.05503	.001400	.05184
3.0	.05914	.001615	.05563	2.6	.05060	.001192	.04791
2.8	.05468	.001389	.05168	2.4	.04627	.001003	.04402
2.6	.05031	.001183	.04777	2.2	.04202	.000832	.04016
2.4	.04603	.000996	.04390	2.0	.03785	.000679	.03635
2.2	.04182	.000827	.04007	1.8	.03377	.000544	.03257
2.0	.03770	.000675	.03627	1.6	.02976	.000425	.02883
1.8	.03364	.000541	.03251	1.4	.02582	.000322	.02512
1.6	.02966	.000423	.02878	1.2	.02194	.000234	.02144
1.4	.02575	.000320	.02508	1.0	.01814	.000161	.01779
1.2	.02189	.000233	.02141	0.8	.01440	.000102	.01418
1.0	.01811	.000160	.01778	0.6	.01071	.000057	.01059
0.8	.01438	.000102	.01417	0.4	.00709	.000025	.00703
0.6	.01071	.000057	.01059	+.2	.00352	.000006	.00350
0.4	.00709	.000025	.00704	0.0	.00000	.000000	.00000
+.2	.00352	.000006	.00351	—.2	.00347	.000006	.00347
0.0	.00000	.000000	.00000	0.4	.00689	.000024	.00692
—.2	.00345	.000006	.00348	0.6	.01026	.000053	.01035
0.4	.00686	.000024	.00694	0.8	.01358	.000094	.01376
0.6	.01024	.000053	.01037	1.0	.01685	.000145	.01715
0.8	.01358	.000094	.01378	1.2	.02008	.000207	.02051

$\gamma = 2.2$				$\gamma = 2.3$			
φ	X	Y	T	φ	X	Y	T
0				0			
8.0	.26801	.023841	.18851	7.6	.25022	.020996	.17785
7.8	.24848	.021130	.18019	7.4	.23197	.018592	.16980
7.6	.23217	.018925	.17259	7.2	.21660	.016622	.16241
7.4	.21803	.017062	.16550	7.0	.20318	.014950	.15552
7.2	.20544	.015449	.15882	6.8	.19120	.013500	.14900
7.0	.19404	.014029	.15246	6.6	.18032	.012221	.14280
6.8	.18359	.012764	.14638	6.4	.17031	.011081	.13685
6.6	.17390	.011626	.14053	6.2	.16104	.010057	.13113
6.4	.16486	.010596	.13487	6.0	.15236	.009129	.12559
6.2	.15637	.009658	.12940	5.8	.14420	.008286	.12023
6.0	.14834	.008800	.12407	5.6	.13648	.007516	.11501
5.8	.14073	.008013	.11889	5.4	.12916	.006810	.10993
5.6	.13348	.007289	.11383	5.2	.12217	.006162	.10497
5.4	.12654	.006622	.10889	5.0	.11550	.005566	.10012
5.2	.11990	.006005	.10405	4.8	.10909	.005017	.09538
5.0	.11352	.005436	.09932	4.6	.10294	.004511	.09073
4.8	.10737	.004909	.09467	4.4	.09701	.004044	.08616
4.6	.10144	.004421	.09010	4.2	.09128	.003613	.08168
4.4	.09571	.003970	.08561	4.0	.08575	.003216	.07727
4.2	.09016	.003552	.08120	3.8	.08038	.002850	.07294
4.0	.08477	.003166	.07685	3.6	.07518	.002514	.06866
3.8	.07954	.002810	.07257	3.4	.07013	.002205	.06446
3.6	.07446	.002481	.06835	3.2	.06521	.001921	.06031
3.4	.06951	.002178	.06419	3.0	.06043	.001662	.05622
3.2	.06469	.001900	.06008	2.8	.05576	.001426	.05218
3.0	.05998	.001645	.05602	2.6	.05121	.001212	.04819
2.8	.05539	.001412	.05201	2.4	.04677	.001018	.04424
2.6	.05090	.001201	.04805	2.2	.04243	.000843	.04035
2.4	.04651	.001009	.04413	2.0	.03818	.000687	.03649
2.2	.04222	.000837	.04026	1.8	.03402	.000550	.03268
2.0	.03802	.000683	.03642	1.6	.02995	.000429	.02891
1.8	.03389	.000546	.03263	1.4	.02596	.000324	.02518
1.6	.02985	.000426	.02887	1.2	.02205	.000235	.02149
1.4	.02589	.000322	.02515	1.0	.01821	.000162	.01782
1.2	.02200	.000234	.02146	0.8	.01444	.000102	.01420
1.0	.01817	.000161	.01781	0.6	.01074	.000057	.01060
0.8	.01442	.000102	.01419	0.4	.00710	.000025	.00704
0.6	.01072	.000057	.01060	+.2	.00352	.000006	.00351
0.4	.00709	.000025	.00704	0.0	.00000	.000000	.00000
+.2	.00352	.000006	.00351	—.2	.00346	.000006	.00348
0.0	.00000	.000000	.00000	0.4	.00687	.000024	.00693
—.2	.00347	.000006	.00348	0.6	.01023	.000053	.01035
0.4	.00689	.000024	.00694	0.8	.01354	.000094	.01375
0.6	.01026	.000053	.01037	1.0	.01680	.000145	.01712
0.8	.01357	.000094	.01377	1.2	.02002	.000206	.02047
1.0	.01683	.000145	.01714	1.4	.02319	.000277	.02380
1.2	.02005	.000207	.02049	1.6	.02632	.000359	.02711
1.4	.02323	.000280	.02382	1.8	.02940	.000451	.03039

$\gamma = 2.4$				$\gamma = 2.5$			
φ	X	Y	T	φ	X	Y	T
0				0			
7.4	.25182	.020836	.17534	7.0	.23004	.017756	.16361
7.2	.23130	.018206	.16682	6.8	.21205	.015577	.15563
7.0	.21464	.016130	.15914	6.6	.19704	.013813	.14834
6.8	.20040	.014406	.15204	6.4	.18402	.012329	.14155
6.6	.18786	.012933	.14538	6.2	.17243	.011049	.13515
6.4	.17660	.011649	.13906	6.0	.16193	.009927	.12907
6.2	.16632	.010514	.13304	5.8	.15231	.008933	.12324
6.0	.15685	.009501	.12726	5.6	.14340	.008043	.11764
5.8	.14803	.008590	.12168	5.4	.13508	.007241	.11222
5.6	.13977	.007765	.11628	5.2	.12726	.006516	.10697
5.4	.13198	.007016	.11104	5.0	.11987	.005856	.10188
5.2	.12461	.006332	.10595	4.8	.11286	.005255	.09691
5.0	.11760	.005706	.10098	4.6	.10618	.004706	.09207
4.8	.11091	.005132	.09613	4.4	.09980	.004204	.08733
4.6	.10451	.004606	.09139	4.2	.09369	.003744	.08270
4.4	.09836	.004122	.08674	4.0	.08781	.003322	.07816
4.2	.09245	.003677	.08219	3.8	.08215	.002937	.07370
4.0	.08675	.003269	.07772	3.6	.07669	.002583	.06933
3.8	.08125	.002893	.07332	3.4	.07141	.002260	.06503
3.6	.07592	.002549	.06900	3.2	.06630	.001965	.06079
3.4	.07076	.002232	.06475	3.0	.06134	.001696	.05663
3.2	.06574	.001943	.06056	2.8	.05652	.001452	.05252
3.0	.06087	.001680	.05643	2.6	.05184	.001232	.04848
2.8	.05614	.001439	.05236	2.4	.04728	.001032	.04448
2.6	.05152	.001222	.04834	2.2	.04284	.000854	.04054
2.4	.04702	.001025	.04437	2.0	.03851	.000695	.03665
2.2	.04263	.000849	.04045	1.8	.03428	.000555	.03281
2.0	.03834	.000692	.03658	1.6	.03015	.000432	.02901
1.8	.03415	.000553	.03275	1.4	.02611	.000326	.02525
1.6	.03005	.000431	.02897	1.2	.02215	.000237	.02154
1.4	.02603	.000325	.02522	1.0	.01828	.000162	.01786
1.2	.02210	.000236	.02152	0.8	.01448	.000102	.01422
1.0	.01824	.000162	.01785	0.6	.01076	.000057	.01062
0.8	.01446	.000102	.01421	0.4	.00711	.000025	.00704
0.6	.01075	.000057	.01061	+.2	.00352	.000006	.00351
0.4	.00710	.000025	.00704	0.0	.00000	.000000	.00000
+.2	.00352	.000006	.00351	—.2	.00346	.000006	.00348
0.0	.00000	.000000	.00000	0.4	.00686	.000024	.00692
—.2	.00346	.000006	.00348	0.6	.01021	.000053	.01034
0.4	.00687	.000024	.00693	0.8	.01350	.000093	.01373
0.6	.01022	.000053	.01035	1.0	.01675	.000144	.01710
0.8	.01352	.000094	.01374	1.2	.01995	.000205	.02044
1.0	.01677	.000145	.01711	1.4	.02310	.000276	.02376
1.2	.01998	.000206	.02045	1.6	.02620	.000357	.02705
1.4	.02314	.000277	.02377	1.8	.02925	.000448	.03031
1.6	.02626	.000358	.02707	2.0	.03225	.000548	.03355
1.8	.02933	.000449	.03035	2.2	.03521	.000657	.03677
2.0	.03235	.000551	.03360	2.4	.03814	.000775	.03997

$\gamma = 2.6$				$\gamma = 2.7$			
φ °	X	Y	T	φ °	X	Y	T
6.6	.20876	.014962	.15189	6.4	.20465	.014281	.14792
6.4	.19307	.013173	.14445	6.2	.18842	.012488	.14035
6.2	.17964	.011690	.13756	6.0	.17470	.011021	.13339
6.0	.16780	.010425	.13110	5.8	.16271	.009782	.12689
5.8	.15716	.009324	.12497	5.6	.15199	.008711	.12074
5.6	.14744	.008355	.11912	5.4	.14224	.007773	.11488
5.4	.13848	.007491	.11350	5.2	.13328	.006941	.10927
5.2	.13014	.006717	.10808	5.0	.12496	.006198	.10386
5.0	.12232	.006019	.10283	4.8	.11718	.005531	.09862
4.8	.11494	.005387	.09774	4.6	.10985	.004929	.09355
4.6	.10796	.004813	.09279	4.4	.10293	.004383	.08862
4.4	.10132	.004290	.08796	4.2	.09635	.003889	.08381
4.2	.09499	.003814	.08324	4.0	.09007	.003439	.07912
4.0	.08892	.003379	.07863	3.8	.08407	.003030	.07453
3.8	.08309	.002982	.07411	3.6	.07832	.002657	.07004
3.6	.07749	.002620	.06968	3.4	.07278	.002319	.06564
3.4	.07209	.002289	.06533	3.2	.06745	.002011	.06132
3.2	.06687	.001988	.06105	3.0	.06230	.001732	.05707
3.0	.06182	.001714	.05685	2.8	.05732	.001480	.05290
2.8	.05692	.001466	.05271	2.6	.05250	.001253	.04879
2.6	.05217	.001242	.04863	2.4	.04782	.001048	.04474
2.4	.04756	.001040	.04461	2.2	.04327	.000866	.04075
2.2	.04306	.000860	.04065	2.0	.03885	.000704	.03682
2.0	.03869	.000699	.03674	1.8	.03455	.000561	.03294
1.8	.03442	.000558	.03288	1.6	.03035	.000436	.02911
1.6	.03026	.000434	.02906	1.4	.02626	.000329	.02533
1.4	.02619	.000328	.02529	1.2	.02226	.000238	.02159
1.2	.02221	.000237	.02156	1.0	.01835	.000163	.01790
1.0	.01832	.000163	.01788	0.8	.01453	.000103	.01424
0.8	.01451	.000103	.01423	0.6	.01078	.000057	.01063
0.6	.01077	.000057	.01062	0.4	.00712	.000025	.00705
0.4	.00711	.000025	.00705	+.2	.00352	.000006	.00351
+.2	.00352	.000006	.00351	0.0	.00000	.000000	.00000
0.0	.00000	.000000	.00000	—.2	.00346	.000006	.00348
—.2	.00346	.000006	.00348	0.4	.00686	.000024	.00692
0.4	.00686	.000024	.00692	0.6	.01019	.000053	.01033
0.6	.01020	.000053	.01034	0.8	.01347	.000093	.01371
0.8	.01349	.000093	.01372	1.0	.01669	.000144	.01707
1.0	.01672	.000144	.01708	1.2	.01986	.000204	.02040
1.2	.01990	.000205	.02042	1.4	.02298	.000274	.02370
1.4	.02303	.000276	.02373	1.6	.02606	.000354	.02698
1.6	.02612	.000357	.02701	1.8	.02909	.000444	.03023
1.8	.02916	.000447	.03027	2.0	.03207	.000544	.03345
2.0	.03216	.000547	.03350	2.2	.03501	.000652	.03665
2.2	.03512	.000656	.03671	2.4	.03791	.000769	.03983
2.4	.03804	.000773	.03990	2.6	.04077	.000894	.04299
2.6	.04092	.000898	.04307	2.8	.04359	.001027	.04614
2.8	.04376	.001031	.04622	3.0	.04636	.001167	.04927

$\gamma = 2.8$				$\gamma = 2.9$			
φ	X	Y	T	φ	X	Y	T
0				0			
6.2	.19970	.013534	.14368	6.0	.19388	.012730	.13921
6.0	.18312	.011761	.13603	5.8	.17717	.011002	.13154
5.8	.16925	.010328	.12903	5.6	.16330	.009618	.12455
5.6	.15721	.009125	.12252	5.4	.15131	.008463	.11805
5.4	.14649	.008092	.11637	5.2	.14067	.007475	.11193
5.2	.13678	.007191	.11053	5.0	.13105	.006616	.10611
5.0	.12786	.006395	.10493	4.8	.12223	.005861	.10054
4.8	.11961	.005687	.09954	4.6	.11408	.005190	.09519
4.6	.11190	.005053	.09433	4.4	.10647	.004591	.09002
4.4	.10465	.004483	.08929	4.2	.09933	.004054	.08501
4.2	.09780	.003968	.08439	4.0	.09258	.003570	.08015
4.0	.09130	.003502	.07961	3.8	.08618	.003134	.07541
3.8	.08511	.003080	.07495	3.6	.08009	.002739	.07079
3.6	.07919	.002697	.07040	3.4	.07427	.002383	.06628
3.4	.07352	.002350	.06594	3.2	.06870	.002062	.06186
3.2	.06807	.002036	.06157	3.0	.06334	.001772	.05753
3.0	.06282	.001751	.05728	2.8	.05818	.001510	.05328
2.8	.05775	.001495	.05307	2.6	.05320	.001275	.04910
2.6	.05285	.001264	.04893	2.4	.04839	.001065	.04500
2.4	.04811	.001056	.04486	2.2	.04373	.000878	.04096
2.2	.04350	.000872	.04085	2.0	.03921	.000712	.03699
2.0	.03903	.000708	.03689	1.8	.03483	.000566	.03307
1.8	.03469	.000564	.03300	1.6	.03056	.000440	.02921
1.6	.03046	.000438	.02915	1.4	.02641	.000331	.02540
1.4	.02634	.000330	.02536	1.2	.02237	.000239	.02165
1.2	.02232	.000238	.02161	1.0	.01842	.000164	.01793
1.0	.01839	.000163	.01791	0.8	.01457	.000103	.01427
0.8	.01455	.000103	.01425	0.6	.01081	.000057	.01064
0.6	.01080	.000057	.01063	0.4	.00713	.000025	.00706
0.4	.00712	.000025	.00705	+.2	.00353	.000006	.00351
+.2	.00353	.000006	.00351	0.0	.00000	.000000	.00000
0.0	.00000	.000000	.00000	—.2	.00346	.000006	.00347
—.2	.00346	.000006	.00347	0.4	.00685	.000024	.00691
0.4	.00685	.000024	.00692	0.6	.01017	.000052	.01032
0.6	.01018	.000053	.01033	0.8	.01343	.000092	.01369
0.8	.01345	.000093	.01371	1.0	.01664	.000143	.01704
1.0	.01667	.000143	.01706	1.2	.01979	.000203	.02036
1.2	.01983	.000203	.02038	1.4	.02289	.000273	.02364
1.4	.02294	.000273	.02368	1.6	.02594	.000353	.02691
1.6	.02600	.000353	.02695	1.8	.02893	.000442	.03014
1.8	.02901	.000443	.03019	2.0	.03188	.000540	.03335
2.0	.03197	.000542	.03341	2.2	.03479	.000646	.03654
2.2	.03489	.000649	.03661	2.4	.03766	.000760	.03970
2.4	.03777	.000765	.03978	2.6	.04048	.000883	.04284
2.6	.04061	.000889	.04293	2.8	.04326	.001015	.04596
2.8	.04342	.001021	.04606	3.0	.04600	.001155	.04906
3.0	.04618	.001161	.04917	3.2	.04871	.001303	.05214
3.2	.04890	.001308	.05226	3.4	.05138	.001458	.05520

$\gamma = 3.0$				$\gamma = 3.1$			
φ	X	Y	T	φ	X	Y	T
0				0			
5.6	.17062	.010218	.12684	5.6	.17983	.010990	.12957
5.4	.15690	.008897	.11989	5.4	.16358	.009425	.12201
5.2	.14506	.007798	.11344	5.2	.15014	.008177	.11513
5.0	.13457	.006862	.10736	5.0	.13855	.007143	.10875
4.8	.12510	.006050	.10159	4.8	.12829	.006262	.10274
4.6	.11644	.005337	.09608	4.6	.11901	.005499	.09703
4.4	.10842	.004706	.09077	4.4	.11053	.004831	.09157
4.2	.10094	.004144	.08565	4.2	.10268	.004241	.08632
4.0	.09393	.003641	.08068	4.0	.09536	.003716	.08126
3.8	.08731	.003189	.07586	3.8	.08849	.003248	.07635
3.6	.08103	.002783	.07117	3.6	.08201	.002829	.07158
3.4	.07505	.002417	.06660	3.4	.07587	.002453	.06694
3.2	.06934	.002088	.06212	3.2	.07001	.002115	.06241
3.0	.06387	.001791	.05775	3.0	.06442	.001812	.05799
2.8	.05861	.001525	.05346	2.8	.05907	.001541	.05366
2.6	.05355	.001287	.04925	2.6	.05393	.001298	.04942
2.4	.04867	.001074	.04512	2.4	.04897	.001082	.04526
2.2	.04396	.000884	.04106	2.2	.04420	.000890	.04117
2.0	.03939	.000717	.03707	2.0	.03958	.000721	.03715
1.8	.03497	.000570	.03313	1.8	.03511	.000573	.03320
1.6	.03067	.000442	.02926	1.6	.03078	.000444	.02931
1.4	.02649	.000332	.02543	1.4	.02657	.000334	.02548
1.2	.02242	.000240	.02167	1.2	.02248	.000241	.02170
1.0	.01846	.000164	.01795	1.0	.01850	.000165	.01797
0.8	.01459	.000103	.01427	0.8	.01462	.000104	.01429
0.6	.01082	.000057	.01064	0.6	.01083	.000057	.01065
0.4	.00713	.000025	.00706	0.4	.00714	.000025	.00706
+.2	.00353	.000006	.00351	+.2	.00353	.000006	.00351
0.0	.00000	.000000	.00000	0.0	.00000	.000000	.00000
−.2	.00346	.000006	.00347	−.2	.00345	.000006	.00347
0.4	.00684	.000024	.00691	0.4	.00684	.000024	.00691
0.6	.01016	.000053	.01032	0.6	.01015	.000052	.01031
0.8	.01342	.000092	.01369	0.8	.01340	.000092	.01368
1.0	.01662	.000142	.01703	1.0	.01659	.000142	.01701
1.2	.01976	.000203	.02034	1.2	.01972	.000202	.02032
1.4	.02284	.000273	.02363	1.4	.02279	.000272	.02360
1.6	.02587	.000352	.02688	1.6	.02581	.000351	.02684
1.8	.02886	.000441	.03011	1.8	.02878	.000439	.03006
0.0	.03179	.000538	.03331	2.0	.03171	.000536	.03326
2.2	.03468	.000646	.03649	2.2	.03458	.000641	.03643
2.4	.03753	.000761	.03964	2.4	.03741	.000755	.03957
2.6	.04034	.000883	.04277	2.6	.04019	.000876	.04270
2.8	.04310	.001012	.04588	2.8	.04294	.001006	.04579
3.0	.04582	.001149	.04897	3.0	.04564	.001143	.04887
3.2	.04850	.001295	.05204	3.2	.04830	.001288	.05193
3.4	.05115	.001448	.05509	3.4	.05093	.001440	.05497
3.6	.05377	.001608	.05812	3.6	.05353	.001599	.05799
3.8	.05635	.001775	.06113	3.8	.05609	.001764	.06098

$\gamma = 3.2$				$\gamma = 3.3$			
φ	X	Y	T	φ	X	Y	T
5.2°	.15612	.008631	.11704	5.2°	.16339	.009192	.11926
5.0	.14309	.007467	.11027	5.0	.14836	.007850	.11199
4.8	.13183	.006502	.10398	4.8	.13583	.006775	.10535
4.6	.12184	.005680	.09805	4.6	.12496	.005880	.09917
4.4	.11281	.004969	.09242	4.4	.11529	.005119	.09334
4.2	.10454	.004347	.08703	4.2	.10653	.004460	.08780
4.0	.09689	.003798	.08185	4.0	.09850	.003885	.08249
3.8	.08975	.003311	.07685	3.8	.09107	.003377	.07738
3.6	.08304	.002878	.07200	3.6	.08412	.002928	.07245
3.4	.07671	.002490	.06729	3.4	.07760	.002529	.06766
3.2	.07071	.002144	.06271	3.2	.07143	.002174	.06301
3.0	.06400	.001835	.05824	3.0	.06559	.001857	.05849
2.8	.05954	.001558	.05387	2.8	.06002	.001575	.05407
2.6	.05431	.001311	.04959	2.6	.05469	.001323	.04976
2.4	.04928	.001092	.04539	2.4	.04959	.001101	.04553
2.2	.04444	.000897	.04128	2.2	.04468	.000904	.04139
2.0	.03977	.000726	.03724	2.0	.03996	.000730	.03733
1.8	.03526	.000576	.03327	1.8	.03540	.000579	.03334
1.6	.03089	.000446	.02936	1.6	.03100	.000448	.02941
1.4	.02665	.000335	.02551	1.4	.02673	.000336	.02555
1.2	.02253	.000242	.02172	1.2	.02259	.000243	.02175
1.0	.01853	.000165	.01799	1.0	.01857	.000165	.01800
0.8	.01464	.000104	.01430	0.8	.01466	.000104	.01431
0.6	.01085	.000058	.01066	0.6	.01086	.000057	.01066
0.4	.00714	.000025	.00706	0.4	.00715	.000025	.00706
+.2	.00353	.000006	.00351	+.2	.00353	.000006	.00351
0.0	.00000	.000000	.00000	0.0	.00000	.000000	.00000
—.2	.00345	.000006	.00347	—.2	.00345	.000006	.00347
0.4	.00683	.000024	.00691	0.4	.00683	.000024	.00690
0.6	.01014	.000053	.01030	0.6	.01013	.000052	.01030
0.8	.01338	.000092	.01367	0.8	.01337	.000092	.01366
1.0	.01656	.000142	.01700	1.0	.01654	.000142	.01698
1.2	.01968	.000202	.02030	1.2	.01965	.000201	.02028
1.4	.02275	.000272	.02357	1.4	.02270	.000271	.02354
1.6	.02575	.000350	.02681	1.6	.02569	.000349	.02678
1.8	.02871	.000438	.03003	1.8	.02864	.000436	.02999
2.0	.03162	.000535	.03321	2.0	.03153	.000532	.03317
2.2	.03447	.000639	.03637	2.2	.03437	.000636	.03632
2.4	.03729	.000752	.03951	2.4	.03717	.000749	.03945
2.6	.04006	.000873	.04262	2.6	.03992	.000869	.04255
2.8	.04278	.001001	.04571	2.8	.04263	.000997	.04563
3.0	.04547	.001137	.04878	3.0	.04530	.001132	.04869
3.2	.04812	.001280	.05183	3.2	.04793	.001274	.05173
3.4	.05073	.001430	.05486	3.4	.05052	.001423	.05474
3.6	.05331	.001587	.05786	3.6	.05308	.001579	.05773
3.8	.05585	.001752	.06084	3.8	.05560	.001742	.06070
4.0	.05835	.001924	.06380	4.0	.05808	.001912	.06365
4.2	.06082	.002102	.06675	4.2	.06053	.002088	.06658

$\gamma = 3.4$				$\gamma = 3.5$			
φ	X	Y	T	φ	X	Y	T
°				°			
5.0	.15467	.008315	.11392	4.8	.14583	.007473	.10854
4.8	.14042	.007093	.10685	4.6	.13241	.006369	.10167
4.6	.12845	.006108	.10036	4.4	.12102	.005473	.09535
4.4	.11801	.005286	.09430	4.2	.11104	.004722	.08943
4.2	.10869	.004585	.08859	4.0	.10210	.004086	.08383
4.0	.10023	.003979	.08314	3.8	.09395	.003525	.07849
3.8	.09246	.003449	.07792	3.6	.08646	.003040	.07336
3.6	.08525	.002983	.07289	3.4	.07949	.002614	.06842
3.4	.07852	.002570	.06803	3.2	.07297	.002238	.06364
3.2	.07218	.002205	.06332	3.0	.06683	.001905	.05901
3.0	.06619	.001881	.05875	2.8	.06102	.001611	.05450
2.8	.06051	.001592	.05428	2.6	.05550	.001350	.05010
2.6	.05508	.001337	.04993	2.4	.05023	.001120	.04581
2.4	.04990	.001110	.04567	2.2	.04519	.000918	.04161
2.2	.04493	.000910	.04150	2.0	.04036	.000740	.03750
2.0	.04015	.000735	.03742	1.8	.03571	.000586	.03347
1.8	.03555	.000582	.03340	1.6	.03122	.000453	.02952
1.6	.03111	.000451	.02946	1.4	.02689	.000340	.02563
1.4	.02681	.000338	.02559	1.2	.02270	.000244	.02180
1.2	.02265	.000244	.02178	1.0	.01865	.000166	.01804
1.0	.01861	.000166	.01802	0.8	.01471	.000105	.01433
0.8	.01468	.000104	.01432	0.6	.01088	.000058	.01067
0.6	.01087	.000058	.01067	0.4	.00716	.000025	.00707
0.4	.00715	.000025	.00707	+.2	.00354	.000006	.00351
+.2	.00353	.000006	.00351	0.0	.00000	.000000	.00000
0.0	.00000	.000000	.00000	−.2	.00345	.000006	.00347
−.2	.00345	.000006	.00347	0.4	.00682	.000024	.00690
0.4	.00682	.000024	.00690	0.6	.01011	.000052	.01029
0.6	.01012	.000052	.01029	0.8	.01333	.000092	.01365
0.8	.01335	.000092	.01365	1.0	.01649	.000141	.01696
1.0	.01651	.000141	.01697	1.2	.01958	.000201	.02025
1.2	.01961	.000201	.02026	1.4	.02260	.000269	.02350
1.4	.02265	.000271	.02352	1.6	.02558	.000347	.02672
1.6	.02563	.000349	.02675	1.8	.02849	.000434	.02991
1.8	.02856	.000436	.02995	2.0	.03135	.000529	.03307
2.0	.03144	.000531	.03312	2.2	.03417	.000632	.03621
2.2	.03427	.000635	.03626	2.4	.03693	.000743	.03932
2.4	.03705	.000747	.03938	2.6	.03965	.000861	.04240
2.6	.03978	.000866	.04247	2.8	.04233	.000988	.04546
2.8	.04248	.000993	.04554	3.0	.04496	.001121	.04850
3.0	.04513	.001127	.04859	3.2	.04756	.001261	.05151
3.2	.04774	.001268	.05161	3.4	.05012	.001408	.05450
3.4	.05031	.001416	.05461	3.6	.05264	.001562	.05747
3.6	.05285	.001571	.05759	3.8	.05511	.001723	.06042
3.8	.05535	.001733	.06055	4.0	.05755	.001890	.06335
4.0	.05781	.001901	.06349	4.2	.05996	.002063	.06626
4.2	.06024	.002075	.06641	4.4	.06234	.002242	.06915
4.4	.06264	.002255	.06931	4.6	.06469	.002427	.07202

$\gamma = 3.6$				$\gamma = 3.7$			
φ	X	Y	T	φ	X	Y	T
0 4.6	.13697	.006674	.10314	0 4.6	.14235	.007040	.10480
4.4	.12439	.005683	.09650	4.4	.12820	.005925	.09775
4.2	.11361	.004872	.09035	4.2	.11645	.005041	.09133
4.0	.10410	.004190	.08457	4.0	.10627	.004311	.08536
3.8	.09554	.003606	.07909	3.8	.09723	.003695	.07973
3.6	.08772	.003101	.07386	3.6	.08906	.003166	.07437
3.4	.08050	.002659	.06883	3.4	.08157	.002708	.06925
3.2	.07378	.002272	.06398	3.2	.07463	.002308	.06432
3.0	.06748	.001931	.05928	3.0	.06816	.001957	.05956
2.8	.06154	.001630	.05472	2.8	.06208	.001649	.05495
2.6	.05592	.001364	.05029	2.6	.05635	.001378	.05047
2.4	.05056	.001130	.04596	2.4	.05090	.001140	.04611
2.2	.04545	.000925	.04173	2.2	.04572	.000932	.04185
2.0	.04056	.000745	.03760	2.0	.04076	.000750	.03769
1.8	.03586	.000590	.03354	1.8	.03602	.000593	.03362
1.6	.03134	.000455	.02957	1.6	.03145	.000457	.02962
1.4	.02698	.000341	.02567	1.4	.02706	.000342	.02571
1.2	.02276	.000245	.02183	1.2	.02282	.000246	.02186
1.0	.01868	.000167	.01806	1.0	.01872	.000167	.01808
0.8	.01473	.000105	.01434	0.8	.01476	.000105	.01435
0.6	.01089	.000058	.01068	0.6	.01091	.000058	.01069
0.4	.00716	.000025	.00707	0.4	.00717	.000025	.00708
+.2	.00354	.000006	.00351	+.2	.00354	.000006	.00351
0.0	.00000	.000000	.00000	0.0	.00000	.000000	.00000
—.2	.00345	.000006	.00347	—.2	.00345	.000006	.00347
0.4	.00681	.000024	.00690	0.4	.00681	.000024	.00690
0.6	.01010	.000052	.01028	0.6	.01009	.000052	.01028
0.8	.01332	.000092	.01363	0.8	.01330	.000091	.01363
1.0	.01646	.000141	.01695	1.0	.01644	.000140	.01694
1.2	.01954	.000200	.02023	1.2	.01951	.000199	.02021
1.4	.02256	.000269	.02347	1.4	.02252	.000268	.02346
1.6	.02552	.000346	.02669	1.6	.02546	.000345	.02666
1.8	.02842	.000432	.02987	1.8	.02835	.000431	.02984
2.0	.03127	.000527	.03303	2.0	.03119	.000525	.03299
2.2	.03407	.000629	.03615	2.2	.03397	.000627	.03611
2.4	.03682	.000740	.03925	2.4	.03670	.000737	.03920
2.6	.03952	.000858	.04233	2.6	.03939	.000854	.04226
2.8	.04218	.000983	.04538	2.8	.04203	.000978	.04530
3.0	.04479	.001116	.04840	3.0	.04463	.001110	.04832
3.2	.04737	.001255	.05140	3.2	.04719	.001249	.05131
3.4	.04991	.001401	.05438	3.4	.04971	.001394	.05428
3.5	.05241	.001554	.05734	3.6	.05219	.001546	.05723
3.8	.05487	.001713	.06028	3.8	.05463	.001704	.06016
4.0	.05729	.001878	.06320	4.0	.05704	.001868	.06306
4.2	.05968	.002049	.06610	4.2	.05941	.002038	.06594
4.4	.06204	.002226	.06898	4.4	.06175	.002214	.06881
4.6	.06437	.002409	.07184	4.6	.06406	.002396	.07166
4.8	.06667	.002598	.07468	4.8	.06634	.002583	.07449

γ = 3.8				γ = 3.9			
φ	X	Y	T	φ	X	Y	T
0				0			
4.4	.13261	.006209	.09915	4.4	.13783	.006551	.10072
4.2	.11962	.005231	.09240	4.2	.12321	.005449	.09357
4.0	.10864	.004444	.08619	4.0	.11126	.004592	.08709
3.8	.09905	.003790	.08039	3.8	.10102	.003894	.08110
3.6	.09048	.003235	.07491	3.6	.09199	.003310	.07548
3.4	.08268	.002758	.06969	3.4	.08387	.002813	.07014
3.2	.07552	.002345	.06468	3.2	.07645	.002385	.06504
3.0	.06886	.001984	.05985	3.0	.06960	.002013	.06015
2.8	.06264	.001669	.05519	2.8	.06322	.001690	.05542
2.6	.05679	.001393	.05066	2.6	.05724	.001408	.05085
2.4	.05125	.001151	.04626	2.4	.05160	.001162	.04641
2.2	.04599	.000939	.04197	2.2	.04626	.000947	.04209
2.0	.04097	.000755	.03778	2.0	.04118	.000761	.03788
1.8	.03617	.000596	.03369	1.8	.03633	.000600	.03376
1.6	.03157	.000460	.02968	1.6	.03169	.000462	.02973
1.4	.02714	.000344	.02574	1.4	.02723	.000345	.02579
1.2	.02288	.000247	.02189	1.2	.02294	.000248	.02191
1.0	.01876	.000168	.01809	1.0	.01880	.000168	.01811
0.8	.01478	.000105	.01436	0.8	.01480	.000105	.01438
0.6	.01092	.000058	.01069	0.6	.01093	.000058	.01070
0.4	.00718	.000025	.00708	0.4	.00718	.000025	.00708
+.2	.00354	.000006	.00351	+.2	.00354	.000006	.00352
0.0	.00000	.000000	.00000	0.0	.00000	.000000	.00000
—.2	.00345	.000006	.00347	—.2	.00344	.000006	.00347
0.4	.00681	.000024	.00689	0.4	.00680	.000024	.00689
0.6	.01008	.000052	.01028	0.6	.01007	.000052	.01027
0.8	.01329	.000092	.01362	0.8	.01327	.000091	.01361
1.0	.01641	.000141	.01693	1.0	.01639	.000140	.01691
1.2	.01948	.000199	.02020	1.2	.01944	.000198	.02017
1.4	.02247	.000267	.02343	1.4	.02242	.000266	.02340
1.6	.02541	.000344	.02663	1.6	.02535	.000342	.02660
1.8	.02828	.000430	.02980	1.8	.02821	.000427	.02976
2.0	.03111	.000523	.03294	2.0	.03102	.000521	.03289
2.2	.03388	.000625	.03605	2.2	.03377	.000622	.03600
2.4	.03660	.000734	.03913	2.4	.03648	.000730	.03907
2.6	.03927	.000850	.04219	2.6	.03913	.000846	.04212
2.8	.04189	.000974	.04522	2.8	.04175	.000969	.04514
3.0	.04448	.001105	.04823	3.0	.04431	.001099	.04814
3.2	.04702	.001242	.05121	3.2	.04683	.001235	.05111
3.4	.04952	.001386	.05417	3.4	.04931	.001378	.05406
3.6	.05198	.001537	.05711	3.6	.05176	.001528	.05699
3.8	.05440	.001694	.06002	3.8	.05417	.001684	.05989
4.0	.05678	.001857	.06291	4.0	.05654	.001846	.06277
4.2	.05913	.002026	.06578	4.2	.05888	.002014	.06563
4.4	.06145	.002200	.06864	4.4	.06118	.002187	.06847
4.6	.06374	.002380	.07148	4.6	.06345	.002366	.07130
4.8	.06600	.002566	.07430	4.8	.06569	.002550	.07411
5.0	.06824	.002757	.07710	5.0	.06790	.002739	.07690

φ	$\gamma = 4.0$ X	Y	T	φ	$\gamma = 4.1$ X	Y	T
0				0			
4.2	.12735	.005704	.09487	4.2	.13224	.006010	.09634
4.0	.11417	.004759	.08807	4.0	.11746	.004949	.08914
3.8	.10317	.004008	.08186	3.8	.10552	.004135	.08268
3.6	.09362	.003390	.07608	3.6	.09537	.003478	.07671
3.4	.08512	.002870	.07062	3.4	.08645	.002932	.07112
3.2	.07743	.002426	.06543	3.2	.07845	.002470	.06583
3.0	.07036	.002044	.06046	3.0	.07116	.002075	.06078
2.8	.06382	.001712	.05567	2.8	.06444	.001735	.05593
2.6	.05771	.001424	.05105	2.6	.05819	.001440	.05125
2.4	.05197	.001173	.04657	2.4	.05235	.001185	.04673
2.2	.04655	.000955	.04221	2.2	.04684	.000963	.04234
2.0	.04140	.000766	.03797	2.0	.04162	.000772	.03807
1.8	.03650	.000604	.03383	1.8	.03666	.000607	.03391
1.6	.03181	.000464	.02979	1.6	.03193	.000467	.02984
1.4	.02732	.000347	.02582	1.4	.02740	.000348	.02587
1.2	.02300	.000249	.02194	1.2	.02306	.000250	.02197
1.0	.01884	.000169	.01813	1.0	.01888	.000169	.01815
0.8	.01483	.000106	.01439	0.8	.01485	.000106	.01440
0.6	.01095	.000058	.01071	0.6	.01096	.000058	.01071
0.4	.00719	.000025	.00708	0.4	.00719	.000025	.00709
+.2	.00354	.000006	.00352	+.2	.00354	.000006	.00352
0.0	.00000	.000000	.00000	0.0	.00000	.000000	.00000
—.2	.00344	.000006	.00347	—.2	.00344	.000006	.00347
0.4	.00680	.000024	.00689	0.4	.00679	.000024	.00689
0.6	.01006	.000052	.01027	0.6	.01006	.000052	.01026
0.8	.01325	.000091	.01360	0.8	.01324	.000091	.01360
1.0	.01636	.000140	.01690	1.0	.01634	.000139	.01689
1.2	.01941	.000198	.02016	1.2	.01937	.000198	.02014
1.4	.02238	.000266	.02338	1.4	.02234	.000265	.02336
1.6	.02529	.000342	.02657	1.6	.02523	.000341	.02654
1.8	.02814	.000427	.02972	1.8	.02807	.000425	.02969
2.0	.03094	.000519	.03284	2.0	.03085	.000517	.03281
2.2	.03368	.000620	.03594	2.2	.03358	.000617	.03590
2.4	.03637	.000728	.03901	2.4	.03626	.000725	.03896
2.6	.03901	.000843	.04205	2.6	.03888	.000839	.04199
2.8	.04160	.000965	.04506	2.8	.04146	.000961	.04499
3.0	.04415	.001094	.04805	3.0	.04399	.001089	.04797
3.2	.04666	.001229	.05101	3.2	.04649	.001224	.05092
3.4	.04913	.001371	.05395	3.4	.04893	.001365	.05385
3.6	.05156	.001520	.05687	3.6	.05134	.001512	.05676
3.8	.05395	.001675	.05976	3.8	.05372	.001666	.05964
4.0	.05629	.001836	.06263	4.0	.05605	.001825	.06250
4.2	.05860	.002002	.06548	4.2	.05835	.001990	.06534
4.4	.06088	.002174	.06831	4.4	.06062	.002160	.06816
4.6	.06313	.002351	.07112	4.6	.06286	.002336	.07096
4.8	.06536	.002534	.07392	4.8	.06506	.002517	.07374
5.0	.06756	.002722	.07670	5.0	.06723	.002704	.07651
5.2	.06973	.002915	.07946	5.2	.06938	.002896	.07926

$\gamma = 4.2$				$\gamma = 4.3$			
φ	X	Y	T	φ	X	Y	T
0				0			
4.0	.12122	.005169	.09032	4.0	.12561	.005431	.09165
3.8	.10813	.004276	.08355	3.8	.11103	.004435	.08450
3.6	.09726	.003573	.07738	3.6	.09932	.003677	.07810
3.4	.08787	.002998	.07165	3.4	.08938	.003069	.07220
3.2	.07953	.002517	.06624	3.2	.08067	.002566	.06667
3.0	.07199	.002109	.06110	3.0	.07286	.002143	.06144
2.8	.06509	.001759	.05619	2.8	.06575	.001783	.05646
2.6	.05870	.001457	.05146	2.6	.05921	.001474	.05167
2.4	.05273	.001197	.04689	2.4	.05312	.001209	.04706
2.2	.04713	.000972	.04247	2.2	.04743	.000980	.04260
2.0	.04185	.000778	.03817	2.0	.04207	.000783	.03827
1.8	.03683	.000611	.03398	1.8	.03700	.000615	.03406
1.6	.03205	.000469	.02990	1.6	.03218	.000472	.02996
1.4	.02749	.000350	.02591	1.4	.02758	.000351	.02595
1.2	.02312	.000251	.02200	1.2	.02318	.000251	.02203
1.0	.01892	.000170	.01817	1.0	.01896	.000170	.01819
0.8	.01487	.000106	.01441	0.8	.01490	.000106	.01442
0.6	.01097	.000059	.01072	0.6	.01098	.000059	.01072
0.4	.00720	.000026	.00709	0.4	.00720	.000025	.00709
+.2	.00354	.000006	.00352	+.2	.00354	.000006	.00352
0.0	.00000	.000000	.00000	0.0	.00000	.000000	.00000
—.2	.00344	.000006	.00347	—.2	.00344	.000006	.00347
0.4	.00679	.000024	.00689	0.4	.00678	.000023	.00688
0.6	.01004	.000052	.01026	0.6	.01004	.000052	.01025
0.8	.01322	.000091	.01359	0.8	.01320	.000090	.01358
1.0	.01631	.000139	.01687	1.0	.01629	.000139	.01686
1.2	.01934	.000197	.02012	1.2	.01930	.000197	.02010
1.4	.02229	.000264	.02333	1.4	.02225	.000263	.02331
1.6	.02518	.000340	.02651	1.6	.02512	.000339	.02648
1.8	.02800	.000424	.02965	1.8	.02794	.000422	02961
2.0	.03077	.000516	.03276	2.0	.03070	.000514	.03271
2.2	.03348	.000615	.03584	2.2	.03339	.000612	.03579
2.4	.03614	.000722	.03889	2.4	.03604	.000719	.03883
2.6	.03875	.000836	.04192	2.6	.03863	.000832	.04184
2.8	.04132	.000957	.04491	2.8	.04118	.000952	.04483
3.0	.04384	.001085	.04788	3.0	.04368	.001079	.04779
3.2	.04631	.001219	.05082	3.2	.04614	.001212	.05072
3.4	.04874	.001359	.05374	3.4	.04856	.001351	.05363
3.6	.05114	.001505	.05664	3.6	.05094	.001497	.05652
3.8	.05349	.001658	.05951	3.8	.05328	.001648	.05938
4.0	.05581	.001816	.06236	4.0	.05558	.001805	.06222
4.2	.05809	.001979	.06519	4.2	.05784	.001967	.06504
4.4	.06034	.002148	.06800	4.4	.06007	.002135	.06784
4.6	.06256	.002322	.07079	4.6	.06227	.002308	.07062
4.8	.06475	.002502	.07356	4.8	.06444	.002486	.07338
5.0	.06691	.002687	.07632	5.0	.06658	.002670	.07612
5.2	.06904	.002877	.07906	5.2	.06869	.002859	.07885
5.4	.07114	.003072	.08178	5.4	.07077	.003052	.08156

$\gamma = 4.4$				$\gamma = 4.5$			
φ	X	Y	T	φ	X	Y	T
0				0			
3.8	.11434	.004621	.08554	3.8	.11816	.004833	.08671
3.6	.10159	.003794	.07886	3.6	.10409	.003923	.07969
3.4	.09102	.003147	.07278	3.4	.09278	.003230	.07340
3.2	.08188	.002620	.06712	3.2	.08317	.002676	.06760
3.0	.07378	.002180	.06180	3.0	.07474	.002219	.06216
2.8	.06645	.001809	.05673	2.8	.06718	.001836	.05702
2.6	.05974	.001493	.05189	2.6	.06030	.001511	.05212
2.4	.05354	.001222	.04723	2.4	.05396	.001234	.04741
2.2	.04775	.000989	.04273	2.2	.04807	.000998	.04287
2.0	.04231	.000789	.03837	2.0	.04255	.000795	.03848
1.8	.03718	.000619	.03414	1.8	.03736	.000623	.03422
1.6	.03231	.000474	.03001	1.6	.03244	.000477	.03007
1.4	.02767	.000353	.02599	1.4	.02777	.000354	.02603
1.2	.02324	.000252	.02206	1.2	.02331	.000253	.02209
1.0	.01900	.000171	.01821	1.0	.01904	.000171	.01823
0.8	.01492	.000107	.01443	0.8	.01495	.000107	.01445
0.6	.01100	.000059	.01073	0.6	.01101	.000059	.01074
0.4	.00721	.000025	.00709	0.4	.00721	.000026	.00710
+.2	.00355	.000006	.00352	+.2	.00355	.000006	.00352
0.0	.00000	.000000	.00000	0.0	.00000	.000000	.00000
−.2	.00344	.000006	.00347	−.2	.00344	.000006	.00346
0.4	.00678	.000024	.00688	0.4	.00678	.000023	.00688
0.6	.01002	.000052	.01025	0.6	.01002	.000052	.01024
0.8	.01318	.000090	.01357	0.8	.01317	.000090	.01356
1.0	.01626	.000139	.01685	1.0	.01624	.000138	.01683
1.2	.01927	.000197	.02009	1.2	.01924	.000196	.02007
1.4	.02220	.000263	.02329	1.4	.02216	.000262	.02326
1.6	.02507	.000338	.02645	1.6	.02501	.000337	.02642
1.8	.02787	.000421	.02958	1.8	.02781	.000420	.02954
2.0	.03061	.000512	.03268	2.0	.03054	.000510	.03263
2.2	.03330	.000611	.03574	2.2	.03321	.000608	.03569
2.4	.03593	.000717	.03878	2.4	.03583	.000713	.03872
2.6	.03851	.000830	.04178	2.6	.03839	.000825	.04171
2.8	.04105	.000949	.04476	2.8	.04091	.000944	.04468
3.0	.04353	.001075	.04771	3.0	.04338	.001069	.04762
3.2	.04598	.001207	.05063	3.2	.04581	.001201	.05054
3.4	.04838	.001346	.05353	3.4	.04820	.001338	.05343
3.6	.05074	.001490	.05641	3.6	.05054	.001482	.05630
3.8	.05306	.001640	.05926	3.8	.05285	.001631	.05914
4.0	.05535	.001796	.06209	4.0	.05512	.001785	.06196
4.2	.05760	.001957	.06490	4.2	.05735	.001945	.06476
4.4	.05982	.002123	.06769	4.4	.05955	.002110	.06754
4.6	.06200	.002295	.07046	4.6	.06172	.002281	.07030
4.8	.06415	.002472	.07321	4.8	.06386	.002457	.07304
5.0	.06627	.002654	.07594	5.0	.06596	.002638	.07576
5.2	.06836	.002840	.07865	5.2	.06804	.002824	.07846
5.4	.07043	.003031	.08134	5.4	.07009	.003014	.08114
5.6	.07247	.003227	.08402	5.6	.07211	.003208	.08381

γ = 4.6				γ = 4.7			
φ	X	Y	T	φ	X	Y	T
°				°			
3.8	.12268	.005092	.08803	3.6	.11009	.004240	.08158
3.6	.10690	.004070	.08060	3.4	.09679	.003425	.07476
3.4	.09470	.003323	.07406	3.2	.08601	.002803	.06862
3.2	.08454	.002737	.06810	3.0	.07682	.002304	.06295
3.0	.07575	.002260	.06255	2.8	.06873	.001894	.05763
2.8	.06794	.001864	.05732	2.6	.06146	.001551	.05258
2.6	.06087	.001531	.05235	2.4	.05483	.001262	.04777
2.4	.05439	.001248	.04759	2.2	.04872	.001017	.04315
2.2	.04839	.001007	.04301	2.0	.04304	.000808	.03869
2.0	.04280	.000802	.03858	1.8	.03772	.000631	.03438
1.8	.03754	.000627	.03430	1.6	.03270	.000482	.03019
1.6	.03257	.000480	.03013	1.4	.02795	.000358	.02612
1.4	.02786	.000356	.02607	1.2	.02343	.000255	.02215
1.2	.02337	.000254	.02212	1.0	.01912	.000172	.01827
1.0	.01908	.000172	.01825	0.8	.01499	.000108	.01447
0.8	.01497	.000107	.01446	0.6	.01103	.000059	.01075
0.6	.01102	.000059	.01075	0.4	.00722	.000026	.00710
0.4	.00722	.000026	.00710	+.2	.00355	.000006	.00352
+.2	.00355	.000006	.00352	0.0	.00000	.000000	.00000
0.0	.00000	.000000	.00000	—.2	.00344	.000006	.00346
—.2	.00344	.000006	.00346	0.4	.00677	.000023	.00687
0.4	.00677	.000023	.00688	0.6	.01000	.000052	.01023
0.6	.01001	.000052	.01024	0.8	.01314	.000090	.01354
0.8	.01315	.000090	.01355	1.0	.01619	.000138	.01681
1.0	.01622	.000138	.01682	1.2	.01917	.000195	.02004
1.2	.01920	.000196	.02005	1.4	.02207	.000261	.02322
1.4	.02212	.000262	.02324	1.6	.02490	.000335	.02636
1.6	.02496	.000336	.02639	1.8	.02767	.000417	.02947
1.8	.02774	.000419	.02951	2.0	.03038	.000507	.03255
2.0	.03046	.000509	.03259	2.2	.03303	.000604	.03559
2.2	.03312	.000606	.03564	2.4	.03562	.000708	.03860
2.4	.03572	.000711	.03866	2.6	.03816	.000819	.04158
2.6	.03828	.000823	.04164	2.8	.04065	.000936	.04453
2.8	.04078	.000941	.04460	3.0	.04309	.001060	.04745
3.0	.04324	.001065	.04754	3.2	.04549	.001189	.05035
3.2	.04565	.001196	.05044	3.4	.04784	.001325	.05322
3.4	.04802	.001332	.05332	3.6	.05016	.001467	.05607
3.6	.05035	.001475	.05618	3.8	.05243	.001614	.05890
3.8	.05264	.001623	.05901	4.0	.05467	.001766	.06170
4.0	.05490	.001777	.06182	4.2	.05687	.001923	.06448
4.2	.05712	.001936	.06461	4.4	.05904	.002086	.06724
4.4	.05931	.002100	.06738	4.6	.06117	.002254	.06998
4.6	.06146	.002269	.07013	4.8	.06327	.002427	.07270
4.8	.06357	.002443	.07286	5.0	.06534	.002606	.07539
5.0	.06565	.002621	.07557	5.2	.06738	.002789	.07807
5.2	.06771	.002804	.07826	5.4	.06939	.002976	.08073
5.4	.06974	.002992	.08093	5.6	.07138	.003167	.08338
5.6	.07174	.003185	.08359	5.8	.07334	.003362	.08601

φ	$\gamma = 4.8$ X	Y	T	φ	$\gamma = 4.9$ X	Y	T
0				0			
3.6	.11380	.004438	.08269	3.6	.11823	.004679	.08395
3.4	.09911	.003539	.07552	3.4	.10171	.003667	.07635
3.2	.08760	.002874	.06917	3.2	.08932	.002951	.06977
3.0	.07795	.002351	.06336	3.0	.07915	.002400	.06380
2.8	.06955	.001925	.05794	2.8	.07043	.001958	.05828
2.6	.06207	.001572	.05282	2.6	.06272	.001595	.05308
2.4	.05529	.001276	.04796	2.4	.05577	.001291	.04816
2.2	.04907	.001026	.04329	2.2	.04942	.001036	.04344
2.0	.04330	.000814	.03880	2.0	.04356	.000821	.03892
1.8	.03791	.000635	.03446	1.8	.03810	.000640	.03455
1.6	.03284	.000485	.03025	1.6	.03297	.000487	.03032
1.4	.02805	.000359	.02616	1.4	.02814	.000361	.02621
1.2	.02350	.000256	.02217	1.2	.02356	.000257	.02221
1.0	.01916	.000173	.01828	1.0	.01921	.000173	.01831
0.8	.01502	.000108	.01448	0.8	.01505	.000108	.01449
0.6	.01105	.000059	.01076	0.6	.01106	.000059	.01076
0.4	.00723	.000026	.00710	0.4	.00724	.000026	.00711
+.2	.00355	.000006	.00352	+.2	.00355	.000006	.00352
0.0	.00000	.000000	.00000	0.0	.00000	.000000	.00000
—.2	.00343	.000006	.00346	—.2	.00343	.000006	.00346
0.4	.00676	.000023	.00687	0.4	.00676	.000023	.00687
0.6	.00999	.000051	.01023	0.6	.00998	.000051	.01022
0.8	.01312	.000090	.01353	0.8	.01311	.000090	.01353
1.0	.01617	.000138	.01679	1.0	.01615	.000137	.01679
1.2	.01913	.000195	.02001	1.2	.01910	.000194	.02000
1.4	.02203	.000260	.02319	1.4	.02199	.000260	.02317
1.6	.02485	.000334	.02633	1.6	.02480	.000333	.02631
1.8	.02761	.000416	.02943	1.8	.02754	.000415	.02940
2.0	.03030	.000506	.03250	2.0	.03022	.000504	.03247
2.2	.03293	.000602	.03554	2.2	.03285	.000600	.03549
2.4	.03551	.000706	.03854	2.4	.03541	.000703	.03849
2.6	.03804	.000816	.04151	2.6	.03792	.000813	.04145
2.8	.04052	.000933	.04446	2.8	.04039	.000929	.04439
3.0	.04294	.001056	.04737	3.0	.04280	.001051	.04730
3.2	.04533	.001185	.05026	3.2	.04517	.001179	.05018
3.4	.04767	.001320	.05312	3.4	.04749	.001313	.05303
3.6	.04997	.001460	.05596	3.6	.04978	.001453	.05586
3.8	.05223	.001607	.05877	3.8	.05202	.001598	.05867
4.0	.05445	.001758	.06157	4.0	.05423	.001748	.06145
4.2	.05663	.001914	.06434	4.2	.05640	.001903	.06421
4.4	.05878	.002075	.06709	4.4	.05854	.002063	.06695
4.6	.06090	.002242	.06982	4.6	.06064	.002228	.06967
4.8	.06299	.002414	.07253	4.8	.06271	.002399	.07237
5.0	.06504	.002590	.07521	5.0	.06475	.002575	.07504
5.2	.06707	.002771	.07788	5.2	.06676	.002755	.07770
5.4	.06907	.002957	.08053	5.4	.06874	.002939	.08034
5.6	.07104	.003147	.08316	5.6	.07070	.003127	.08296
5.8	.07298	.003341	.08578	5.8	.07263	.003319	.08557

$\gamma = 5.0$				$\gamma = 5.0$			
φ	X	Y	T	φ	X	Y	T
0				0			
3.4	.10465	.003815	.07725	1.4	.02194	.000259	.02315
3.2	.09119	.003038	.07039	1.6	.02474	.000332	.02628
3.0	.08044	.002455	.06425	1.8	.02748	.000414	.02937
2.8	.07134.	.001993	.05861	2.0	.03015	.000502	.03242
2.6	.06338	.001618	.05334	2.2	.03276	.000598	.03544
2.4	.05626	.001306	.04834	2.4	.03531	.000700	.03843
2.2	.04978	.001046	.04359	2.6	.03781	.000809	.04139
2.0	.04383	.000828	.03902	2.8	.04026	.000925	.04431
1.8	.03829	.000644	.03463	3.0	.04266	.001046	.04721
1.6	.03311	.000490	.03037	3.2	.04501	.001174	.05008
1.4	.02824	.000362	.02625	3.4	.04732	.001307	.05293
1.2	.02363	.000258	.02224	3.6	.04959	.001446	.05575
1.0	.01925	.000174	.01832	3.8	.05182	.001590	.05854
0.8	.01507	.000108	.01451	4.0	.05401	.001740	.06131
0.6	.01108	.000059	.01077	4.2	.05616	.001895	.06406
0.4	.00724	.000026	.00711	4.4	.05828	.002054	.06679
+.2	.00355	.000006	.00352	4.6	.06037	.002218	.06950
0.0	.00000	.000000	.00000	4.8	.06243	.002387	.07219
—.2	.00343	.000006	.00346	5.0	.06446	.002560	.07486
0.4	.00675	.000023	.00687	5.2	.06646	.002738	.07751
0.6	.00997	.000051	.01022	5.4	.06843	.002920	.08014
0.8	.01309	.000089	.01352	5.6	.07037	.003107	.08275
1.0	.01612	.000137	.01677	5.8	.07228	.003298	.08535
1.2	.01907	.000194	.01998	6.0	.07416	.003493	.08793

V. $P_\varphi = 3 \tan \varphi + \tan^3 \varphi$.

φ	.0	.2	.4	.6	.8
0					
0	.000 000	.010 472	.020 945	.031 418	.041 893
1	.052 371	.062 850	.073 333	.083 819	.094 310
2	.104 805	.115 305	.125 811	.136 323	.146 842
3	.157 367	.167 901	.178 442	.188 993	.199 533
4	.210 122	.220 702	.231 293	.241 895	.252 509
5	.263 136	.273 775	.284 428	.295 095	.305 777
6	.316 474	.327 186	.337 915	.348 661	.359 424
7	.370 205	.381 004	.391 823	.402 661	.413 519
8	.424 398	.435 299	.446 222	.457 167	.468 135
9	.479 126	.490 143	.501 184	.512 251	.523 344
10	.534 463	.545 610	.556 785	.567 989	.579 222
11	.590 485	.601 779	.613 104	.624 461	.635 850
12	.647 273	.658 730	.670 221	.681 748	.693 310
13	.704 910	.716 547	.728 222	.739 936	.751 690

$$P_\varphi = 3 \tan \varphi + \tan^3 \varphi.$$

φ °	.0	.2	.4	.6	.8
14	.763 483	.775 319	.787 196	.799 115	.811 078
15	.823 086	.835 138	.847 236	.859 381	.871 573
16	.883 813	.896 103	.908 442	.920 832	.933 275
17	.945 769	.958 317	.970 919	.983 577	.996 291
18	1.009 062	1.021 891	1.034 779	1.047 727	1.060 736
19	1.073 807	1.086 941	1.100 139	1.113 402	1.126 731
20	1.140 127	1.153 592	1.167 126	1.180 730	1.194 407
21	1.208 115	1.221 978	1.235 875	1.249 849	1.263 901
22	1.278 031	1.292 241	1.306 532	1.320 906	1.335 363
23	1.349 906	1.364 535	1.379 252	1.394 058	1.408 955
24	1.423 943	1.439 025	1.454 202	1.469 476	1.484 847
25	1.500 318	1.515 890	1.531 565	1.547 344	1.563 229
26	1.579 221	1.595 323	1.611 535	1.627 861	1.644 301
27	1.660 857	1.677 532	1.694 327	1.711 244	1.728 284
28	1.745 450	1.762 745	1.780 169	1.797 726	1.815 417
29	1.833 244	1.851 209	1.869 315	1.887 564	1.905 959
30	1.924 501	1.943 193	1.962 038	1.981 038	2.000 195
31	2.019 513	2.038 993	2.058 639	2.078 452	2.098 437
32	2.118 596	2.138 931	2.159 446	2.180 143	2.201 026
33	2.222 098	2.243 361	2.264 820	2.286 477	2.308 337
34	2.330 401	2.352 674	2.375 160	2.397 862	2.420 783
35	2.443 928	2.467 300	2.490 904	2.514 743	2.538 821
36	2.563 143	2.587 714	2.612 536	2.637 615	2.662 957
37	2.688 563	2.714 441	2.740 594	2.767 029	2.793 748
38	2.820 759	2.848 066	2.875 675	2.903 591	2.931 820
39	2.960 368	2.989 240	3.018 444	3.047 983	3.077 866
40	3.108 099	3.138 688	3.169 640	3.200 962	3.232 661
41	3.264 745	3.297 220	3.330 095	3.363 377	3.397 074
42	3.431 194	3.465 746	3.500 739	3.536 180	3.572 079
43	3.608 446	3.645 289	3.682 618	3.720 444	3.758 776
44	3.797 624	3.837 000	3.876 914	3.917 378	3.958 402
45	4.000 000	4.042 183	4.084 962	4.128 352	4.172 365
46	4.217 014	4.262 314	4.308 277	4.354 920	4.402 257
47	4.450 304	4.499 074	4.548 585	4.598 854	4.649 898
48	4.701 734	4.754 380	4.807 854	4.862 177	4.917 366
49	4.973 442	5.030 427	5.088 340	5.147 206	5.207 045
50	5.267 881	5.329 737	5.392 639	5.456 611	5.521 681
51	5.587 874	5.655 218	5.723 742	5.793 475	5.864 448
52	5.936 691	6.010 238	6.085 117	6.161 368	6.239 026
53	6.318 124	6.398 702	6.480 797	6.564 452	6.649 706
54	6.736 602	6.825 183	6.915 496	7.007 588	7.101 509
55	7.197 304	7.295 031	7.394 739	7.496 488	7.600 333
56	7.706 333	7.814 550	7.925 047	8.037 894	8.153 153
57	8.270 898	8.391 203	8.514 142	8.639 795	8.768 244
58	8.899 574	9.033 869	9.171 225	9.311 731	9.455 492
59	9.602 605	9.753 175	9.907 314	10.065 136	10.226 756

VI. VALUES OF X, Y & T FOR INTERVALS OF 1°.

$\gamma = 0.00$				$\gamma = 0.00$			
φ	X	Y	T	φ	X	Y	T
°				°			
60	1.73205	1.50000	1.73205	18	.32492	.052786	.32492
59	1.66428	1.38492	1.66428	17	.30573	.046736	.30573
58	1.60033	1.28054	1.60033	16	.28675	.041112	.28675
57	1.53986	1.18559	1.53986	15	.26795	.035898	.26795
56	1.48256	1.09899	1.48256	14	.24933	.031082	.24933
55	1.42815	1.01980	1.42815	13	.23087	.026650	.23087
54	1.37638	.947215	1.37638	12	.21256	.022590	.21256
53	1.32704	.880524	1.32704	11	.19438	.018892	.19438
52	1.27994	.819125	1.27994	10	.17633	.015546	.17633
51	1.23490	.762486	1.23490	9	.15838	.012543	.15838
50	1.19175	.710138	1.19175	8	.14054	.009876	.14054
49	1.15037	.661674	1.15037	7	.12279	.007538	.12279
48	1.11061	.616730	1.11061	6	.10510	.005524	.10510
47	1.07237	.574987	1.07237	5	.08749	.003827	.08749
46	1.03553	.536162	1.03553	4	.06993	.002445	.06993
45	1.00000	.500000	1.00000	3	.05241	.001373	.05241
44	.96569	.466278	.96569	2	.03492	.000610	.03492
43	.93252	.434792	.93252	+1	.01746	.000152	.01746
42	.90040	.405363	.90040	0	00000	000000	00000
41	.86929	.377830	.86929				
40	.83910	.352044	.83910	$\gamma = 0.01$			
39	.80978	.327875	.80978				
38	.78129	.305204	.78129	φ	X	Y	T
37	.75355	.283922	.75355	°			
36	.72654	.263932	.72654	60	1.77949	1.55885	1.75552
35	.70021	.245145	.70021	59	1.70679	1.43539	1.68533
34	.67451	.227481	.67451	58	1.63857	1.32404	1.61928
33	.64941	.210865	.64941	57	1.57437	1.22324	1.55697
32	.62487	.195231	.62487	56	1.51380	1.13170	1.49806
31	.60086	.180517	.60086	55	1.45651	1.04831	1.44222
30	.57735	.166667	.57735	54	1.40219	.97214	1.38919
29	.55431	.153629	.55431	53	1.35058	.90238	1.33873
28	.53171	.141358	.53171	52	1.30144	.83834	1.29063
27	.50953	.129808	.50953	51	1.25458	.77941	1.24468
26	.48773	.118942	.48773	50	1.20980	.72508	1.20073
25	.46631	.108721	.46631	49	1.16694	.67488	1.15861
24	.44523	.099114	.44523	48	1.12585	.62843	1.11820
23	.42448	.090090	.42448	47	1.08640	.58536	1.07935
22	.40403	.081619	.40403	46	1.04847	.54537	1.04196
21	.38386	.073676	.38386	45	1.01192	.50818	1.00593
20	.36397	.066237	.36397	44	.97669	.47355	.97116
19	.34433	.059281	.34433	43	.94267	.44127	.93757

φ	X	Y	T
	$\gamma = 0.01$		
42°	.90978	.41114	.90507
41	.87795	.38297	.87361
40	.84710	.35662	.84309
39	.81718	.33195	.81347
38	.78812	.30883	.78469
37	.75986	.28715	.75670
36	.73237	.26681	.72944
35	.70559	.24769	.70290
34	.67947	.22974	.67698
33	.65398	.21287	.65169
32	.62908	.19701	.62697
31	.60473	.18209	.60279
30	.58091	.168051	.57913
29	.55758	.154847	.55594
28	.53470	.142427	.53320
27	.51226	.130745	.51089
26	.49023	.119760	.48898
25	.46859	.109433	.46744
24	.44729	.099732	.44626
23	.42635	.090623	.42541
22	.40572	.082077	.40487
21	.38539	.074067	.38462
20	.36534	.066569	.36465
19	.34555	.059561	.34494
18	.32601	.053021	.32546
17	.30669	.046931	.30621
16	.28758	.041272	.28717
15	.26868	.036029	.26831
14	.24996	.031187	.24964
13	.23141	.026734	.23114
12	.21302	.022655	.21279
11	.19476	.018941	.19457
10	.17664	.015583	.17649
9	.15863	.012570	.15850
8	.14074	.009894	.14064
7	.12294	.007550	.12286
6	.10521	.005531	.10516
5	.08757	.003832	.08752
4	.06998	.002447	.06995
3	.05244	.001374	.05242
2	.03493	.000610	.03493
+1	.01746	.000152	.01746
	+	+	+
0	00000	000000	00000
	−	+	−
−1°	.01745	.000152	.01745
2	.03490	.000610	.03491
3	.05238	.001373	.05239

φ	X	Y	T
	$\gamma = 0.01$		
4°	.06988	.002443	.06990
5	.08741	.003823	.08745
6	.10499	.005516	.10505
7	.12264	.007525	.12271
8	.14034	.009857	.14044
9	.15813	.012516	.15826
10	.17602	.015509	.17618
11	.19400	.018843	.19420
12	.21211	.022526	.21234
13	.23034	.026568	.23060
14	.24870	.030978	.24902
15	.26723	.035769	.26759
16	.28592	.040952	.28633
17	.30479	.046543	.30526
18	.32385	.052554	.32439
19	.34313	.059005	.34373
20	.36262	.065909	.36330
21	.38236	.073290	.38311
22	.40236	.081168	.40319
23	.42263	.089565	.42355
24	.44320	.098508	.44421
25	.46407	.108022	.46519
26	.48528	.118139	.48650
27	.50684	.128889	.50818
28	.52878	.140309	.53024
29	.55111	.152437	.55270
30	.57387	.165314	.57560
31	.59707	.178985	.59896
32	.62075	.193499	.62281
33	.64494	.208911	.64717
34	.66967	.225279	.67208
35	.69497	.242668	.69758
36	.72087	.261147	.72370
37	.74742	.280795	.75048
38	.77465	.301694	.77796
39	.80262	.323939	.80619
40	.83135	.347631	.83521
41	.86092	.372884	.86509
42	.89136	.399820	.89586
43	.92274	.428576	.92761
44	.95512	.459307	.96038
45	.98856	.492182	.99426
46	1.02315	.527388	1.02931
47	1.05896	.565132	1.06564
48	1.09608	.605648	1.10331
49	1.13461	.649198	1.14245
50	1.17464	.696076	1.18315
51	1.21629	.746612	1.22554

$\gamma = 0.02$			
φ °	X	Y	T
52	1.25968	.801177	1.26976
53	1.30496	.860189	1.31593
54	1.35226	.924126	1.36424
55	1.40176	.993530	1.41486
56	1.45363	1.069017	1.46799
57	1.50807	1.151292	1.52384
58	1.56531	1.241166	1.58267
59	1.62559	1.339565	1.64476
60	1.68919	1.447563	1.71042

$\gamma = 0.02$			
φ °	X	Y	T
60	1.83254	1.62567	1.78117
59	1.75391	1.49213	1.70817
58	1.68062	1.37250	1.63971
57	1.61206	1.26485	1.57533
56	1.54771	1.16759	1.51460
55	1.48712	1.07941	1.45718
54	1.42990	.99918	1.40276
53	1.37575	.92598	1.35107
52	1.32435	.85898	1.30187
51	1.27548	.79753	1.25494
50	1.22890	.74101	1.21012
49	1.18443	.68892	1.16721
48	1.14188	.64082	1.12609
47	1.10111	.59632	1.08660
46	1.06198	.55508	1.04863
45	1.02436	.51679	1.01207
44	.98814	.48119	.97682
43	.95322	.44805	.94278
42	.91950	.41716	.90988
41	.88692	.38832	.87804
40	.85537	.36138	.84718
39	.82481	.33618	.81725
38	.79516	.31259	.78818
37	.76636	.29049	.75992
36	.73836	.26977	.73241
35	.71111	.25032	.70563
34	.68455	.23207	.67950
33	.65866	.21493	.65401
32	.63339	.19883	.62911
31	.60869	.18370	.60476
30	.58454	.169469	.58093
29	.56091	.156094	.55759
28	.53775	.143521	.53471

$\gamma = 0.02$			
φ °	X	Y	T
27	.51505	.131702	.51227
26	.49277	.120594	.49024
25	.47090	.110159	.46859
24	.44939	.100361	.44730
23	.42825	.091165	.42635
22	.40743	.082542	.40572
21	.38693	.074464	.38539
20	.36672	.066906	.36534
19	.34678	.059845	.34555
18	.32710	.053259	.32600
17	.30765	.047128	.30669
16	.28843	.041434	.28759
15	.26942	.036161	.26868
14	.25060	.031293	.24996
13	.23196	.026818	.23141
12	.21348	.022720	.21302
11	.19515	.018991	.19476
10	.17696	.015620	.17665
9	.15889	.012597	.15863
8	.14094	.009913	.14074
7	.12309	.007563	.12294
6	.10532	.005539	.10521
5	.08765	.003836	.08756
4	.07003	.002450	.06998
3	.05247	.001376	.05244
2	.03494	.000611	.03493
+1	.01746	.000153	.01746
	+	+	+
0	00000	000000	00000
°	—	—	—
—1	.01745	.000152	.01745
2	.03489	.000610	.03491
3	.05235	.001372	.05238
4	.06983	.002440	.06988
5	.08734	.003818	.08741
6	.10488	.005508	.10499
7	.12249	.007513	.12264
8	.14015	.009839	.14034
9	.15788	.012490	.15813
10	.17571	.015473	.17602
11	.19362	.018794	.19401
12	.21166	.022462	.21211
13	.22981	.026486	.23034
14	.24808	.030875	.24871
15	.26651	.035641	.26723
16	.28510	.040795	.28592
17	.30385	.046352	.30479
18	.32279	.052324	.32386

$\gamma = 0.02$				$\gamma = 0.03$			
φ	X	Y	T	φ	X	Y	T
°				°			
19	.34194	.058732	.34314	60	1.89266	1.70264	1.80950
20	.36129	.065586	.36263	59	1.80671	1.55667	1.73318
21	.38088	.072911	.38237	58	1.72729	1.42703	1.66191
22	.40072	.080724	.40237	57	1.65355	1.31123	1.59513
23	.42082	.089050	.42264	56	1.58476	1.20728	1.53235
24	.44119	.097912	.44320	55	1.52035	1.11354	1.47315
25	.46187	.107336	.46408	54	1.45983	1.02867	1.41718
26	.48287	.117351	.48529	53	1.40278	.95155	1.36413
27	.50420	.127989	.50685	52	1.34885	.88125	1.31372
28	.52590	.139284	.52879	51	1.29773	.81697	1.26574
29	.54797	.151271	.55113	50	1.24916	.75803	1.21996
30	.57045	.163992	.57389	49	1.20291	.70387	1.17621
31	.59336	.177489	.59710	48	1.15877	.65397	1.13432
32	.61673	.191811	.62078	47	1.11657	.60792	1.09414
33	.64058	.207008	.64497	46	1.07614	.56532	1.05555
34	.66495	.223138	.66971	45	1.03735	.52585	1.01843
35	.68986	.240262	.69501	44	1.00008	.48921	.98267
36	.71535	.258446	.72092	43	.96419	.45514	.94817
37	.74146	.277765	.74747	42	.92960	.42344	.91484
38	.76822	.298300	.77471	41	.89621	.39389	.88260
39	.79567	.320137	.80268	40	.86393	.36632	.85139
40	.82385	.343375	.83143	39	.83269	.34057	.82113
41	.85282	.368121	.86100	38	.80242	.31648	.79175
42	.88262	.394495	.89145	37	.77305	.29395	.76321
43	.91331	.422624	.92284	36	.74452	.27283	.73545
44	.94494	.452645	.95523	35	.71678	.25304	.70842
45	.97758	.484721	.98870	34	.68977	.23447	.68208
46	1.01129	.519028	1.02330	33	.66346	.21705	.65638
47	1.04614	.555761	1.05914	32	.63780	.20070	.63128
48	1.08221	.595136	1.09628	31	.61274	.18535	.60676
49	1.11960	.637396	1.13483	30	.58825	.170923	.58277
50	1.15838	.682811	1.17489	29	.56430	.157371	.55927
51	1.19866	.731683	1.21658	28	.54085	.144639	.53625
52	1.24054	.784351	1.26002	27	.51788	.132679	.51367
53	1.28415	.841196	1.30534	26	.49535	.121445	.49152
54	1.32961	.902648	1.35270	25	.47324	.110898	.46976
55	1.37707	.969193	1.40226	24	.45152	.101000	.44836
56	1.42667	1.041380	1.45421	23	.43017	.091716	.42731
57	1.47859	1.119831	1.50875	22	.40917	.083014	.40659
58	1.53299	1.205257	1.56611	21	.38849	.074867	.38617
59	1.59010	1.298469	1.62654	20	.36811	.067249	.36603
60	1.65012	1.400388	1.69032	19	.34802	.060134	.34617
				18	.32820	.053501	.32655
				17	.30863	.047329	.30717
				16	.28928	.041599	.28801
				15	.27016	.036295	.26905
				14	.25124	.031401	.25028
				13	.23251	.026903	.23168

$\gamma = 0.03$			
φ	X	Y	T
°			
12	.21394	.022786	.21325
11	.19553	.019041	.19496
10	.17727	.015657	.17681
9	.15914	.012624	.15876
8	.14114	.009932	.14084
7	.12324	.007575	.12301
6	.10543	.005547	.10527
5	.08772	.003841	.08760
4	.07008	.002452	.07000
3	.05249	.001376	.05245
2	.03496	.000611	.03494
+1	.01747	.000152	.01746
	+	+	+
0	00000	000000	00000
°	−	+	−
−1	.01745	.000152	.01745
2	.03488	.000609	.03490
3	.05232	.001371	.05237
4	.06978	.002438	.06985
5	.08726	.003814	.08738
6	.10477	.005501	.10494
7	.12233	.007501	.12256
8	.13995	.009820	.14025
9	.15763	.012463	.15801
10	.17540	.015437	.17587
11	.19325	.018746	.19382
12	.21121	.022399	.21189
13	.22928	.026405	.23007
14	.24747	.030773	.24840
15	.26580	.035514	.26687
16	.28428	.040640	.28551
17	.30292	.046163	.30432
18	.32174	.052098	.32333
19	.34076	.058462	.34255
20	.35998	.065267	.36197
21	.37942	.072536	.38163
22	.39910	.080287	.40155
23	.41903	.088543	.42174
24	.43923	.097325	.44221
25	.45971	.106662	.46299
26	.48050	.116579	.48410
27	.50162	.127107	.50555
28	.52308	.138279	.52737
29	.54490	.150130	.54958
30	.56712	.162699	.57220
31	.58974	.176029	.59527
32	.61281	.190164	.61880
33	.63633	.205154	.64282

$\gamma = 0.04$			
φ	X	Y	T
°			
34	.66035	.221054	.66738
35	.68490	.237922	.69249
36	.70999	.255823	.71820
37	.73567	.274828	.74454
38	.76197	.295012	.77154
39	.78893	.316461	.79926
40	.81659	.339267	.82774
41	.84500	.363530	.85702
42	.87419	.389362	.88716
43	.90423	.416885	.91822
44	.93515	.446235	.95024
45	.96702	.477561	.98331
46	.99991	.511027	1.01749
47	1.03386	.546814	1.05286
48	1.06897	.585125	1.08950
49	1.10529	.626186	1.12750
50	1.14291	.670247	1.16696
51	1.18193	.717586	1.20799
52	1.22243	.768515	1.25070
53	1.26452	.823382	1.29523
54	1.30832	.882577	1.34171
55	1.35393	.946541	1.39031
56	1.40150	1.015767	1.44118
57	1.45116	1.090812	1.49453
58	1.50307	1.172306	1.55055
59	1.55738	1.260959	1.60949
60	1.61429	1.357583	1.67159

$\gamma = 0.04$			
φ	X	Y	T
°			
60	1.96194	1.79302	1.84116
59	1.86669	1.63124	1.76082
58	1.77967	1.48920	1.68623
57	1.69963	1.36351	1.61666
56	1.62556	1.25157	1.55151
55	1.55667	1.15130	1.49029
54	1.49231	1.06105	1.43256
53	1.43195	.97945	1.37799
52	1.37514	.90540	1.32626
51	1.32150	.83795	1.27711
50	1.27071	.77632	1.23030
49	1.22249	.71985	1.18563
48	1.17661	.66798	1.14292
47	1.13285	.62022	1.10201
46	1.09102	.57614	1.06275

$\gamma = 0.04$			
φ (°)	X	Y	T
45	1.05097	.53538	1.02503
44	1.01256	.49762	.98873
43	.97564	.46258	.95373
42	.94011	.43002	.91996
41	.90587	.39971	.88731
40	.87281	.37147	.85572
39	.84085	.34513	.82511
38	.80992	.32052	.79542
37	.77995	.29752	.76659
36	.75086	.27599	.73856
35	.72261	.25584	.71128
34	.69513	.23695	.68471
33	.66838	.21924	.65880
32	.64231	.20263	.63350
31	.61688	.18704	.60879
30	.59204	.172413	.58463
29	.56777	.158678	.56098
28	.54402	.145783	.53782
27	.52077	.133677	.51510
26	.49798	.122314	.49282
25	.47563	.111652	.47094
24	.45369	.101651	.44943
23	.43213	.092276	.42828
22	.41093	.083494	.40746
21	.39007	.075276	.38695
20	.36953	.067596	.36673
19	.34928	.060427	.34679
18	.32932	.053746	.32711
17	.30961	.047532	.30766
16	.29015	.041766	.28844
15	.27091	.036430	.26942
14	.25189	.031509	.25060
13	.23306	.026988	.23195
12	.21441	.022853	.21348
11	.19592	.019092	.19515
10	.17759	.015695	.17697
9	.15940	.012651	.15889
8	.14134	.009951	.14094
7	.12340	.007588	.12309
6	.10555	.005555	.10532
5	.08780	.003845	.08764
4	.07012	.002454	.07003
3	.05252	.001377	.05247
2	.03497	.000611	.03494
+1	.01747	.000152	.01746
	+	+	+
0	00000	000000	00000

$\gamma = 0.04$			
φ (°)	X	Y	T
—1	.01745	.000152	.01745
2	.03487	.000609	.03490
3	.05230	.001370	.05235
4	.06973	.002435	.06983
5	.08719	.003809	.08734
6	.10467	.005493	.10488
7	.12219	.007489	.12249
8	.13976	.009802	.14015
9	.15739	.012437	.15788
10	.17510	.015401	.17571
11	.19288	.018698	.19363
12	.21076	.022336	.21166
13	.22875	.026325	.22981
14	.24686	.030671	.24810
15	.26509	.035388	.26652
16	.28347	.040486	.28510
17	.30200	.045976	.30386
18	.32071	.051874	.32281
19	.33960	.058195	.34196
20	.35868	.064953	.36131
21	.37798	.072167	.38091
22	.39750	.079857	.40075
23	.41726	.088044	.42085
24	.43728	.096749	.44123
25	.45758	.105999	.46191
26	.47817	.115820	.48292
27	.49907	.126241	.50426
28	.52030	.137294	.52596
29	.54188	.149013	.54805
30	.56383	.161436	.57054
31	.58618	.174602	.59346
32	.60895	.188556	.61684
33	.63216	.203346	.64071
34	.65585	.219024	.66509
35	.68003	.235647	.69002
36	.70474	.253275	.71553
37	.73001	.271977	.74166
38	.75588	.291827	.76844
39	.78237	.312903	.79592
40	.80953	.335295	.82414
41	.83740	.259099	.85314
42	.86602	.384420	.88298
43	.89543	.411374	.91371
44	.92568	.440090	.94539
45	.95683	.470706	.97809
46	.98894	.503379	1.01186
47	1.02205	.538280	1.04679
48	1.05624	.575598	1.08295

$\gamma = 0.05$			
φ	X	Y	T
°			
49	1.09158	.615542	1.12043
50	1.12813	.658346	1.15932
51	1.16598	.704267	1.19973
52	1.20521	.753593	1.24176
53	1.24591	.806644	1.28555
54	1.28817	.863779	1.33122
55	1.33212	.925397	1.37891
56	1.37785	.991947	1.42879
57	1.42548	1.063932	1.48104
58	1.47515	1.141917	1.53584
59	1.52700	1.226536	1.59342
60	1.58116	1.318507	1.65401

$\gamma = 0.05$			
φ	X	Y	T
°			
60	2.04361	1.90178	1.87718
59	1.93605	1.71908	1.79181
58	1.83932	1.56116	1.71316
57	1.75143	1.42316	1.64026
56	1.67093	1.30150	1.57234
55	1.59669	1.19344	1.50878
54	1.52782	1.09686	1.44908
53	1.46362	1.01007	1.39280
52	1.40351	.93171	1.33958
51	1.34701	.86067	1.28914
50	1.29373	.79602	1.24119
49	1.24333	.73699	1.19552
48	1.19551	.68293	1.15192
47	1.15004	.63329	1.11022
46	1.10669	.58760	1.07025
45	1.06527	.54544	1.03189
44	1.02563	.50647	.99501
43	.98759	.47039	.95949
42	.95106	.43690	.92524
41	.91591	.40579	.89217
40	.88202	.37684	.86018
39	.84931	.34987	.82921
38	.81768	.32471	.79919
37	.78707	.30122	.77006
36	.75740	.27926	.74175
35	.72861	.25873	.71421
34	.70064	.23950	.68740
33	.67343	.22149	.66127
32	.64694	.20461	.63577
31	.62112	.18878	.61087

$\gamma = 0.05$			
φ	X	Y	T
°			
30	.59593	.173941	.58653
29	.57131	.160017	.56272
28	.54726	.146954	.53941
27	.52372	.134698	.51655
26	.50067	.123201	.49414
25	.47806	.112420	.47214
24	.45589	.102314	.45052
23	.43412	.092847	.42926
22	.41272	.083983	.40834
21	.39168	.075692	.38774
20	.37096	.067948	.36744
19	.35056	.060724	.34742
18	.33045	.053993	.32767
17	.31061	.047737	.30815
16	.29103	.041934	.28887
15	.27167	.036566	.26980
14	.25254	.031618	.25093
13	.23362	.027075	.23223
12	.21488	.022920	.21372
11	.19631	.019143	.19535
10	.17791	.015733	.17713
9	.15966	.012678	.15902
8	.14154	.009970	.14104
7	.12355	.007600	.12316
6	.10566	.005563	.10538
5	.08788	.003850	.08768
4	.07017	.002457	.07005
3	.05255	.001378	.05248
2	.03498	.000612	.03495
+1	.01747	.000152	.01747
	+	+	+
0	00000	000000	00000
	—	+	—
—1	.01745	.000152	.01745
2	.03486	.000609	.03489
3	.05227	.001369	.05234
4	.06968	.002433	.06980
5	.08711	.003805	.08730
6	.10456	.005485	.10483
7	.12204	.007477	.12241
8	.13956	.009784	.14005
9	.15714	.012411	.15776
10	.17479	.015365	.17556
11	.19251	.018651	.19345
12	.21032	.022273	.21144
13	.22823	.026245	.22955
14	.24625	.030571	.24779
15	.26439	.035263	.26616

γ = 0.05				γ = 0.06			
φ	X	Y	T	φ	X	Y	T
0				0			
16	.28267	.040334	.28470	60	2.14308	2.03739	1.91913
17	.30110	.045792	.30340	59	2.01825	1.82534	1.82716
18	.31969	.051653	.32229	58	1.90851	1.64619	1.74339
19	.33845	.057932	.34138	57	1.81053	1.49233	1.66642
20	.35740	.064643	.36067	56	1.72199	1.35850	1.59520
21	.37655	.071804	.38018	55	1.64122	1.24094	1.52890
22	.39592	.079434	.39995	54	1.56696	1.13679	1.46690
23	.41552	.087553	.41996	53	1.49824	1.04390	1.40867
24	.43537	.096183	.44026	52	1.43431	.96056	1.35379
25	.45548	.105349	.46085	51	1.37454	.88540	1.30191
26	.47587	.115076	.48175	50	1.31844	.81732	1.25271
27	.49656	.125393	.50299	49	1.26558	.75542	1.20594
28	.51757	.136330	.52457	48	1.21561	.69894	1.16137
29	.53891	.147920	.54654	47	1.16824	.64723	1.11881
30	.56061	.160200	.56890	46	1.12322	.59977	1.07808
31	.58269	.173208	.59168	45	1.08031	.55610	1.03903
32	.60518	.186988	.61492	44	1.03933	.51582	1.00153
33	.62809	.201584	.63863	43	1.00010	.47860	.96546
34	.65145	.217048	.66284	42	.96249	.44412	.93071
35	.67529	.233433	.68759	41	.92636	.41215	.89718
36	.69963	.250799	.71291	40	.89158	.38245	.86478
37	.72451	.269211	.73884	39	.85807	.35481	.83343
38	.74996	.288738	.76540	38	.82571	.32907	.80307
39	.77600	.309458	.79264	37	.79443	.30506	.77361
40	.80268	.331455	.82061	36	.76415	.28265	.74501
41	.83004	.354821	.84935	35	.73479	.26171	.71721
42	.85811	.379656	.87890	34	.70631	.24213	.69015
43	.88693	.406069	.90932	33	.67862	.22380	.66379
44	.91655	.434183	.94067	32	.65169	.20665	.63808
45	.94702	.464131	.97300	31	.62547	.19057	.61299
46	.97839	.496058	1.00639	30	.59990	.175509	.58847
47	1.01071	.530125	1.04089	29	.57494	.161389	.56449
48	1.04405	.566510	1.07660	28	.55057	.148151	.54102
49	1.07846	.605410	1.11358	27	.52673	.135741	.51803
50	1.11401	.647042	1.15194	26	.50340	.124107	.49548
51	1.15077	.691646	1.19176	25	.48054	.113204	.47335
52	1.18882	.739489	1.23316	24	.45813	.102991	.45162
53	1.22824	.790867	1.27625	23	.43614	.093428	.43025
54	1.26911	.846111	1.32116	22	.41454	.084480	.40923
55	1.31153	.905589	1.36802	21	.39331	.076116	.38854
56	1.35559	.969709	1.41698	20	.37242	.068306	.36816
57	1.40139	1.038928	1.46821	19	.35186	.061024	.34806
58	1.44905	1.113758	1.52190	18	.33160	.054244	.32823
59	1.49869	1.194772	1.57823	17	.31162	.047945	.30865
60	1.55041	1.282610	1.63744	16	.29191	.042104	.28931
				15	.27244	.036704	.27018
				14	.25320	.031728	.25125
				13	.23418	.027162	.23251

$\gamma = 0.06$			
φ ⁰	X	Y	T
12	.21535	.022988	.21395
11	.19670	.019194	.19554
10	.17824	.015771	.17729
9	.15992	.012706	.15915
8	.14175	.009989	.14114
7	.12371	.007613	.12324
6	.10577	.005571	.10544
5	.08795	.003854	.08772
4	.07022	.002459	.07007
3	.05257	.001379	.05249
2	.03499	.000612	.03496
+1	.01748	.000152	.01747
	+	+	+
0	00000	000000	00000
	—	+	—
—1	.01744	.000152	.01745
2	.03484	.000608	.03488
3	.05224	.001368	.05233
4	.06963	.002431	.06978
5	.08703	.003801	.08726
6	.10445	.005478	.10478
7	.12189	.007465	.12234
8	.13937	.009766	.13995
9	.15690	.012385	.15764
10	.17449	.015330	.17541
11	.19214	.018603	.19326
12	.20988	.022212	.21122
13	.22772	.026165	.22929
14	.24565	.030471	.24749
15	.26370	.035140	.26581
16	.28188	.040183	.28430
17	.30020	.045610	.30295
18	.31867	.051435	.32178
19	.33732	.057673	.34080
20	.35614	.064337	.36002
21	.37515	.071446	.37947
22	.39437	.079016	.39916
23	.41381	.087070	.41909
24	.43348	.095626	.43930
25	.45341	.104709	.45980
26	.47361	.114345	.48060
27	.49410	.124559	.50173
28	.51489	.135383	.52320
29	.53600	.146849	.54505
30	.55746	.158990	.56729
31	.57928	.171845	.58994
32	.60149	.185455	.61303
33	.62410	.199864	.63658

$\gamma = 0.07$			
φ ⁰	X	Y	T
34	.64715	.215120	.66063
35	.67065	.231277	.68521
36	.69464	.248390	.71035
37	.71915	.266522	.73607
38	.74419	.285740	.76242
39	.76981	.306119	.78944
40	.79603	.327738	.81717
41	.82289	.350684	.84564
42	.85044	.375055	.87492
43	.87870	.400955	.90504
44	.90772	.428499	.93607
45	.93754	.457812	.96806
46	.96822	.489034	1.00108
47	.99980	.522316	1.03518
48	1.03233	.557825	1.07046
49	1.06588	.595747	1.10697
50	1.10049	.636285	1.14482
51	1.13625	.679664	1.18410
52	1.17320	.726132	1.22490
53	1.21144	.775964	1.26734
54	1.25102	.829467	1.31153
55	1.29204	.886981	1.35761
56	1.33457	.948832	1.40572
57	1.37871	1.015585	1.45601
58	1.42456	1.087557	1.50866
59	1.47220	1.165322	1.56386
60	1.52175	1.249463	1.62181

$\gamma = 0.07$			
φ ⁰	X	Y	T
60	2.27039	2.21597	1.96977
59	2.11908	1.95891	1.86852
58	1.99085	1.74955	1.77798
57	1.87926	1.57430	1.69584
56	1.78031	1.42473	1.62054
55	1.69135	1.29524	1.55096
54	1.61049	1.18185	1.48627
53	1.53638	1.08165	1.42580
52	1.46794	.99244	1.36902
51	1.40439	.91252	1.31552
50	1.34506	.84053	1.26492
49	1.28942	.77537	1.21694
48	1.23705	.71616	1.17131
47	1.18757	.66215	1.12781
46	1.14070	.61274	1.08626

	$\gamma = 0.07$		
φ	X	Y	T
0			
45	1.09615	.56741	1.04648
44	1.05372	.52571	1.00832
43	1.01320	.48725	.97165
42	.97443	.45171	.93637
41	.93724	.41882	.90236
40	.90153	.38830	.86952
39	.86716	.35996	.83777
38	.83402	.33360	.80705
37	.80203	.30905	.77726
36	.77110	.28616	.74836
35	.74116	.26480	.72028
34	.71215	.24485	.69296
33	.68395	.22619	.66637
32	.65656	.20874	.64044
31	.62992	.19241	.61515
30	.60396	.177118	.59044
29	.57864	.162794	.56629
28	.55394	.149377	.54266
27	.52980	.136807	.51952
26	.50618	.125032	.49684
25	.48306	.114005	.47458
24	.46041	.103681	.45273
23	.43820	.094020	.43125
22	.41639	.084986	.41014
21	.39496	.076546	.38935
20	.37390	.068670	.36889
19	.35317	.061330	.34871
18	.33276	.054498	.32880
17	.31264	.048154	.30915
16	.29280	.042276	.28975
15	.27321	.036843	.27056
14	.25386	.031840	.25158
13	.23475	.027250	.23279
12	.21583	.023056	.21419
11	.19710	.019246	.19574
10	.17856	.015809	.17745
9	.16018	.012734	.15928
8	.14195	.010008	.14124
7	.12386	.007626	.12332
6	.10588	.005579	.10550
5	.08802	.003859	.08776
4	.07027	.002461	.07010
3	.05260	.001380	.05251
2	.03500	.000612	.03496
+1	.01748	.000153	.01747
	+	+	+
0	00000	000000	00000

	$\gamma = 0.07$		
φ	X	Y	T
0			
—1	.01744	.000152	.01745
2	.03483	.000608	.03488
3	.05222	.001367	.05231
4	.06959	.002428	.06975
5	.08696	.003796	.08722
6	.10434	.005470	.10472
7	.12174	.007453	.12226
8	.13918	.009748	.13986
9	.15666	.012360	.15752
10	.17419	.015294	.17526
11	.19178	.018556	.19308
12	.20945	.022151	.21100
13	.22721	.026088	.22903
14	.24506	.030373	.24719
15	.26301	.035018	.26546
16	.28110	.040034	.28390
17	.29931	.045430	.30250
18	.31767	.051219	.32127
19	.33620	.057416	.34023
20	.35488	.064035	.35939
21	.37376	.071092	.37877
22	.39283	.078605	.39837
23	.41211	.086593	.41823
24	.43162	.095078	.43835
25	.45138	.104080	.45876
26	.47139	.113626	.47946
27	.49168	.123742	.50049
28	.51226	.134455	.52186
29	.53315	.145799	.54359
30	.55436	.157805	.56570
31	.57593	.170511	.58822
32	.59787	.183957	.61117
33	.62020	.198184	.63457
34	.64295	.213240	.65847
35	.66613	.229175	.68288
36	.68978	.246045	.70783
37	.71391	.263907	.73337
38	.73857	.282829	.75951
39	.76377	.302880	.78631
40	.78956	.324136	.81381
41	.81595	.346683	.84203
42	.84300	.370611	.87104
43	.87072	.396021	.90088
44	.89917	.423022	.93160
45	.92839	.451733	.96326
46	.95841	.482286	.99592
47	.98928	.514825	1.02965
48	1.02106	.549509	1.06451

φ	X	Y	T
°			
49	1.05379	.586512	1.10058
50	1.08754	.626026	1.13795
51	1.12234	.668261	1.17670
52	1.15828	.713449	1.21693
53	1.19541	.761847	1.25876
54	1.23381	.813741	1.30228
55	1.27353	.869445	1.34763
56	1.31467	.929307	1.39494
57	1.35729	.993714	1.44436
58	1.40148	1.063094	1.49605
59	1.44733	1.137924	1.55019
60	1.49492	1.218733	1.60698

$\gamma = 0.08$

φ	X	Y	T
°			
60	2.44854	2.47491	2.03488
59	2.24980	2.13716	1.91887
58	2.09255	1.88037	1.81862
57	1.96134	1.67428	1.72956
56	1.84826	1.50334	1.64906
55	1.74864	1.35834	1.57545
54	1.65951	1.23333	1.50752
53	1.57878	1.12419	1.44441
52	1.50497	1.02797	1.38545
51	1.43696	.94244	1.33010
50	1.37389	.86591	1.27794
49	1.31509	.79704	1.22860
48	1.25999	.73476	1.18180
47	1.20817	.67819	1.13728
46	1.15924	.62662	1.09483
45	1.11290	.57945	1.05425
44	1.06888	.53619	1.01539
43	1.02695	.49639	.97809
42	.98692	.45970	.94224
41	.94861	.42581	.90771
40	.91188	.39443	.87442
39	.87660	.36534	.84225
38	.84264	.33832	.81114
37	.80990	.31320	.78101
36	.77829	.28980	.75179
35	.74773	.26800	.72342
34	.71813	.24765	.69584
33	.68943	.22865	.66900
32	.66156	.21090	.64285
31	.63447	.19430	.61735

$\gamma = 0.08$

φ	X	Y	T
°			
30	.60811	.178769	.59245
29	.58243	.164235	.56813
28	.55738	.150632	.54433
27	.53292	.137898	.52104
26	.50901	.125978	.49821
25	.48562	.114822	.47583
24	.46272	.104384	.45386
23	.44028	.094623	.43227
22	.41826	.085501	.41105
21	.39664	.076983	.39017
20	.37539	.069039	.36962
19	.35449	.061639	.34936
18	.33393	.054756	.32938
17	.31367	.048366	.30966
16	.29369	.042449	.29019
15	.27399	.036984	.27094
14	.25453	.031952	.25191
13	.23532	.027338	.23307
12	.21631	.023125	.21442
11	.19750	.019299	.19593
10	.17889	.015848	.17761
9	.16044	.012761	.15941
8	.14216	.010028	.14135
7	.12402	.007639	.12339
6	.10600	.005587	.10555
5	.08811	.003864	.08780
4	.07032	.002463	.07012
3	.05263	.001381	.05252
2	.03502	.000612	.03497
+1	.01748	.000153	.01747
	+	+	+
0	00000	000000	00000
	—	+	—
—1	.01744	.000152	.01745
2	.03482	.000608	.03487
3	.05219	.001366	.05230
4	.06954	.002426	.06973
5	.08688	.003792	.08719
6	.10424	.005462	.10467
7	.12160	.007441	.12219
8	.13899	.009730	.13976
9	.15641	.012334	.15739
10	.17389	.015259	.17510
11	.19142	.018509	.19290
12	.20902	.022090	.21079
13	.22670	.026010	.22877
14	.24447	.030275	.24689
15	.26233	.034897	.26512

$\gamma = 0.08$			
φ	X	Y	T
0			
16	.28032	.039887	.28351
17	.29843	.045251	.30205
18	.31668	.051006	.32077
19	.33509	.057164	.33967
20	.35365	.063737	.35876
21	.37238	.070744	.37807
22	.29131	.078200	.39760
23	.41044	.086125	.41738
24	.42979	.094538	.43742
25	.44937	.103462	.45773
26	.46920	.112920	.47834
27	.48929	.122939	.49927
28	.50967	.133545	.52053
29	.53034	.144770	.54214
30	.55132	.156645	.56413
31	.57265	.169207	.58652
32	.59432	.182492	.60933
33	.61638	.196544	.63260
34	.63883	.211406	.65634
35	.66170	.227128	.68058
36	.68502	.243762	.70536
37	.70881	.261365	.73071
38	.73309	.280001	.75666
39	.75790	.299737	.78325
40	.78326	.320646	.81052
41	.80921	.342809	.83850
42	.83577	.366314	.86725
43	.86299	.391257	.89682
44	.89090	.417741	.92724
45	.91953	.445881	.95859
46	.94893	.475801	.99091
47	.97914	.507638	1.02427
48	1.01020	.541543	1.05873
49	1.04217	.577681	1.09438
50	1.07509	.616232	1.13129
51	1.10901	.657393	1.16955
52	1.14400	.701385	1.20925
53	1.18011	.748448	1.25049
54	1.21740	.798848	1.29338
55	1.25593	.852879	1.33804
56	1.29577	.910864	1.38461
57	1.33700	.973161	1.43321
58	1.37968	1.040167	1.48401
59	1.42389	1.112321	1.53718
60	1.46970	1.190111	1.59290

$\gamma = 0.09$			
φ	X	Y	T
0	+	+	+
59	2.43774	2.40308	1.98477
58	2.22605	2.05726	1.86850
57	2.06336	1.80168	1.76934
56	1.92967	1.59956	1.68182
55	1.81551	1.43338	1.60302
54	1.71558	1.29321	1.53110
53	1.62653	1.17283	1.46482
52	1.54614	1.06802	1.40328
51	1.47280	.97579	1.34581
50	1.40535	.89393	1.29186
49	1.34287	.82076	1.24101
48	1.28467	.75496	1.19291
47	1.23020	.69549	1.14727
46	1.17897	.64151	1.10383
45	1.13065	.59231	1.06239
44	1.08488	.54733	1.02276
43	1.04141	.50607	.98479
42	1.00002	.46813	.94833
41	.96050	.43316	.91326
40	.92268	.40086	.87947
39	.88642	.37096	.84687
38	.85159	.34324	.81536
37	.81805	.31751	.78487
36	.78572	.29358	.75532
35	.75450	.27131	.72664
34	.72430	.25055	.69878
33	.69506	.23119	.67169
32	.66669	.21313	.64531
31	.63914	.19624	.61959
30	.61237	.180466	.59450
29	.58630	.165714	.56999
28	.56089	.151918	.54603
27	.53610	.139014	.52258
26	.51190	.126944	.49961
25	.48823	.115655	.47710
24	.46508	.105100	.45500
23	.44239	.095236	.43330
22	.42015	.086024	.41198
21	.39833	.077427	.39100
20	.37690	.069413	.37036
19	.35583	.061952	.35002
18	.33511	.055016	.32996
17	.31470	.048581	.31017
16	.29460	.042625	.29063
15	.27478	.037126	.27133
14	.25521	.032066	.25224
13	.23589	.027428	.23336

φ	$\gamma = 0.09$ X	Y	T
0			
12	.21679	.023194	.21466
11	.19790	.019351	.19613
10	.17922	.015887	.17777
9	.16070	.012790	.15954
8	.14236	.010047	.14145
7	.12417	.007652	.12347
6	.10611	.005595	.10561
5	.08819	.003868	.08784
4	.07037	.002466	.07015
3	.05266	.001382	.05254
2	.03503	.000612	.03497
+1	.01749	.000153	.01747
	+	+	+
0	00000	000000	00000
	—	+	—
—1	.01743	.000152	.01745
2	.03481	.000607	.03487
3	.05217	.001365	.05228
4	.06949	.002424	.06970
5	.08681	.003787	.08715
6	.10413	.005455	.10461
7	.12145	.007429	.12211
8	.13880	.009713	.13967
9	.15617	.012309	.15727
10	.17359	.015224	.17495
11	.19106	.018462	.19271
12	.20859	.022029	.21057
13	.22619	.025932	.22852
14	.24388	.030179	.24654
15	.26166	.034779	.26478
16	.27955	.039741	.28312
17	.29756	.045075	.30161
18	.31570	.050795	.32027
19	.33399	.056914	.33911
20	.35242	.063443	.35814
21	.37103	.070400	.37737
22	.38981	.077800	.39684
23	.40879	.085663	.41654
24	.42798	.094007	.43649
25	.44740	.102854	.45672
26	.46704	.112227	.47724
27	.48695	.122151	.49807
28	.50712	.132653	.51922
29	.52758	.143761	.54072
30	.54834	.155509	.56259
31	.56942	.167930	.58486
32	.59085	.181061	.60754
33	.61263	.194942	.63066

φ	$\gamma = 0.10$ X	Y	T
0			
34	.63480	.209616	.65425
35	.65738	.225131	.67833
36	.68037	.241538	.70294
37	.70382	.258891	.72811
38	.72775	.277251	.75387
39	.75218	.296684	.78025
40	.77713	.317260	.80730
41	.80265	.339056	.83506
42	.82876	.362156	.86356
43	.85549	.386652	.89286
44	.88287	.412643	.92300
45	.91095	.440239	.95404
46	.93976	.469558	.98603
47	.96934	.500731	1.01904
48	.99972	.533901	1.05313
49	1.03097	.569223	1.08837
50	1.06311	.606867	1.12485
51	1.09621	.647021	1.16263
52	1.13031	.689892	1.20182
53	1.16546	.735708	1.24251
54	1.20172	.784717	1.28481
55	1.23914	.837193	1.32882
56	1.27779	.893440	1.37468
57	1.31773	.953792	1.42252
58	1.35902	1.018617	1.47249
59	1.40173	1.088323	1.52475
60	1.44592	1.163360	1.57947

φ	$\gamma = 0.10$ X	Y	T
0			
58	2.42326	2.32865	1.93480
57	2.19876	1.97583	1.81849
56	2.03136	1.72270	1.72059
55	1.89581	1.52534	1.63472
54	1.78106	1.36438	1.55766
53	1.68116	1.22932	1.48746
52	1.59248	1.11371	1.42283
51	1.51262	1.01330	1.36286
50	1.43993	.925075	1.30685
49	1.37315	.846868	1.25428
48	1.31137	.777020	1.20472
47	1.25387	.714251	1.15783
46	1.20007	.657546	1.11331

$\gamma = 0.10$				$\gamma = 0.10$			
φ	X	Y	T	φ	X	Y	T
°				°			
45	1.14951	.606087	1.07093	—1	.01743	.000152	.01744
44	1.10182	.559206	1.03047	2	.03480	.000607	.03486
43	1.05666	.516347	.99177	3	.05214	.001364	.05227
42	1.01378	.477046	.95466	4	.06944	.002422	.06968
41	.97295	.440911	.91902	5	.08673	.003783	.08711
40	.93396	.407608	.88471	6	.10402	.005447	.10456
39	.89665	.376850	.85164	7	.12130	.007417	.12204
38	.86088	.348387	.81971	8	.13861	.009695	.13957
37	.82650	.322004	.78884	9	.15593	.012284	.15715
36	.79341	.297513	.75894	10	.17329	.015190	.17480
35	.76149	.274747	.72995	11	.19070	.018416	.19253
34	.73067	.253559	.70180	12	.20816	.021969	.21035
33	.70085	.233820	.67445	13	.22569	.025856	.22826
32	.67196	.215416	.64782	14	.24330	.030083	.24629
31	.64394	.198242	.62188	15	.26099	.034660	.26444
30	.61673	.182208	.59659	16	.27879	.039596	.28273
29	.59026	.167230	.57189	17	.29670	.044901	.30117
28	.56448	.153234	.54776	18	.31473	.050587	.31977
27	.53936	.140154	.52415	19	.33290	.056667	.33855
26	.51484	.127928	.50103	20	.35121	.063153	.35752
25	.49089	.116503	.47838	21	.36969	.070061	.37669
24	.46747	.105828	.45616	22	.38834	.077406	.39608
23	.44454	.095858	.43435	23	.40717	.085208	.41570
22	.42208	.086553	.41292	24	.42620	.093484	.43558
21	.40005	.077875	.39184	25	.44545	.102256	.45572
20	.37843	.069790	.37110	26	.46492	.111545	.47614
19	.35719	.062268	.35068	27	.48464	.121376	.49687
18	.33630	.055279	.33054	28	.50461	.131776	.51793
17	.31575	.048799	.31069	29	.52487	.142772	.53932
16	.29551	.042803	.29108	30	.54541	.154396	.56108
15	.27557	.037270	.27172	31	.56626	.166680	.58322
14	.25589	.032181	.25258	32	.58744	.179660	.60577
13	.23647	.027518	.23364	33	.60897	.193376	.62875
12	.21728	.023264	.21490	34	.63086	.207868	.65219
11	.19831	.019404	.19633	35	.65314	.223183	.67612
10	.17955	.015926	.17793	36	.67583	.239370	.70057
9	.16097	.012818	.15967	37	.69896	.256482	.72556
8	.14257	.010067	.14155	38	.72254	.274577	.75113
7	.12433	.007665	.12355	39	.74660	.293718	.77732
6	.10623	.005603	.10567	40	.77117	.313973	.80415
5	.08827	.003873	.08788	41	.79627	.335417	.83168
4	.07042	.002468	.07017	42	.82194	.358129	.85994
3	.05269	.001383	.05255	43	.84820	.382198	.88898
2	.03504	.000613	.03498	44	.87510	.407719	.91885
+1	.01749	.000153	.01747	45	.90265	.434796	.94960
	+	+	+	46	.93089	.463544	.98128
0	00000	000000	00000	47	.95987	.494086	1.01395
				48	.98962	.526557	1.04768

$\gamma = 0.11$			
φ °	X	Y	T
49	1.02018	.561106	1.08254
50	1.05160	.597895	1.11860
51	1.08391	.637102	1.15593
52	1.11717	.678923	1.19464
53	1.15143	.723571	1.23481
54	1.18672	.771281	1.27654
55	1.22312	.822311	1.31994
56	1.26066	.876946	1.36514
57	1.29941	.935498	1.41226
58	1.33942	.998312	1.46145
59	1.38075	1.065767	1.51286
60	1.42345	1.138282	1.56665

$\gamma = 0.11$			
φ °	X	Y	T
57	2.40402	2.25049	1.88501
56	2.16753	1.89271	1.76874
55	1.99642	1.64352	1.67229
54	1.85974	1.45177	1.58819
53	1.74491	1.29650	1.51294
52	1.64542	1.16679	1.44448
51	1.55739	1.05607	1.38151
50	1.47829	.96008	1.32310
49	1.40639	.87587	1.26855
48	1.34042	.80128	1.21734
47	1.27944	.73471	1.16905
46	1.22271	.67491	1.12334
45	1.16965	.62091	1.07992
44	1.11981	.57192	1.03857
43	1.07279	.52730	.99907
42	1.02827	.48651	.96127
41	.98601	.44910	.92501
40	.94576	.41471	.89015
39	.90733	.38304	.85658
38	.87055	.35377	.82420
37	.83528	.32669	.79293
36	.80137	.30160	.76267
35	.76873	.27832	.73335
34	.73724	.25668	.70490
33	.70682	.23654	.67727
32	.67739	.21779	.65039
31	.64887	.20030	.62422
30	.62120	.184005	.59872
29	.59431	.168790	.57383
28	.56815	.154589	.54952

$\gamma = 0.11$			
φ °	X	Y	T
27	.54268	.141327	.52575
26	.51784	.128940	.50248
25	.49360	.117373	.47969
24	.46991	.106575	.45734
23	.44673	.096497	.43541
22	.42404	.087096	.41387
21	.40180	.078334	.39269
20	.37998	.070177	.37186
19	.35856	.062591	.35135
18	.33751	.055547	.33114
17	.31682	.049020	.31121
16	.29644	.042983	.29154
15	.27637	.037416	.27211
14	.25658	.032297	.25292
13	.23706	.027609	.23393
12	.21777	.023335	.21514
11	.19872	.019457	.19653
10	.17989	.015965	.17809
9	.16124	.012845	.15980
8	.14278	.010086	.14165
7	.12449	.007678	.12363
6	.10635	.005611	.10573
5	.08835	.003878	.08792
4	.07047	.002470	.07020
3	.05271	.001384	.05256
2	.03505	.000613	.03499
+1	.01749	.000153	.01748
	+	+	+
0	00000	000000	00000
	—	+	—
—1	.01743	.000152	.01744
2	.03478	.000607	.03485
3	.05211	.001363	.05225
4	.06939	.002418	.06965
5	.08666	.003779	.08707
6	.10391	.005440	.10451
7	.12116	.007405	.12197
8	.13842	.009677	.13948
9	.15569	.012259	.15703
10	.17300	.015156	.17465
11	.19034	.018370	.19235
12	.20774	.021910	.21014
13	.22519	.025780	.22801
14	.24272	.029988	.24600
15	.26033	.034543	.26411
16	.27804	039453	.28234
17	.29585	.044728	.30073
18	.31377	.050381	.31928

$\gamma = 0.11$			
φ	X	Y	T
°			
19	.33182	.056423	.33800
20	.35002	.062866	.35691
21	.36836	.069726	.37601
22	.38688	.077018	.39533
23	.40556	.084760	.41488
24	.42444	.092970	.43467
25	.44353	.101668	.45473
26	.46283	.110875	.47506
27	.48237	.120616	.49570
28	.50215	.130916	.51665
29	.52220	.141803	.53793
30	.54253	.153305	.55958
31	.56315	.165456	.58160
32	.58410	.178290	.60402
33	.60537	.191845	.62687
34	.62700	.206161	.65017
35	.64900	.221282	.67394
36	.67139	.237256	.69823
37	.69420	.254135	.72305
38	.71744	.271974	.74844
39	.74115	.290835	.77443
40	.76535	.310781	.80106
41	.79006	.331886	.82837
42	.81530	.354226	.85640
43	.84112	.377886	.88520
44	.86754	.402958	.91480
45	.89459	.429541	.94526
46	.92230	.457744	.97664
47	.95071	.487685	1.00899
48	.97985	.519494	1.04237
49	1.00977	.553311	1.07686
50	1.04049	.589292	1.11252
51	1.07207	.627606	1.14943
52	1.10455	.668438	1.18768
53	1.13796	.711989	1.22735
54	1.17236	.758483	1.26854
55	1.20779	.808164	1.31137
56	1.24430	.861298	1.35594
57	1.28194	.918179	1.40239
58	1.32076	.979130	1.45084
59	1.36082	1.044507	1.50145
60	1.40216	1.114701	1.55438

$\gamma = 0.12$			
φ	X	Y	T
°			
56	2.37888	2.16734	1.83487
55	2.13210	1.80775	1.71917
54	1.95854	1.56419	1.62444
53	1.82153	1.37892	1.54224
52	1.70717	1.22979	1.46886
51	1.60846	1.10564	1.40218
50	1.52134	.99992	1.34088
49	1.44320	.90839	1.28401
48	1.37225	.82817	1.23090
47	1.30720	.75716	1.18103
46	1.24710	.69382	1.13398
45	1.19122	.63693	1.08942
44	1.13897	.58557	1.04708
43	1.08989	.53899	1.00672
42	1.04359	.49655	.96817
41	.99976	.45777	.93124
40	.95814	.42221	.89579
39	.91850	.38953	.86170
38	.88064	.35941	.82885
37	.84440	.33160	.79715
36	.80963	.30587	.76651
35	.77622	.28203	.73684
34	.74403	.25991	.70808
33	.71298	.23935	.68016
32	.68298	.22023	.65303
31	.65394	.20243	.62662
30	.62579	.185852	.60090
29	.59847	.170393	.57581
28	.57192	.155976	.55131
27	.54608	.142525	.52737
26	.52091	.129973	.50395
25	.49636	.118261	.48102
24	.47239	.107335	.45854
23	.44896	.097145	.43648
22	.42603	.087647	.41483
21	.40358	.078800	.39355
20	.38156	.070569	.37263
19	.35996	.062919	.35203
18	.33875	.055820	.33174
17	.31790	.049244	.31173
16	.29738	.043166	.29200
15	.27718	.037563	.27251
14	.25727	.032414	.25326
13	.23765	.027701	.23422
12	.21827	.023406	.21539
11	.19917	.019511	.19673
10	.18022	.016005	.17826

γ = 0.12			
φ (°)	X	Y	T
9	.16151	.012874	.15993
8	.14299	.010106	.14176
7	.12465	.007691	.12371
6	.10647	.005619	.10579
5	.08843	.003882	.08796
4	.07052	.002473	.07022
3	.05274	.001385	.05258
2	.03507	.000613	.03499
+1	.01750	.000153	.01748
	+	+	+
0	00000	000000	00000
	—	+	—
—1	.01742	.000152	.01744
2	.03477	.000606	.03485
3	.05208	.001361	.05224
4	.06935	.002417	.06963
5	.08658	.003774	.08703
6	.10380	.005432	.10445
7	.12101	.007394	.12190
8	.13823	.009660	.13938
9	.15546	.012234	.15691
10	.17271	.015121	.17450
11	.18999	.018325	.19217
12	.20732	.021851	.20993
13	.22470	.025705	.22777
14	.24215	.029894	.24571
15	.25967	.034427	.26377
16	.27729	.039311	.28196
17	.29500	.044558	.30030
18	.31282	.051178	.31879
19	.33076	.056182	.33745
20	.34884	.062583	.35630
21	.36706	.069396	.37534
22	.38543	.076635	.39459
23	.40398	.084318	.41406
24	.42271	.092463	.43377
25	.44164	.101089	.45375
26	.46077	.110216	.47400
27	.48013	.119869	.49454
28	.49973	.130072	.51539
29	.51958	.140851	.53657
30	.53970	.152236	.55810
31	.56011	.164257	.58000
32	.58082	.176949	.60230
33	.60185	.190347	.62502
34	.62322	.204492	.64817
35	.64494	.219426	.67180
36	.66705	.235194	.69593

γ = 0.13			
φ (°)	X	Y	T
37	.68955	.251848	.72059
38	.71248	.269440	.74580
39	.73584	.288029	.77161
40	.75968	.307679	.79804
41	.78400	.328458	.82514
42	.80885	.350442	.85294
43	.83424	.373710	.88150
44	.86020	.398351	.91084
45	.88677	.424461	.94104
46	.91397	.452144	.97212
47	.94184	.481513	1.00416
48	.97040	.512692	1.03722
49	.99970	.545816	1.07135
50	1.02978	.581032	1.10663
51	1.06066	.618502	1.14313
52	1.09239	.658401	1.18094
53	1.12501	.700922	1.22014
54	1.15857	.746275	1.26082
55	1.19310	.794691	1.30310
56	1.22864	.846423	1.34708
57	1.26526	.901747	1.39288
58	1.30298	.960968	1.44062
59	1.34185	1.024421	1.49050
60	1.38193	1.092474	1.54262

γ = 0.13			
φ (°)	X	Y	T
55	2.34664	2.07817	1.78424
54	2.09231	1.72105	1.66973
53	1.91777	1.48495	1.57699
52	1.78130	1.30698	1.49683
51	1.66795	1.16439	1.42538
50	1.57040	1.04600	1.36052
49	1.43445	.94533	1.30088
48	1.40745	.85826	1.24556
47	1.33759	.78200	1.19387
46	1.27358	.71452	1.14530
45	1.21445	.65434	1.09946
44	1.15948	.60030	1.05604
43	1.10809	.55152	1.01474
42	1.05981	.50727	.97537
41	1.01426	.46697	.93773
40	0.97114	.43013	.90165

φ	X	Y	T
39°	.93019	.39636	.86700
38	.89117	.36533	.83365
37	.85391	.33673	.80150
36	.81821	.31032	.77046
35	.78398	.28589	.74043
34	.75106	.26326	.71134
33	.71934	.24226	.68312
32	.68874	.22276	.65572
31	.65915	.20462	.62907
30	.63050	.187754	.60312
29	.60273	.172040	.57783
28	.57577	.157400	.55314
27	.54956	.143753	.52902
26	.52405	.131030	.50544
25	.49918	.119169	.48236
24	.47492	.108111	.45975
23	.45123	.097806	.43757
22	.42806	.088208	.41580
21	.40538	.079274	.39443
20	.38316	.070968	.37340
19	.36138	.063252	.35272
18	.34000	.056096	.33234
17	.31899	.049471	.31226
16	.29833	.043350	.29246
15	.27800	.037712	.27291
14	.25797	.032532	.25361
13	.23824	.027794	.23451
12	.21877	.023478	.21563
11	.19955	.019566	.19694
10	.18056	.016045	.17842
9	.16178	.012903	.16007
8	.14320	.010126	.14186
7	.12481	.007704	.12378
6	.10658	.005627	.10584
5	.08851	.003887	.08800
4	.07058	.002475	.07025
3	.05277	.001386	.05259
2	.03508	.000614	.03500
+1	.01750	.000153	.01748
	+	+	+
0	00000	000000	00000
	−	+	−
−1	.01742	.000152	.01744
2	.03476	.000606	.03484
3	.05206	.001361	.05223
4	.06930	.002415	.06961
5	.08651	.003770	.08700
6	.10370	.005425	.10440

γ = 0.13

φ	X	Y	T
7°	.12087	.007382	.12182
8	.13804	.009642	.13928
9	.15522	.012209	.15679
10	.17242	.015088	.17436
11	.18964	.018280	.19199
12	.20690	.021792	.20971
13	.22421	.025630	.22751
14	.24158	.029801	.24542
15	.25902	.034312	.26344
16	.27655	.039171	.28158
17	.29417	.044389	.29987
18	.31188	.049977	.31831
19	.32971	.055944	.33691
20	.34767	.062304	.35570
21	.36576	.069070	.37467
22	.38401	.076258	.39385
23	.40242	.083883	.41325
24	.42100	.091964	.43289
25	.43977	.100518	.45278
26	.45874	.109568	.47294
27	.47793	.119134	.49339
28	.49734	.129242	.51414
29	.51700	.139917	.53522
30	.53692	.151186	.55664
31	.55711	.163082	.57843
32	.57759	.175635	.60061
33	.59838	.188882	.62319
34	.61950	.202861	.64622
35	.64096	.217613	.66970
36	.66279	.233182	.69368
37	.68500	.249618	.71817
38	.70761	.266971	.74321
39	.73065	.285299	.76883
40	.75414	.304663	.79507
41	.77810	.325129	.82197
42	.80256	.346769	.84956
43	.82754	.369661	.87788
44	.85307	.393890	.90698
45	.87917	.419547	.93691
46	.90589	.446733	.96772
47	.93324	.475557	.99946
48	.96125	.506137	1.03219
49	.98997	.538603	1.06598
50	1.01943	.573094	1.10089
51	1.04965	.609765	1.13701
52	1.08068	.648783	1.17439
53	1.11256	.690331	1.21314
54	1.14532	.734609	1.25334

$\gamma = 0.14$			
φ	X	Y	T
0			
55	1.17900	.781837	1.29510
56	1.21364	.832254	1.33852
57	1.24929	.886123	1.38371
58	1.28598	.943732	1.43082
59	1.32376	1.005397	1.47997
60	1.36267	1.071464	1.53132

$\gamma = 0.14$			
φ	X	Y	T
0			
54	2.30632	1.98239	1.73297
53	2.04816	1.63293	1.62037
52	1.87425	1.40607	1.52992
51	1.73918	1.23615	1.45195
50	1.62737	1.10043	1.38250
49	1.53132	.98792	1.31946
48	1.44679	.89233	1.26149
47	1.37111	.80971	1.20770
46	1.30247	.73736	1.15741
45	1.23959	.67336	1.11015
44	1.18152	.61627	1.06551
43	1.12752	.56502	1.02319
42	1.07703	.51874	.98292
41	1.02959	.47676	.94450
40	.98483	.43853	.90775
39	.94245	.40358	.87250
38	.90218	.37155	.83862
37	.86381	.34210	.80600
36	.82714	.31496	.77453
35	.79203	.28991	.74412
34	.75833	.26674	.71469
33	.72591	.24528	.68616
32	.69467	.22538	.65848
31	.66451	.20689	.63157
30	.63535	.189715	.60538
29	.60711	.173734	.57988
28	.57972	.158861	.55500
27	.55312	.145012	.53071
26	.52725	.132113	.50696
25	.50206	.120097	.48373
24	.47750	.108904	.46098
23	.45354	.098481	.43868
22	.43012	.088780	.41679
21	.40722	.079757	.39531
20	.38479	.071373	.37418
19	.36282	.063590	.35341

$\gamma = 0.14$			
φ	X	Y	T
0			
18	.34126	.056376	.33295
17	.32009	.049700	.31280
16	.29929	.043537	.29293
15	.27883	.037862	.27332
14	.25868	.032652	.25395
13	.23884	.027888	.23480
12	.21927	.023550	.21588
11	.19996	.019621	.19714
10	.18090	.016086	.17859
9	.16205	.012932	.16020
8	.14341	.010146	.14197
7	.12497	.007717	.12386
6	.10670	.005635	.10590
5	.08859	.003892	.08804
4	.07062	.002478	.07027
3	.05280	.001387	.05261
2	.03509	.000614	.03501
+1	.01750	.000153	.01748
	+	+	+
0	00000	000000	00000
	—	+	—
—1	.01742	.000152	.01744
2	.03475	.000606	.03484
3	.05203	.001360	.05222
4	.06925	.002413	.06958
5	.08643	.003766	.08696
6	.10358	.005417	.10434
7	.12072	.007370	.12175
8	.13787	.009625	.13919
9	.15499	.012185	.15667
10	.17213	.015054	.17421
11	.18929	.018235	.19181
12	.20649	.021734	.20950
13	.22372	.025556	.22726
14	.24102	.029708	.24513
15	.25838	.034198	.26311
16	.27581	.039032	.28120
17	.29334	.044222	.29944
18	.31095	.049778	.31783
19	.32867	.055709	.33637
20	.34651	.062028	.35510
21	.36449	.068749	.37401
22	.38260	.075886	.39312
23	.40087	.083454	.41245
24	.41931	.091472	.43201
25	.43793	.099958	.45182
26	.45674	.108931	.47190
27	.47576	.118413	.49225

$\gamma = 0.15$

φ (0)	X	Y	T
28	.49499	.128427	.51291
29	.51446	.139000	.53389
30	.53418	.150158	.55520
31	.55416	.161930	.57688
32	.57443	.174349	.59893
33	.59499	.187449	.62139
34	.61586	.201266	.64428
35	.63707	.215841	.66763
36	.65862	.231218	.69145
37	.68055	.247442	.71579
38	.70286	.264565	.74066
39	.72558	.282641	.76611
40	.74873	.301729	.79216
41	.77234	.321893	.81886
42	.79643	.343203	.84623
43	.82101	.365734	.87433
44	.84612	.389568	.90319
45	.87179	.414793	.93287
46	.89803	.441504	.96341
47	.92489	.469807	.99486
48	.95238	.499816	1.02729
49	.98055	.531655	1.06075
50	1.00941	.565458	1.09531
51	1.03901	.601371	1.13105
52	1.06938	.639555	1.16803
53	1.10055	.680185	1.20635
54	1.13256	.723452	1.24609
55	1.16545	.769562	1.28735
56	1.19924	.818746	1.33023
57	1.23399	.871253	1.37485
58	1.26973	.927355	1.42134
59	1.30648	.987352	1.46982
60	1.34430	1.051571	1.52045

$\gamma = 0.15$

φ (0)	X	Y	T
53	2.25742	1.88017	1.68106
52	1.99983	1.54391	1.57118
51	1.82819	1.32791	1.48331
50	1.69536	1.16667	1.40764
49	1.58558	1.03806	1.34024
48	1.49136	.93151	1.27905
47	1.40847	.84102	1.22275
46	1.33427	.76281	1.17047

$\gamma = 0.15$

φ (0)	X	Y	T
45	1.26697	.69430	1.12157
44	1.20531	.63368	1.07558
43	1.14836	.57963	1.03212
42	1.09539	.53107	.99087
41	1.04585	.48723	.95160
40	.99928	.44746	.91412
39	.95534	.41122	.87822
38	.91371	.37810	.84378
37	.87414	.34774	.81066
36	.83643	.31982	.77874
35	.80038	.29411	.74793
34	.76585	.27037	.71814
33	.73269	.24842	.68929
32	.70078	.22809	.66131
31	.67003	.20923	.63413
30	.64032	.191738	.60770
29	.61160	.175479	.58198
28	.58376	.160365	.55690
27	.55675	.146306	.53242
26	.53051	.133222	.50851
25	.50499	.121046	.48512
24	.48013	.109714	.46223
23	.45588	.099169	.43980
22	.43221	.089363	.41779
21	.40908	.080249	.39620
20	.38644	.071785	.37497
19	.36427	.063933	.35411
18	.34254	.056659	.33357
17	.32121	.049933	.31334
16	.30026	.043726	.29340
15	.27967	.038014	.27372
14	.25940	.032773	.25430
13	.23945	.027983	.23510
12	.21978	.023623	.21613
11	.20038	.019676	.19735
10	.18124	.016126	.17875
9	.16232	.012961	.16034
8	.14362	.010166	.14207
7	.12513	.007730	.12394
6	.10681	.005643	.10596
5	.08867	.003896	.08808
4	.07067	.002480	.07030
3	.05283	.001388	.05262
2	.03511	.000614	.03502
+1	.01751	.000153	.01749
	+	+	+
0	00000	000000	00000

$\gamma = 0.15$			
φ	X	Y	T
0			
1	.01741	.000152	.01744
2	.03474	.000605	.03483
3	.05200	.001359	.05220
4	.06920	.002412	.06956
5	.08636	.003762	.08692
6	.10349	.005410	.10429
7	.12059	.007358	.12168
8	.13767	.009608	.13910
9	.15475	.012160	.15655
10	.17184	.015021	.17406
11	.18895	.018191	.19164
12	.20608	.021676	.20929
13	.22324	.025483	.22701
14	.24046	.029616	.24484
15	.25774	.034085	.26278
16	.27509	.038895	.28083
17	.29252	.044057	.29902
18	.31003	.049581	.31735
19	.32764	.055476	.33584
20	.34537	.061755	.35451
21	.36322	.068431	.37336
22	.38121	.075518	.39240
23	.39935	.083032	.41166
24	.41765	.090988	.43115
25	.43612	.099405	.45088
26	.45477	.108303	.47087
27	.47362	.117703	.49113
28	.49268	.127627	.51170
29	.51197	.138100	.53258
30	.53149	.149148	.55379
31	.55128	.160801	.57535
32	.57133	.173088	.59729
33	.59166	.186045	.61963
34	.61230	.199705	.64239
35	.63325	.214109	.66560
36	.65455	.229298	.68928
37	.67619	.245318	.71346
38	.69822	.262218	.73817
39	.72063	.280050	.76345
40	.74346	.298871	.78932
41	.76673	.318745	.81582
42	.79045	.339737	.84299
43	.81466	.361920	.87087
44	.83937	.385373	.89950
45	.86461	.410182	.92893
46	.89041	.436439	.95921
47	.91680	.464244	.99038
48	.94379	.493707	1.02251

$\gamma = 0.16$			
φ	X	Y	T
0			
49	.97143	.524947	1.05566
50	.99973	.558094	1.08989
51	1.02874	.593287	1.12526
52	1.05848	.630680	1.16186
53	1.08898	.670440	1.19977
54	1.12028	.712750	1.23907
55	1.15242	.757808	1.27985
56	1.18542	.805832	1.32223
57	1.21932	.857060	1.36630
58	1.25415	.911751	1.41220
59	1.28996	.970188	1.46005
60	1.32676	1.032683	1.50999

$\gamma = 0.16$			
φ	X	Y	T
0			
52	2.20019	1.77260	1.62859
51	1.94773	1.45469	1.52223
50	1.77989	1.25088	1.43719
49	1.65007	1.09878	1.36392
48	1.54278	.97743	1.29862
47	1.45067	.87687	1.23927
46	1.36962	.79142	1.18463
45	1.29703	.71754	1.13385
44	1.23118	.65280	1.08632
43	1.17082	.59551	1.04157
42	1.11504	.54438	.99925
41	1.06314	.49845	.95906
40	1.01458	.45697	.92078
39	.96893	.41933	.88419
38	.92582	.38503	.84914
37	.88496	.35367	.81548
36	.84612	.32492	.78309
35	.80907	.29850	.75186
34	.77366	.27415	.72169
33	.73971	.25168	.69249
32	.70710	.23090	.66421
31	.67571	.21166	.63676
30	.64544	.193826	.61007
29	.61620	.177278	.58412
28	.58790	.161911	.55883
27	.56047	.147632	.53416
26	.53385	.134358	.51008
25	.50798	.122017	.48653

$\gamma = 0.16$			
φ°	X	Y	T
24	.48281	.110541	.46350
23	.45827	.099872	.44093
22	.43434	.089958	.41881
21	.41097	.080750	.39710
20	.38811	.072204	.37578
19	.36574	.064281	.35481
18	.34383	.056947	.33419
17	.32234	.050169	.31388
16	.30124	.043918	.29387
15	.28051	.038168	.27413
14	.26012	.032895	.25465
13	.24006	.028078	.23539
12	.22029	.023696	.21638
11	.20081	.019731	.19756
10	.18159	.016167	.17892
9	.16260	.012990	.16047
8	.14384	.010186	.14218
7	.12529	.007744	.12402
6	.10693	.005652	.10602
5	.08875	.003901	.08812
4	.07073	.002482	.07033
3	.05286	.001389	.05263
2	.03512	.000614	.03502
+1	.01751	.000153	.01749
	+	+	+
0	00000	000000	00000
	—	+	—
—1	.01741	.000152	.01743
2	.03473	.000605	.03482
3	.05198	.001358	.05219
4	.06916	.002409	.06954
5	.08629	.003757	.08688
6	.10338	.005403	.10424
7	.12044	.007347	.12161
8	.13749	.009591	.13901
9	.15452	.012136	.15644
10	.17156	.014987	.17392
11	.18860	.018146	.19146
12	.20567	.021619	.20908
13	.22276	.025410	.22677
14	.23991	.029525	.24456
15	.25710	.033973	.26246
16	.27436	.038759	.28046
17	.29170	.043894	.29860
18	.30911	.049386	.31688
19	.32662	.055246	.33531
20	.34424	.061486	.35392
21	.36197	.068118	.37271

$\gamma = 0.16$			
φ°	X	Y	T
22	.37984	.075156	.39169
23	.39784	.082615	.41087
24	.41600	.090511	.43029
25	.43433	.098862	.44994
26	.45283	.107686	.46985
27	.47151	.117005	.49003
28	.49041	.126840	.51050
29	.50951	.137215	.53128
30	.52885	.148157	.55239
31	.54844	.159693	.57385
32	.56828	.171853	.59567
33	.58839	.184670	.61789
34	.60880	.198178	.64052
35	.62952	.212416	.66359
36	.65055	.227423	.68713
37	.67193	.243245	.71116
38	.69367	.259928	.73572
39	.71579	.277525	.76082
40	.73831	.296098	.78652
41	.76125	.315682	.81283
42	.78463	.336368	.83980
43	.80847	.358217	.86747
44	.83280	.381306	.89588
45	.85763	.405716	.92507
46	.88301	.431537	.95510
47	.90894	.458866	.98600
48	.93545	.487808	1.01785
49	.96259	.518477	1.05069
50	.99036	.550998	1.08459
51	1.01880	.585506	1.11962
52	1.04794	.622148	1.15585
53	1.07782	.661084	1.19336
54	1.10845	.702489	1.23224
55	1.13987	.746553	1.27257
56	1.17212	.793483	1.31446
57	1.20523	.843506	1.35801
58	1.23922	.896870	1.40335
59	1.27412	.953845	1.45060
60	1.30998	1.014728	1.49989

$\gamma = 0.17$			
φ	X	Y	T
51°	2.13564	1.66158	1.57577
50	1.89240	1.36603	1.47358
49	1.72971	1.17536	1.39159
48	1.60356	1.03268	1.32079
47	1.49914	.91866	1.25760
46	1.40939	.82405	1.20011
45	1.33034	.74358	1.14712
44	1.25950	.67394	1.09782
43	1.19518	.61288	1.05163
42	1.13618	.55880	1.00811
41	1.08162	.51053	.96690
40	1.03083	.46714	.92775
39	.98329	.42795	.89042
38	.93856	.39236	.85471
37	.89630	.35992	.82048
36	.85624	.33028	.78759
35	.81813	.30309	.75591
34	.78177	.27809	.72534
33	.74698	.25506	.69579
32	.71363	.23381	.66718
31	.68157	.21417	.63944
30	.65071	.195981	.61250
29	.62093	.179130	.58631
28	.59215	.163500	.56080
27	.56428	.148994	.53594
26	.53727	.135523	.51167
25	.51104	.123011	.48797
24	.48554	.111386	.46479
23	.46072	.100590	.44208
22	.43651	.090564	.41984
21	.41289	.081259	.39801
20	.38981	.072629	.37659
19	.36724	.064634	.35553
18	.34514	.057238	.33482
17	.32348	.050407	.31443
16	.30224	.044112	.29435
15	.28137	.038324	.27454
14	.26085	.033019	.25500
13	.24067	.028175	.23569
12	.22081	.023770	.21663
11	.20123	.019788	.19777
10	.18193	.016208	.17909
9	.16287	.013019	.16061
8	.14405	.010206	.14228
7	.12545	.007757	.12410
6	.10704	.005660	.10608
5	.08883	.003906	.08816
4	.07078	.002485	.07035

$\gamma = 0.17$			
φ	X	Y	T
3°	.05288	.001390	.05265
2	.03513	.000615	.03503
+1	.01751	.000153	.01749
	+	+	+
0	00000	000000	00000
	—	+	—
—1	.01741	.000152	.01743
2	.03472	.000605	.03482
3	.05195	.001357	.05218
4	.06911	.002406	.06952
5	.08621	.003752	.08685
6	.10328	.005395	.10419
7	.12031	.007335	.12154
8	.13731	.009574	.13891
9	.15429	.012112	.15632
10	.17127	.014954	.17377
11	.18826	.018102	.19129
12	.20526	.021562	.20887
13	.22229	.025338	.22652
14	.23936	.029435	.24428
15	.25647	.033862	.26213
16	.27364	.038624	.28009
17	.29089	.043732	.29818
18	.30821	.049193	.31641
19	.32561	.055019	.33479
20	.34312	.061220	.35334
21	.36074	.067808	.37206
22	.37848	.074798	.39098
23	.39636	.082204	.41010
24	.41438	.090041	.42944
25	.43256	.098326	.44901
26	.45091	.107078	.46884
27	.46944	.116318	.48893
28	.48817	.126066	.50931
29	.50710	.136347	.53000
30	.52625	.147184	.55101
31	.54564	.158606	.57236
32	.56528	.170642	.59407
33	.58518	.183323	.61617
34	.60537	.196683	.63868
35	.62584	.210759	.66162
36	.64663	.225591	.68502
37	.66776	.241220	.70890
38	.68922	.257694	.73330
39	.71106	.275062	.75825
40	.73327	.293378	.78377
41	.75589	.312700	.80990
42	.77894	.333091	.83668

	$\gamma = 0.17$		
φ	X	Y	T
°			
43	.80243	.354618	.86414
44	.82639	.377356	.89233
45	.85083	.401384	.92130
46	.87579	.426787	.95108
47	.90129	.453660	.98172
48	.92735	.482104	1.01329
49	.95400	.512229	1.04584
50	.98127	.544154	1.07943
51	1.00917	.578010	1.11413
52	1.03774	.613937	1.15001
53	1.06702	.652090	1.18714
54	1.09701	.692636	1.22561
55	1.12777	.735758	1.26551
56	1.15931	.781655	1.30693
57	1.19166	.830542	1.34999
58	1.22485	.882656	1.39479
59	1.25892	.938257	1.44146
60	1.29388	.997630	1.49014

	$\gamma = 0.18$		
φ	X	Y	T
°			
50	2.06533	1.54956	1.52292
49	1.83445	1.27881	1.42538
48	1.67800	1.10181	1.34657
47	1.55606	.96864	1.27830
46	1.45483	.86191	1.21724
45	1.36765	.77315	1.16160
44	1.29074	.69755	1.11023
43	1.22173	.63204	1.06239
42	1.15901	.57455	1.01751
41	1.10143	.52360	.97518
40	1.04814	.47807	.93508
39	.99850	.43714	.89693
38	.95199	.40014	.86052
37	.90821	.36653	.82568
36	.86683	.33591	.79224
35	.82757	.30789	.76009
34	.79020	.28221	.72910
33	.75452	.25859	.69918
32	.72038	.23684	.67023
31	.68763	.21676	.64219
30	.65614	.198209	.61498
29	.62580	.181040	.58854
28	.59651	.165136	.56281

	$\gamma = 0.18$		
φ	X	Y	T
°			
27	.56819	.150393	.53775
26	.54077	.136718	.51330
25	.51417	.124028	.48943
24	.48833	.112251	.46609
23	.46320	.101322	.44325
22	.43872	.091182	.42088
21	.41485	.081777	.39894
20	.39154	.073061	.37741
19	.36876	.064992	.35626
18	.34647	.057533	.33546
17	.32464	.050649	.31499
16	.30324	.044308	.29483
15	.28223	.038482	.27496
14	.26158	.033144	.25536
13	.24129	.028272	.23599
12	.22133	.023845	.21688
11	.20166	.019844	.19798
10	.18228	.016250	.17926
9	.16315	.013049	.16074
8	.14427	.010227	.14239
7	.12561	.007771	.12419
6	.10716	.005669	.10613
5	.08891	.003911	.08820
4	.07083	.002487	.07038
3	.05291	.001391	.05266
2	.03514	.000615	.03504
+1	.01751	.000153	.01749
	+	+	+
0	00000	000000	00000
	—	+	—
—1	.01740	.000152	.01743
2	.03470	.000604	.03481
3	.05192	.001356	.05216
4	.06906	.002405	.06949
5	.08614	.003749	.08681
6	.10317	.005388	.10413
7	.12016	.007324	.12146
8	.13712	.009557	.13882
9	.15406	.012088	.15620
10	.17099	.014921	.17363
11	.18792	.018058	.19111
12	.20486	.021506	.20866
13	.22182	.025266	.22628
14	.23881	.029345	.24400
15	.25584	.033752	.26181
16	.27293	.038491	.27972
17	.29009	.043572	.29777
18	.30731	.049003	.31595

γ = 0.18				γ = 0.19			
φ	X	Y	T	φ	X	Y	T
0				0			
19	.32461	.054794	.33428	49	1.99111	1.43884	1.47035
20	.34201	.060957	.35277	48	1.77459	1.19374	1.37775
21	.35952	.067503	.37143	47	1.62516	1.03053	1.30220
22	.37714	.074445	.39028	46	1.50785	.90683	1.23648
23	.39489	.081798	.40933	45	1.41005	.80725	1.17754
24	.41278	.089577	.42860	44	1.32559	.72422	1.12372
25	.43082	.097798	.44810	43	1.25093	.65335	1.07396
26	.44902	.106480	.46784	42	1.18384	.59185	1.02754
27	.46740	.115643	.48785	41	1.12277	.53780	.98395
28	.48596	.125306	.50814	40	1.06665	.48986	.94279
29	.50472	.135494	.52874	39	1.01466	.44698	.90376
30	.52369	.146230	.54964	38	.96619	.40841	.86659
31	.54289	.157541	.57089	37	.92074	.37353	.83109
32	.56233	.169455	.59249	36	.87792	.34184	.79707
33	.58203	.182004	.61448	35	.83742	.31293	.76442
34	.60200	.195220	.63687	34	.79897	.28650	.73298
35	.62225	.209139	.65968	33	.76235	.26227	.70267
36	.64280	.223799	.68294	32	.72737	.23999	.67337
37	.66367	.239242	.70668	31	.69388	.21945	.64501
38	.68487	.255514	.73093	30	.66173	.200513	.61752
39	.70642	.272661	.75572	29	.63080	.183011	.59082
40	.72835	.290737	.78107	28	.60098	.166821	.56487
41	.75066	.309797	.80702	27	.57219	.151832	.53960
42	.77339	.329903	.83361	26	.54434	.137944	.51496
43	.79654	.351120	.86088	25	.51736	.125070	.49092
44	.82014	.373521	.88886	24	.49117	.113135	.46742
45	.84421	.397179	.91760	23	.46572	.102069	.44444
46	.86878	.422181	.94714	22	.44096	.091811	.42194
47	.89386	.448617	.97754	21	.41683	.082304	.39988
48	.91949	.476583	1.00884	20	.39329	.073501	.37824
49	.94567	.506186	1.04111	19	.37029	.065357	.35699
50	.97245	.537542	1.07440	18	.34781	.057833	.33610
51	.99984	.570776	1.10878	17	.32581	.050895	.31555
52	1.02788	.606023	1.14431	16	.30425	.044507	.29532
53	1.05658	.643431	1.18108	15	.28310	.038641	.27538
54	1.08597	.683162	1.21916	14	.26233	.033270	.25572
55	1.11609	.725390	1.25864	13	.24192	.028371	.23630
56	1.14695	.770306	1.29962	12	.22185	.023921	.21713
57	1.17859	.818118	1.34221	11	.20209	.019901	.19819
58	1.21104	.869053	1.38650	10	.18263	.016292	.17943
59	1.24431	.923360	1.43162	9	.16343	.013079	.16088
60	1.27844	.981309	1.48072	8	.14448	.010247	.14249
				7	.12577	.007784	.12427
				6	.10728	.005676	.10619
				5	.08899	.003915	.08824
				4	.07088	.002490	.07040

γ = 0.19			
φ	X	Y	T
0			
3	.05294	.001392	.05268
2	.03516	.000615	.03504
+1	.01752	.000153	.01749
	+	+	+
0	00000	000000	00000
	—	+	—
—1	.01740	.000152	.01743
2	.03470	.000604	.03481
3	.05190	.001356	.05215
4	.06902	.002402	.06947
5	.08607	.003745	.08678
6	.10307	.005381	.10408
7	.12002	.007312	.12139
8	.13694	.009539	.13872
9	.15383	.012064	.15608
10	.17071	.014889	.17348
11	.18758	.018016	.19094
12	.20446	.021450	.20846
13	.22135	.025195	.22604
14	.23827	.029257	.24372
15	.25522	.033643	.26149
16	.27223	.038359	.27936
17	.28930	.043413	.29736
18	.30642	.048814	.31549
19	.32362	.054572	.33377
20	.34092	.060697	.35220
21	.35831	.067201	.37080
22	.37581	.074097	.38958
23	.39344	.081398	.40857
24	.41120	.089120	.42776
25	.42910	.097278	.44719
26	.44715	.105891	.46686
27	.46538	.114977	.48679
28	.48378	.124558	.50699
29	.50237	.134654	.52749
30	.52117	.145291	.54830
31	.54019	.156493	.56945
32	.55943	.168290	.59094
33	.57893	.180709	.61281
34	.59868	.193785	.63508
35	.61871	.207551	.05777
36	.63903	.222045	.68090
37	.65965	.237308	.70450
38	.68060	.253382	.72860
39	.70181	.270315	.75323
40	.72353	.288158	.77842
41	.74555	.306965	.80420
42	.76796	.326796	.83061

γ = 0.20			
φ	X	Y	T
0			
43	.79078	.347714	.85768
44	.81404	.369788	.88546
45	.83776	.393092	.91398
46	.86194	.417708	.94329
47	.88663	.443723	.97345
48	.91183	.471231	1.00449
49	.93758	.500335	1.03649
50	.96389	.531146	1.06949
51	.99079	.563785	1.10355
52	1.01831	.598384	1.13876
53	1.04646	.635083	1.17518
54	1.07528	.674038	1.21289
55	1.10479	.715418	1.25197
56	1.13502	.759406	1.29253
57	1.16599	.806203	1.33466
58	1.19773	.856028	1.37846
59	1.23025	.909118	1.42407
60	1.26359	.965730	1.47160

γ = 0.20			
φ	X	Y	T
0			
48	1.91475	1.33144	1.41840
47	1.71350	1.11151	1.33081
46	1.57159	.961847	1.25855
45	1.45917	.847381	1.19537
44	1.36498	.754766	1.13853
43	1.28336	.677277	1.08650
42	1.21103	.610979	1.03830
41	1.14590	.553344	.99328
40	1.08653	.502625	.95095
39	1.03190	.457578	.91093
38	.98123	.417263	.87294
37	.93394	.380962	.83673
36	.88956	.348113	.80210
35	.84771	.318258	.76891
34	.80810	.291027	.73700
33	.77047	.266113	.70627
32	.73460	.243260	.67660
31	.70032	.222250	.64791
30	.66748	202899	.62012
29	.63593	.185048	.59316
28	.60557	.168559	.56697
27	.57628	.153312	.54148
26	.54799	.139203	.51665
25	.52061	.126139	.49243

γ = 0.2			
φ	X	Y	T
0			
24	.49406	.114040	.46877
23	.46829	.102832	.44564
22	.44323	.092451	.42301
21	.41884	.082840	.40083
20	.39506	.073948	.37908
19	.37185	.065728	.35773
18	.34917	.058139	.33675
17	.32698	.051144	.31612
16	.30526	.044708	.29581
15	.28397	.038802	.27580
14	.26307	.033397	.25608
13	.24255	.028470	.23661
12	.22238	.023997	.21739
11	.20253	.019958	.19840
10	.18298	.016334	.17961
9	.16371	.013109	.16102
8	.14470	.010268	.14260
7	.12594	.007798	.12435
6	.10740	.005685	.10625
5	.08907	.003920	.08828
4	.07093	.002492	.07043
3	.05297	.001393	.05269
2	.03517	.000615	.03505
+1	.01752	.000153	.01749
	+	+	+
0	.00000	.000800	.00000
	—	+	—
—1	.01740	.000152	.01743
2	.03468	.000604	.03480
3	.05187	.001355	.05214
4	.06897	.002400	.06945
5	.08600	.003741	.08674
6	.10297	.005374	.10403
7	.11988	.007301	.12132
8	.13676	.009523	.13863
9	.15360	.012040	.15597
10	.17042	.014856	.17334
11	.18724	.017972	.19076
12	.20406	.021394	.20825
13	.22088	.025124	.22580
14	.23773	.029169	.24344
15	.25461	.033535	.26117
16	.27153	.038228	.27900
17	.28851	.043256	.29695
18	.30554	.048628	.31503
19	.32264	.054352	.33325
20	.33983	.060440	.35163
21	.35712	.066903	.37017

γ = 0.3			
φ	X	Y	T
0			
22	.37450	.073753	.38890
23	.39201	.081003	.40782
24	.40963	.088669	.42694
25	.42740	.096766	.44629
26	.44531	.105311	.46589
27	.46339	.114323	.48573
28	.48163	.123822	.50585
29	.50006	.133830	.52626
30	.51869	.144370	.54698
31	.53753	.155466	.56802
32	.55659	.167147	.58941
33	.57589	.179441	.61117
34	.59543	.192380	.63332
35	.61524	.205997	.65589
36	.63534	.220330	.67889
37	.65572	.235417	.70236
38	.77642	.251300	.72631
39	.69745	.268026	.75079
40	.71882	.285644	.77582
41	.74055	.304206	.80143
42	.76266	.323771	.82766
43	.78517	.344399	.85455
44	.80810	.366159	.88213
45	.83146	.389121	.91044
46	.85528	.813365	.93953
47	.87959	.438974	.96945
48	.90439	.466041	1.00025
49	.92971	.494666	1.03198
50	.95557	.524955	1.06469
51	.98201	.557024	1.09846
52	1.00903	.591001	1.13335
53	1.03667	.627024	1.16943
54	1.06494	.665241	1.20678
55	1.09388	.705815	1.24548
56	1.12350	.748922	1.28563
57	1.15383	.794754	1.32732
58	1.18489	.843521	1.37066
59	1.21671	.895452	1.41576
60	1.24931	.950797	1.46276

γ = 0.3			
φ	X	Y	T
0			
40	1.47905	.776117	1.08479
39	1.33120	.654103	1.01903
38	1.22128	.566599	.96308
37	1.13198	.498037	.91333

$\gamma = 0.3$

φ	X	Y	T
0			
36	1.05597	.441769	.86803
35	.98937	.394244	.82615
34	.92984	.353312	.78704
33	.87584	.317563	.75023
32	.82632	.286000	.71537
31	.78049	.257908	.68220
30	.73777	.232740	.65051
29	.69772	.210072	.62013
28	.65996	.189569	.59092
27	.62422	.170959	.56276
26	.59026	.154020	.53556
25	.55787	.138568	.50922
24	.52689	.124448	.48366
23	.49718	.111527	.45883
22	.46862	.099695	.43466
21	.44110	.088852	.41111
20	.41453	.078915	.38811
19	.38882	.069810	.36564
18	.36390	.061472	.34365
17	.33972	.053845	.32211
16	.31620	.046879	.30098
15	.29331	.040529	.28024
14	.27099	.034755	.25985
13	.24920	.029523	.23980
12	.22790	.024800	.22005
11	.20706	.020559	.20058
10	.18663	.016773	.18138
9	.16661	.013421	.16243
8	.14694	.010482	.14370
7	.12762	.007937	.12517
6	.10861	.005771	.10684
5	.08989	.003968	.08868
4	.07145	.002516	.07068
3	.05326	.001403	.05283
2	.03529	.000618	.03511
+1	.01755	.000153	.01750
	+	+	+
0	.00000	.000000	.00000
	−	+	−
−1	.01736	.000151	.01741
2	.03456	.000601	.03474
3	.05161	.001345	.05200
4	.06851	.002379	.06921
5	.08529	.003699	.08638
6	.10195	.005304	.10351
7	.11851	.007191	.12062
8	.13498	.009359	.13772
9	.15138	.011809	.15483

$\gamma = 0.3$

φ	X	Y	T
0			
10	.16770	.014542	.17194
11	.18398	.017557	.18908
12	.20020	.020858	.20826
13	.21639	.024448	.22347
14	.23256	.028329	.24075
15	.24871	.032506	.25809
16	.26485	.036984	.27551
17	.28100	.041768	.29302
18	.29717	.046866	.31064
19	.31336	.052284	.32836
20	.32958	.058029	.34622
21	.34585	.064112	.36421
22	.36218	.070542	.38235
23	.37856	.077330	.40065
24	.39502	.084486	.41914
25	.41156	.092025	.43781
26	.42819	.099959	.45669
27	.44493	.108304	.47579
28	.46178	.117075	.49512
29	.47875	.126290	.51470
30	.49585	.135967	.53455
31	.51310	.146127	.55469
32	.53050	.156791	.57513
33	.54807	.167983	.59589
34	.56581	.179727	.61699
35	.58374	.192050	.63846
36	.60187	.204982	.66031
37	.62020	.218553	.68257
38	.63876	.232796	.70525
39	.65756	.247748	.72840
40	.67660	.263447	.75203
41	.69590	.279935	.77616
42	.71548	.297255	.80085
43	.73534	.315457	.02610
44	.75550	.334591	.85196
45	.77597	.354713	.87847
46	.79678	.375883	.90565
47	.81792	.398164	.93356
48	.83942	.421628	.96224
49	.86129	.446352	.99172
50	.88355	.472413	1.02207
51	.90620	.499900	1.05334
52	.92928	.528908	1.08557
53	.95278	.559539	1.11885
54	.97672	.591904	1.15322
55	1.00113	.626124	1.18876
56	1.02601	.662329	1.22556
57	1.05137	.700659	1.26368

$\gamma = 0.3$			
φ	X	Y	T
0			
58	1.07724	.741270	1.30323
59	1.10362	.784329	1.34430
60	1.13053	.830018	1.38701

$\gamma = 0.4$			
φ	X	Y	T
0			
34	1.21572	.514384	.88133
33	1.08894	.430379	.82498
32	.99383	.369734	.77669
31	.91614	.322101	.73351
30	.84976	.282981	.69402
29	.79141	.249954	.65735
28	.73911	.221543	.62298
27	.69155	.196775	.59050
26	.64781	.174966	.55963
25	.60726	.155615	.53015
24	.56937	.138345	.50189
23	.53377	.122862	.47471
22	.50015	.108932	.44849
21	.46826	.096367	.42313
20	.43789	.085011	.39855
19	.40888	.074735	.37468
18	.38108	.065432	.35146
17	.35437	.057009	.32882
16	.32865	.049387	.30672
15	.30382	.042499	.28511
14	.27980	.036286	.26396
13	.25653	.030697	.24324
12	.23393	.025686	.22289
11	.21196	.021215	.20291
10	.19056	.017248	.18326
9	.16969	.013755	.16391
8	.14931	.010709	.14484
7	.12938	.008085	.12602
6	.10987	.005861	.10745
5	.09075	.004019	.08910
4	.07198	.002541	.07094
3	.05355	.001413	.05297
2	.03542	.000621	.03517
+1	.01758	.000154	.01752
	+	+	+
0	.00000	.000000	.00000
	—	+	—
—1	.01733	.000151	.01739
2	.03444	.000599	.03468
3	.05135	.001337	.05187

$\gamma = 0.4$			
φ	X	Y	T
0			
4	.06806	.002358	.06898
5	.08459	.003660	.08602
6	.10097	.005236	.10301
7	.11719	.007085	.11995
8	.13329	.009203	.13685
9	.14926	.011590	.15373
10	.16312	.014245	.17061
11	.18089	.017168	.18748
12	.19658	.020359	.20436
13	.21219	.023820	.22127
14	.22774	.027553	.23821
15	.24323	.031560	.25520
16	.25869	.035846	.27224
17	.27411	.040415	.28935
18	.28951	.045270	.30654
19	.30490	.050419	.32382
20	.32028	.055867	.34121
21	.33567	.061621	.35870
22	.35108	.067690	.87633
23	.36651	.074082	.39409
24	.38197	.080806	.41201
25	.39748	.087874	.43009
26	.41304	.095296	.44834
27	.42866	.103084	.46679
28	.44436	.111252	.48545
29	.46013	.119815	.50433
30	.47599	.128787	.52344
31	.49194	.138186	.54281
32	.50800	.148030	.56245
33	.52418	.158337	.58237
34	.54048	.169128	.60260
35	.55692	.180427	.62316
36	.57351	.192256	.64405
37	.59024	.204642	.66532
38	.60715	.217613	.68697
39	.62422	.231196	.20903
40	.64148	.245426	.73152
41	.65894	.260335	.75448
42	.67660	.275961	.77792
43	.69447	.292342	.80188
44	.71258	.309522	.82638
45	.73091	.327545	.85147
46	.74950	.346460	.87716
47	.76835	.366321	.90351
48	.78746	.387184	.93055
49	.80686	.409110	.95832
50	.82654	.432165	.98686
51	.84654	.456419	1.01623

$\gamma = 0.4$

φ °	X	Y	T
52	.86684	.481950	1.04647
53	.88747	.508840	1.07765
54	.90844	.537178	1.10981
55	.92975	.567061	1.14302
56	.95142	.598594	1.17736
57	.97346	.631891	1.21290
58	.99587	.667075	1.24971
59	1.01866	.704281	1.28789
60	1.04185	.743656	1.32753

$\gamma = 0.5$

φ °	X	Y	T
29	0.98413	.338743	.72106
28	.88201	.283238	.67306
27	.80260	.241866	.63110
26	.73635	.208903	.59316
25	.67940	.181643	.55818
24	.62877	.158557	.52552
23	.58309	.138689	.49473
22	.54135	.121390	.46551
21	.50280	.106200	.43763
20	.46691	.092779	.41092
19	.43328	.080866	.38521
18	.40158	.070258	.36041
17	.37157	.060791	.33641
16	.34303	.052335	.31314
15	.31579	.044778	.29051
14	.28971	.038031	.26847
13	.26466	.032017	.24697
12	.24055	.026670	.22596
11	.21728	.021935	.20539
10	.19478	.017764	.18524
9	17298	.014114	.16546
8	.15181	.010950	.14603
7	.13123	.008240	.12691
6	.11118	.005955	.10808
5	.09163	.004071	.08953
4	.07253	.002567	.07121
3	.05385	.001424	.05312
2	.03555	.000625	.03523
+1	.01761	.000154	.01753
	+	+	+
0	.00000	.000000	.00000

$\gamma = 0.5$

φ °	X	Y	T
—1	.01731	.000151	.01738
2	.03433	.000596	.03462
3	.05109	.001328	.05174
4	.06761	.002338	.06876
5	.08392	.003621	.08568
6	.10001	.005170	.10252
7	.11592	.006982	.11929
8	.13166	.009054	.13600
9	.14724	.011382	.15268
10	.16267	.013965	.16932
11	.17798	.016801	.18594
12	.19316	.019891	.20255
13	.20824	.023234	.21917
14	.22323	.026832	.23580
15	.23813	.030687	.25246
16	.25297	.034800	.26916
17	.26774	.039175	.28590
18	.28245	.043816	.30271
19	.29713	.048726	.31959
20	.31178	.053912	.33655
21	.32640	.059379	.35360
22	.34101	.065134	.37077
23	.35561	.071183	.38805
24	.37022	.077535	.40546
25	.38484	.084199	.42301
26	.39949	.091184	.44073
27	.41416	.098500	.45861
28	.42887	.106160	.47668
29	.44363	.114174	.49494
30	.45845	.122557	.51342
31	.47333	.131323	.53212
32	.48828	.140488	.55107
33	.50332	.150067	.57028
34	.51844	.160078	.58976
35	.53367	.170541	.60954
36	.54900	.181477	.62963
37	.56444	.192907	.65006
38	.58001	.204854	.67084
39	.59572	.217346	.69199
40	.61156	.230407	.71355
41	.62755	.244069	.73552
42	.64371	.258361	.75794
43	.66003	.273319	.78083
44	.67653	.288977	.80423
45	.69322	.305375	.82815
46	.71010	.322553	.85264
47	.72718	.340558	.87773
48	.74448	.359438	.90345

$\gamma = 0.5$			
φ	X	Y	T
°			
49	.76200	.379244	.92984
50	.77975	.400031	.95695
51	.79775	.421860	.98481
52	.81599	.444796	1.01348
53	.83449	.468910	1.04300
54	.85326	.494277	1.07343
55	.87230	.520978	1.10482
56	.89163	.549103	1.13725
57	.91124	.578748	1.17078
58	.93116	.610016	1.20548
59	.95139	.643023	1.24144
60	.97192	.677892	1.27875

$\gamma = 0.6$			
φ	X	Y	T
°			
26	.93344	.290751	.65330
25	.81202	.232737	.60239
24	.72613	.193554	.55987
23	.65771	.163783	.52220
22	.60003	.139873	.48786
21	.54972	.120045	.45602
20	.50484	.103259	.42614
19	.46416	.088847	.39788
18	.42683	.076352	.37096
17	.39225	.065444	.34520
16	.35997	.055877	.32044
15	.32963	.047462	.29657
14	.30098	.040049	.27347
13	.27378	.033518	.25101
12	.24787	.027773	.22928
11	.22310	.022731	.20806
10	.19934	.018327	.18735
9	.17649	.014502	.16711
8	.15446	.011208	.14728
7	.13317	.008403	.12783
6	.11255	.006053	.10874
5	.09254	.004125	.08997
4	.07309	.002594	.07148
3	.05415	.001435	.05327
2	.03568	.000628	.03530
+1	.01764	.000155	.01755
	+	+	+
0	.00000	.000000	.00000

$\gamma = 0.6$			
φ	X	Y	T
°			
—1	.01728	.000150	.01736
2	.03421	.000593	.03456
3	.05084	.001319	.05162
4	.06718	.002318	.06854
5	.08326	.003583	.08534
6	.09909	.005107	.10204
7	.11469	.006885	.11865
8	.13009	.008911	.13518
9	.14530	.011184	.15166
10	.16033	.013699	.16808
11	.17520	.016456	.18446
12	.18993	.019452	.20083
13	.20452	.022687	.21717
14	.21899	.026161	.23352
15	.23336	.029876	.24987
16	.24763	.033833	.26625
17	.26181	.038034	.28266
18	.27592	.042483	.29911
19	.28996	.047181	.31562
20	.30395	.052135	.33219
21	.31789	.057348	.34885
22	.33180	.062826	.36559
23	.34568	.068575	.38244
24	.35954	.074602	.39940
25	.37339	.080915	.41649
26	.38724	.087522	.43372
27	.40110	.094432	.45109
28	.41498	.101655	.46864
29	.42887	.109202	.48636
30	.44280	.117084	.50428
31	.45677	.125314	.52240
32	.47079	.133905	.54075
33	.48487	.142872	.55933
34	.49901	.152230	.57817
35	.51322	.161997	.59728
36	.52751	.172191	.61668
37	.54188	.182830	.63638
38	.55635	.193936	.65642
39	.57093	.205531	.67680
40	.58562	.217638	.69755
41	.60042	.230284	.71869
42	.61535	.243495	.74024
43	.63042	.257303	.76224
44	.64563	.271737	.78470
45	.66099	.286833	.80766
46	.67651	.302626	.83114
47	.69219	.319156	.85518
48	.70805	.336465	.87981

φ	X	Y	T
	$\gamma = 0.6$		
0			
49	.72409	.354598	.90506
50	.74032	.373604	.93098
51	.75675	.393535	.95760
52	.77339	.414449	.98497
53	.79023	.436408	1.01314
54	.80730	.459477	1.04216
55	.82460	.483727	1.07208
56	.84213	.509237	1.10297
57	.85990	.536090	1.13488
58	.87792	.564378	1.16789
59	.89619	.594199	1.20207
60	.91472	.625663	1.23751

φ	X	Y	T
	$\gamma = 0.7$		
0			
23	.81319	.220114	.56922
22	.70121	.173643	.52145
21	.62208	.142434	.48153
20	.55903	.118842	.44613
19	.50586	.099998	.41382
18	.45945	.084464	.38381
17	.41804	.071399	.35562
16	.38047	.060267	.32892
15	.34598	.050697	.30346
14	.31401	.042424	.27906
13	.28414	.035250	.25558
12	.25606	.029022	.23291
11	.22951	.023619	.21094
10	.20430	.018945	.18961
9	.18027	.014921	.16885
8	.15728	.011483	.14859
7	.13521	.008577	.12880
6	.11397	.006156	.10942
5	.09348	.004182	.09042
4	.07366	.002621	.07176
3	.05446	.001446	.05342
2	.03581	.000631	.03536
+1	.01767	.000155	.01756
	+	+	+
0	.00000	.000000	.00000
	—	+	—
—1	.01725	.000150	.01735
2	.03410	.000591	.03451
3	.05059	.001310	.05149

φ	X	Y	T
	$\gamma = 0.7$		
0			
4	.06676	.002299	.06832
5	.08262	.003546	.08500
6	.09819	.005045	.10157
7	.11351	.006790	.11802
8	.12859	.008775	.13439
9	.14344	.010996	.15067
10	.15810	.013448	.16688
11	.17257	.016129	.18305
12	.18687	.019038	.19917
13	.20101	.022174	.21526
14	.21501	.025535	.23134
15	.22888	.029123	.24741
16	.24264	.032938	.26349
17	.25629	.036981	.27959
18	.26985	.041255	.29572
19	.28332	.045763	.31189
20	.29672	.050509	.32811
21	.31006	.055495	.34440
22	.32334	.060728	.36076
23	.33658	.066211	.37722
24	.34978	.071952	.39377
25	.36296	.077958	.41044
26	.37612	.084234	.42723
27	.38927	.090790	.44415
28	.40241	.097634	.46123
29	.41557	.104776	.47847
30	.42873	.112225	.49589
31	.44192	.119994	.51350
32	.45514	.128094	.53131
33	.46839	.136539	.54935
34	.48169	.145341	.56762
35	.49504	.154518	.58614
36	.50845	.164083	.60494
37	.52193	.174056	.62401
38	.53548	.184453	.64340
39	.54911	.195297	.66311
40	.56283	.206607	.68316
41	.57664	.218407	.70359
42	.59056	.230721	.72440
43	.60459	.243577	.74562
44	.61874	.257001	.76728
45	.63301	.271025	.78941
46	.64741	.285682	.81203
47	.66195	.301005	.83517
48	.67663	.317034	.85887
49	.69147	.333809	.88316
50	.70647	.351373	.90807
51	.72164	.369773	.93365

$\gamma = 0.7$

φ°	X	Y	T
52	.73698	.389060	.95994
53	.75250	.409288	.98698
54	.76821	.430517	1.01481
55	.78411	.452812	1.04350
56	.80021	.476241	1.07310
57	.81651	.500878	1.10366
58	.83303	.526806	1.13527
59	.84976	.554113	1.16797
60	.86671	.582897	1.20187

$\gamma = 0.8$

φ°	X	Y	T
20	.65361	.147646	.47637
19	.56945	.117797	.43575
18	.50514	.096255	.40043
17	.45205	.079501	.36852
16	.40632	.065947	.33906
15	.36587	.054722	.31149
14	.32942	.045287	.28544
13	.29609	.037282	.26064
12	.26531	.030454	.23690
11	.23663	.024617	.21407
10	.20973	.019628	.19203
9	.18435	.015379	.17069
8	.16028	.011780	.14997
7	.13737	.008761	.12980
6	.11546	.006264	.11012
5	.09446	.004240	.09088
4	.07426	.002649	.07205
3	.05478	.001457	.05357
2	.03595	.000634	.03543
+1	.01771	.000155	.01758
	+	+	+
0	.00000	.000000	.00000
	−	+	−
−1	.01722	.000150	.01734
2	.03399	.000588	.03445
3	.05035	.001302	.05137
4	.06634	.002279	.06810
5	.08199	.003510	.08468
6	.09732	.004986	.10111
7	.11236	.006699	.11742
8	.12713	.008644	.13361
9	.14166	.010815	.14971

$\gamma = 0.8$

φ°	X	Y	T
10	.15596	.013207	.16573
11	.17005	.015819	.18168
12	.18395	.018647	.19758
13	.19768	.021690	.21343
14	.21125	.024947	.22926
15	.22467	.028418	.24507
16	.23795	.032103	.26087
17	.25112	.036002	.27668
18	.26418	.040119	.29251
19	.27713	.044454	.30836
20	.29000	.049012	.32426
21	.30280	.053795	.34022
22	.31552	.058808	.35624
23	.32819	.064055	.37233
24	.34081	.069541	.38851
25	.35339	.075274	.40480
26	.36593	.081258	.42119
27	.37846	.087501	.43771
28	.39096	.094012	.45437
29	.40346	.100799	.47118
30	.41596	.107871	.48815
31	.42847	.115238	.50530
32	.44099	.122912	.52263
33	.45353	.130904	.54018
34	.46611	.139227	.55794
35	.47872	.147894	.57594
36	.49137	.156920	.59420
37	.50408	.166321	.61272
38	.51684	.176114	.63154
39	.52967	.186317	.65065
40	.54256	.196950	.67010
41	.55554	.208032	.68989
42	.56860	.219588	.71005
43	.58175	.231640	.73060
44	.59500	.244215	.75156
45	.60836	.257340	.77297
46	.62182	.271045	.79484
47	.63541	.285361	.81721
48	.64911	.300323	.84011
49	.66295	.315968	.86357
50	.67693	.332335	.88762
51	.69105	.349466	.91230
52	.70532	.367408	.93765
53	.71975	.386211	.96372
54	.73434	.405928	.99055
55	.74903	.426617	1.01818
56	.76402	.448342	1.04668
57	.77913	.471171	1.07611

$\gamma = 0.8$

φ	X	Y	T
0			
58	.79442	.495177	1.10652
59	.80990	.520441	1.13798
60	.82557	.547052	1.17057

$\gamma = 0.9$

φ	X	Y	T
0			
18	.58115	.116911	.42469
17	.50159	.091787	.38566
16	.44103	.073825	.35177
15	.39111	.059967	.32114
14	.34815	.048848	.29286
13	.31016	.039721	.26638
12	.27592	.032124	.24134
11	.24462	.025753	.21749
10	.21571	.020391	.19464
9	.18878	.015880	.17266
8	.16350	.012100	.15142
7	.13964	.008958	.13084
6	.11702	.006378	.11084
5	.09547	.004301	.09136
4	.07486	.002678	.07234
3	.05510	.001468	.05373
2	.03608	.000637	.03549
+1	.01774	.000156	.01760
	+	+	+
0	.00000	.000000	.00000
	—	+	—
—1	.01719	.000149	.01732
2	.03388	.000586	.03439
3	.05011	.001294	.05124
4	.06593	.002261	.06789
5	.08137	.003476	.08436
6	.09647	.004929	.10067
7	.11125	.006612	.11683
8	.12573	.008518	.13287
9	.13994	.010642	.14879
10	.15391	.012979	.16462
11	.16765	.015525	.18037
12	.18118	.018278	.19605
13	.19452	.021235	.21168
14	.20769	.024395	.22727
15	.22069	.027758	.24283
16	.23354	.031323	.25837
17	.24627	.035091	.27392
18	.25887	.039064	.28946

$\gamma = 0.9$

φ	X	Y	T
0			
19	.27136	.043242	.30503
20	.28375	.047630	.32063
21	.29605	.052229	.33628
22	.30827	.057044	.35198
23	.32043	.062078	.36774
24	.33252	.067337	.38359
25	.34456	.072825	.39952
26	.35656	.078549	.41555
27	.36853	.084515	.43170
28	.38047	.090731	.44797
29	.39239	.097204	.46439
30	.40430	.103943	.48095
31	.41621	.110957	.49768
32	.42812	.118256	.51460
33	.44004	.125851	.53170
34	.45198	.133754	.54901
35	.46395	.141977	.56655
36	.47595	.150534	.58432
37	.48798	.159440	.60235
38	.50006	.168709	.62065
39	.51219	.178358	.63924
40	.52438	.188406	.65815
41	.53663	.198872	.67738
42	.54896	.209775	.69696
43	.56136	.221139	.71692
44	.57384	.232987	.73727
45	.58642	.245343	.75804
46	.59908	.258236	.77925
47	.61185	.271695	.80094
48	.62473	.285751	.82313
49	.63773	.300438	.84586
50	.65084	.315792	.86916
51	.66408	.331853	.89306
52	.67745	.348663	.91760
53	.69096	.366268	.94282
54	.70461	.384717	.96877
55	.71840	.404062	.99550
56	.73235	.424362	1.02305
57	.74646	.445681	1.05148
58	.76073	.468086	1.08086
59	.77517	.491651	1.11124
60	.78978	.516458	1.14271

$\gamma = 1.0$			
φ^{0}	X	Y	T
17	.59414	.116140	.41265
16	.49357	.086268	.36907
15	.42541	.067336	.33331
14	.37195	.053493	.30177
13	.32720	.042738	.27303
12	.28832	.034111	.24635
11	.25371	.027063	.22127
10	.22236	.021249	.19749
9	.19361	.016433	.17477
8	.16696	.012447	.15297
7	.14206	.009167	.13194
6	.11865	.006498	.11160
5	.09652	.004365	.09185
4	.07549	.002708	.07263
3	.05543	.001480	.05389
2	.03622	.000640	.03556
+1	.01777	.000156	.01761
	+	+	+
0	.00000	.000000	.00000
	—	+	—
—1	.01716	.000149	.01731
2	.03377	.000583	.03434
3	.04988	.001286	.05112
4	.06554	.002243	.06768
5	.08078	.003442	.08405
6	.09565	.004873	.10023
7	.11017	.006527	.11625
8	.12438	.008397	.13214
9	.13830	.010477	.14790
10	.15195	.012762	.16355
11	.16536	.015246	.17910
12	.17854	.017928	.19458
13	.19152	.020805	.21000
14	.20431	.023876	.22537
15	.21693	.027138	.24069
16	.22938	.030593	.25600
17	.24170	.034240	.27129
18	.25388	.038081	.28657
19	.26594	.042117	.30187
20	.27789	.046349	.31720
21	.28975	.050781	.33255
22	.30151	.055416	.34796
23	.31320	.060258	.36342
24	.32482	.065311	.37895
25	.33639	.070580	.39456
26	.34790	.076070	.41026
27	.35936	.081788	.42607

$\gamma = 1.0$			
φ^{0}	X	Y	T
28	.37080	.087740	.44199
29	.38220	.093933	.45805
30	.39359	.100375	.47425
31	.40496	.107075	.49060
32	.41633	.114043	.50712
33	.42770	.121287	.52383
34	.43908	.128820	.54073
35	.45048	.136652	.55784
36	.46190	.144797	.57518
37	.47334	.153267	.59276
38	.48482	.162077	.61061
39	.49635	.171242	.62873
40	.50791	.180780	.64714
41	.51954	.190708	.66588
42	.53122	.201044	.68494
43	.54297	.211810	.70436
44	.55479	.223027	.72417
45	.56669	.234719	.74437
46	.57867	.246911	.76500
47	.59074	.259631	.78609
48	.60290	.272908	.80766
49	.61517	.286772	.82974
50	.62754	.301258	.85236
51	.64002	.316402	.87557
52	.65262	.332243	.89939
53	.66534	.348823	.92387
54	.67819	.366188	.94905
55	.69117	.384389	.97497
56	.70429	.403479	1.00169
57	.71755	.423515	1.02926
58	.73095	.444561	1.05773
59	.74451	.466686	1.08717
60	.75822	.489965	1.11765

$\gamma = 1.1$			
φ^{0}	X	Y	T
15	.47885	.079331	.35022
14	.40438	.060032	.31302
13	.34871	.046645	.28098
12	.30320	.036544	.25212
11	.26422	.028605	.22551
10	.22985	.022228	.20060
9	.19892	.017049	.17704
8	.17069	.012826	.15460
7	.14463	.009392	.13309

γ = 1.1			
φ	X	Y	T
0			
6	.12037	.006625	.11238
5	.09761	.004432	.09236
4	.07613	.002739	.07294
3	.05576	.001492	.05405
2	.03636	.000643	.03563
+1	.01780	.000156	.01763
	+	+	+
0	.00000	.000000	.00000
	—	+	—
—1	.01713	.000149	.01729
2	.03366	.000580	.03428
3	.04965	.001278	.05100
4	.06515	.002225	.06748
5	.08020	.003409	.08374
6	.09485	.004819	.09980
7	.10913	.006446	.11569
8	.12308	.008281	.13143
9	.13671	.010319	.14703
10	.15007	.012554	.16251
11	.16317	.014981	.17788
12	.17602	.017596	.19317
13	.18867	.020398	.20839
14	.20111	.023385	.22354
15	.21337	.026555	.23865
16	.22546	.029907	.25372
17	.23739	.033443	.26878
18	.24919	.037162	.28382
19	.26086	.041066	.29887
20	.27241	.045156	.31393
21	.28385	.049436	.32903
22	.29521	.053907	.34415
23	.30647	.058574	.35933
24	.31767	.063441	.37457
25	.32879	.068511	.38989
26	.33986	.073790	.40528
27	.35088	.079283	.42078
28	.36185	.084998	.43638
29	.37280	.090939	.45211
30	.38371	.097116	.46797
31	.39461	.103535	.48397
32	.40550	.110206	.50014
33	.41638	.117138	.51648
34	.42726	.124340	.53301
35	.43815	.131825	.54973
36	.44905	.139603	.56668
37	.45998	.147688	.58386
38	.47093	.156092	.60128
39	.48191	.164829	.61898

γ = 1.2			
φ	X	Y	T
0			
40	.49293	.173917	.63695
41	.50400	.183370	.65523
42	.51512	.193208	.67383
43	.52630	.203449	.69277
44	.53753	.214114	.71208
45	.54884	.225224	.73178

γ = 1.2			
φ	X	Y	T
0			
14	.45528	.070755	.32871
13	.37770	.052079	.29093
12	.32169	.039641	.25892
11	.27662	.030459	.23031
10	.23836	.023359	.20403
9	.20481	.017738	.17950
8	.17474	.013240	.15635
7	.14738	.009634	.13431
6	.12218	.006760	.11320
5	.09874	.004501	.09288
4	.07679	.002772	.07325
3	.05610	.001504	.05421
2	.03650	.000647	.03570
+1	.01783	.000157	.01764
	+	+	+
0	.00000	.000000	.00000
	—	+	—
—1	.01710	.000148	.01728
2	.03355	.000578	.03423
3	.04942	.001270	.05088
4	.06476	.002208	.06728
5	.07963	.003377	.08344
6	.09407	.004767	.09939
7	.10812	.006367	.11515
8	.12181	.008169	.13074
9	.13518	.010167	.14618
10	.14826	.012354	.16150
11	.16106	.014727	.17670
12	.17361	.017280	.19181
13	.18593	.020012	.20683
14	.19805	.022921	.22178
15	.20997	.026004	.23668
16	.22172	.029262	.25154
17	.23331	.032694	.26637
18	.24474	.036300	.28119

φ	$\gamma = 1.2$ X	Y	T
°			
19	.25605	.040083	.29600
20	.26723	.044043	.31082
21	.27830	.048182	.32566
22	.28927	.052504	.34054
23	.30015	.057011	.35545
24	.31095	.061706	.37042
25	.32168	.066595	.38546
26	.33235	.071682	.40058
27	.34296	.076973	.41578
28	.35352	.082472	.43109
29	.36404	.088186	.44651
30	.37454	.094123	.46206
31	.38501	.100289	.47775
32	.39546	.106693	.49359
33	.40589	.113343	.50959
34	.41633	.120250	.52577
35	.42677	.127423	.54215
36	.43721	.134874	.55874
37	.44767	.142614	.57554
38	.45815	.150655	.59259
39	.46866	.159012	.60989
40	.47919	.167699	.62747
41	.48977	.176732	.64534
42	.50039	.186127	.66351
43	.51105	.195902	.68202
44	.52178	.206078	.70088
45	.53256	.216674	.72012

φ	$\gamma = 1.3$ X	Y	T
°			
13	.42223	.060781	.30459
12	.34604	.043839	.26731
11	.29172	.032765	.23591
10	.24823	.024693	.20790
9	.21141	.018522	.18220
8	.17917	.013699	.15822
7	.15032	.009896	.13558
6	.12408	.006903	.11405
5	.09993	.004574	.09342
4	.07748	.002805	.07357
3	.05645	.001517	.05438
2	.03664	.000650	.03577
+1	.01787	.000157	.01766
	+	+	+

φ	$\gamma = 1.3$ X	Y	T
°			
0	.00000	.000000	.00000
	—	+	—
—1	.01707	.000148	.01726
2	.03345	.000576	.03417
3	.04919	.001262	.05077
4	.06438	.002191	.06708
5	.07907	.003346	.08314
6	.09331	.004716	.09898
7	.10713	.006291	.11461
8	.12059	.008061	.13007
9	.13370	.010021	.14536
10	.14651	.012164	.16052
11	.15903	.014484	.17556
12	.17129	.016979	.19048
13	.18332	.019645	.20532
14	.19513	.022480	.22009
15	.20674	.025483	.23479
16	.21817	.028652	.24945
17	.22943	.031988	.26407
18	.24054	.035490	.27867
19	.25151	.039160	.29326
20	.26235	.042999	.30785
21	.27308	.047009	.32246
22	.28370	.051193	.33710
23	.29423	.055553	.35177
24	.30467	.060092	.36648
25	.31503	.064816	.38126
26	.32533	.069727	.39612
27	.33556	.074832	.41105
28	.34575	.080135	.42608
29	.35589	.085643	.44122
30	.36600	.091361	.45648
31	.37608	.097298	.47188
32	.38614	.103460	.48741
33	.39618	.109856	.50311
34	.40621	.116496	.51898
35	.41623	.123388	.53503
36	.42627	.130543	.55128
37	.43630	.137973	.56775
38	.44636	.145689	.58445
39	.45644	.153704	.60140
40	.46654	.162032	.61860
41	.47667	.170687	.63609
42	.48684	.179686	.65388
43	.49705	.189046	.67199
44	.50732	.198785	.69045
45	.51763	.208921	.70926

$\gamma = 1.4$

φ	X	Y	T
0			
12	.38169	.050213	.27842
11	.31095	.035777	.24262
10	.25994	.026303	.21230
9	.21890	.019424	.18517
8	.18405	.014209	.16024
7	.15350	.010180	.13695
6	.12610	.007054	.11495
5	.10116	.004650	.09399
4	.07818	.002839	.07390
3	.05681	.001530	.05455
2	.03678	.000654	.03584
+1	.01790	.000158	.01768
	+	+	+
0	.00000	.000000	.00000
	—	+	—
—1	.01705	.000148	.01725
2	.03334	.000573	.03412
3	.04897	.001255	.05065
4	.06401	.002174	.06689
5	.07853	.003316	.08285
6	.09257	.004667	.09857
7	.10618	.006217	.11409
8	.11940	.007958	.12941
9	.13227	.009881	.14457
10	.14482	.011981	.15957
11	.15708	.014252	.17445
12	.16907	.016692	.18921
13	.18082	.019296	.20388
14	.19234	.022062	.21846
15	.20366	.024989	.23298
16	.21479	.028075	.24745
17	.22575	.031321	.26187
18	.23655	.034726	.27627
19	.24721	.038292	.29065
20	.25774	.042019	.30503
21	.26814	.045909	.31941
22	.27844	.049965	.33382
23	.28864	.054190	.34826
24	.29874	.058585	.36275
25	.30877	.063156	.37729
26	.31873	.067907	.39190
27	.32863	.072841	.40658
28	.33847	.077965	.42136
29	.34827	.083283	.43624
30	.35802	.088803	.45123
31	.36775	.094530	.46635
32	.37744	.100472	.48161
33	.38712	.106637	.49701

$\gamma = 1.5$

φ	X	Y	T
0			
34	.39678	.113034	.51259
35	.40644	.119671	.52834
36	.41610	.126558	.54429
37	.42576	.133707	.56044
38	.43543	.141129	.57682
39	.44511	.148835	.59344
40	.45482	.156838	.61031
41	.46456	.165154	.62745
42	.47433	.173796	.64489
43	.48413	.182782	.66263
44	.49398	.192127	.68070
45	.50387	.201853	.69913

$\gamma = 1.5$

φ	X	Y	T
0			
11	.33734	.040046	.25112
10	.27427	.028320	.21743
9	.22753	.020482	.18848
8	.18946	.014783	.16243
7	.15692	.010491	.13839
6	.12824	.007218	.11588
5	.10245	.004731	.09457
4	.07891	.002875	.07423
3	.05717	.001543	.05472
2	.03693	.000657	.03591
+1	.01793	.000158	.01769
	+	+	+
0	.00000	.000000	.00000
	—	+	—
—1	.01702	.000147	.01723
2	.03324	.000571	.03406
3	.04875	.001248	.05054
4	.06365	.002158	.06669
5	.07799	.003286	.08256
6	.09184	.004619	.09818
7	.10525	.006146	.11358
8	.11825	.007857	.12877
9	.13089	.009746	.14379
10	.14320	.011805	.15865
11	.15521	.014030	.17338
12	.16694	.016417	.18798
13	.17842	.018962	.20248
14	.18968	.021664	.21689
15	.20072	.024520	.23123

$\gamma = 1.6$

φ °	X	Y	T
16	.21157	.027529	.24551
17	.22225	.030690	.25975
18	.23276	.034005	.27396
19	.24312	.037474	.28814
20	.25336	.041097	.30232
21	.26346	.044876	.31650
22	.27346	.048813	.33069
23	.28336	.052912	.34492
24	.29316	.057175	.35918
25	.30288	.061605	.37350
26	.31253	.066207	.38787
27	.32211	.070985	.40232
28	.33164	.075944	.41686
29	.34111	.081089	.43149
30	.35054	.086426	.44624
31	.35994	.091961	.46110
32	.36931	.097702	.47610
33	.37865	.103655	.49124
34	.38798	.109830	.50654
35	.39730	.116235	.52201
36	.40662	.122878	.53768
37	.41593	.129772	.55354
38	.42525	.136925	.56962
39	.43459	.144350	.58593
40	.44394	.152059	.60248
41	.45331	.160066	.61931
42	.46271	.168385	.63641
43	.47215	.177032	.65382
44	.48162	.186022	.67154
45	.49114	.195375	.68961

$\gamma = 1.6$

φ °	X	Y	T
10	.29272	.030982	.22363
9	.23770	.021749	.19224
8	.19554	.015433	.16483
7	.16064	.010830	.13994
6	.13051	.007392	.11686
5	.10380	.004815	.09517
4	.07966	.002912	.07458
3	.05755	.001557	.05490
2	.03708	.000661	.03598
+1	.01797	.000158	.01771
	+	+	+

$\gamma = 1.6$

φ °	X	Y	T
0	.00000	.000000	.00000
	−	+	−
−1	.01699	.000147	.01722
2	.03313	.000569	.03401
3	.04854	.001240	.05042
4	.06330	.002142	.06650
5	.07748	.003257	.08228
6	.09114	.004572	.09780
7	.10435	.006076	.11308
8	.11714	.007760	.12815
9	.12956	.009615	.14304
10	.14164	.011636	.15776
11	.15341	.013817	.17234
12	.16490	.016154	.18679
13	.17613	.018644	.20113
14	.18713	.021285	.21538
15	.19791	.024073	.22955
16	.20850	.027010	.24366
17	.21891	.030093	.25772
18	.22915	.033323	.27174
19	.23925	.036700	.28573
20	.24921	.040226	.29972
21	.25904	.043902	.31370
22	.26876	.047730	.32770
23	.27837	.051712	.34172
24	.28789	.055851	.35578
25	.29733	.060151	.36988
26	.30669	.064616	.38404
27	.31598	.069249	.39827
28	.32522	.074055	.41258
29	.33440	.079040	.42699
30	.34353	.084209	.44150
31	.35263	.089568	.45612
32	.36169	.095123	.47088
33	.37073	.100883	.48577
34	.37976	.106854	.50082
35	.38876	.113046	.51603
36	.39777	.119466	.53142
37	.40676	.126125	.54702
38	.41577	.133033	.56282
39	.42478	.140201	.57884
40	.43380	.147642	.59511
41	.44285	.155368	.61163
42	.45192	.163392	.62843
43	.46102	.171730	.64552
44	.47015	.180397	.66293
45	.47932	.189410	.68067

$\gamma = 1.7$			
φ°	X	Y	T
10	.31860	.034841	.23157
9	.35006	.023321	.19658
8	.20245	.016185	.16746
7	.16472	.011206	.14158
6	.13294	.007578	.11788
5	.10521	.004903	.09579
4	.08043	.002949	.07493
3	.05793	.001570	.05507
2	.03723	.000664	.03605
+1	.01800	.000159	.01772
	+	+	+
0	.00000	.000000	00000
	—	+	—
—1	.01696	.000147	.01721
2	.03303	.000566	.03396
3	.04833	.001233	.05031
4	.06295	.002126	.06632
5	.07697	.003229	.08201
6	.09046	.004527	.09742
7	.10347	.006009	.11259
8	.11606	.007666	.12754
9	.12827	.009490	.14230
10	.14012	.011474	.15689
11	.15167	.013613	.17132
12	.16292	.015903	.18563
13	.17392	.018340	.19982
14	.18468	.020923	.21391
15	.19521	.023648	.22792
16	.20556	.026516	.24186
17	.21571	.029525	.25575
18	.22571	.032675	.26960
19	.23555	.035968	.28342
20	.24525	.039403	.29722
21	.25482	.042982	.31102
22	.26428	.046707	.32483
23	.27363	.050581	.33866
24	.28289	.054605	.35252
25	.29206	.058784	.36642
26	.30115	.063121	.38038
27	.31018	.067620	.39440
28	.31914	.072285	.40850
29	.32805	.077122	.42269
30	.33691	.082135	.43697
31	.34573	.087330	.45137
32	.35451	.092715	.46590
33	.36327	.098295	.48056
34	.37201	.104079	.49537
35	.38073	.110074	.51034
36	.38944	.116289	.52549

$\gamma = 1.8$			
φ°	X	Y	T
37	.39815	.122733	.54082
38	.40680	.129416	.55636
39	.41558	.136349	.57212
40	.42430	.143543	.58812
41	.43305	.151011	.60436
42	.44181	.158766	.62088
43	.45061	.166821	.63768
44	.45943	.175192	.65478
45	.46828	.183895	.67222

$\gamma = 1.8$			
φ°	X	Y	T
9	.26580	.025369	.20180
8	.21048	.017071	.17042
7	.16925	.011628	.14338
6	.13556	.007781	.11897
5	.10670	.004997	.09643
4	.08125	.002989	.07529
3	.05833	.001585	.05525
2	.03739	.000668	.03612
+1	.01803	.000159	.01774
	+	+	+
0	.00000	.000000	.00000
	—	+	—
—1	.01693	.000146	.01719
2	.03293	.000564	.03391
3	.04812	.001226	.05020
4	.06260	.002111	.06613
5	.07647	.003201	.08174
6	.08979	.004483	.09705
7	.10262	.005944	.11211
8	.11501	.007575	.12695
9	.12701	.009368	.14158
10	.13866	.011317	.15604
11	.14999	.013416	.17034
12	.16102	.015661	.18450
13	.17180	.018049	.19855
14	.18233	.020577	.21249
15	.19263	.023242	.22634
16	.20274	.026045	.24013
17	.21267	.028985	.25385
18	.22242	.032060	.26753
19	.23202	.035272	.28118
20	.24148	.038622	.29482
21	.25082	.042111	.30844

$\gamma = 1.9$

φ	X	Y	T
22°	.26003	.045740	.32207
23	.26914	.049512	.33572
24	.27815	.053430	.34939
25	.28707	.057496	.36310
26	.29592	.061714	.37687
27	.30469	.066088	.39069
28	.31340	.076622	.40459
29	.32205	.075320	.41858
30	.33066	.080189	.43266
31	.33922	.085234	.44685
32	.34775	.090460	.46116
33	.35625	.095875	.47560
34	.36473	.101485	.49018
35	.37319	.107298	.50493
36	.38163	.113323	.51984
37	.39007	.119569	.53494
38	.39851	.126044	.55024
39	.40695	.132760	.56575
40	.41541	.139727	.58149
41	.42387	.146957	.59747
42	.43236	.154464	.61372
43	.44087	.162259	.63024
44	.44940	.170359	.64707
45	.45797	.178778	.66421

$\gamma = 1.9$

φ	X	Y	T
9°	.28737	.028267	.20836
8	.21997	.018142	.17377
7	.17426	.012104	.14531
6	.13836	.008003	.12012
5	.10826	.005098	.09710
4	.08207	.003032	.07566
3	.05872	.001600	.05544
2	.03753	.000672	.03619
+1	.01807	.000160	.01776
	+	+	+
0	.00000	.000000	.00000
	—	+	—
—1	.01691	.000146	.01718
2	.03283	.000562	.03385
3	.04791	.001219	.05009
4	.06227	.002096	.06595
5	.07598	.003174	.08147
6	.08913	.004440	.09669

$\gamma = 1.9$

φ	X	Y	T
7°	.10179	.005881	.11165
8	.11399	.007487	.12637
9	.12580	.009251	.14088
10	.13725	.011166	.15521
11	.14837	.013227	.16938
12	.15919	.015429	.18341
13	.16975	.017770	.19732
14	.18007	.020245	.21111
15	.19016	.022855	.22482
16	.20005	.025596	.23845
17	.20975	.028470	.25202
18	.21928	.031475	.26555
19	.22865	.034612	.27904
20	.23789	.037881	.29251
21	.24699	.041285	.30596
22	.25598	.044825	.31942
23	.26486	.048502	.33290
24	.27364	.052319	.34640
25	.28233	.056280	.35992
26	.29094	.060387	.37351
27	.29948	.064644	.38716
28	.30795	.069055	.40087
29	.31637	.073626	.41466
30	.32474	.078361	.42854
31	.33307	.083264	.44253
32	.34135	.088343	.45664
33	.34961	.093604	.47087
34	.35784	.099053	.48525
35	.36606	.0104699	.49978
36	.37426	.110548	.51447
37	.38245	.116609	.52935
38	.39064	.122892	.54442
39	.39883	.129407	.55969
40	.40703	.136164	.57519
41	.41524	.143175	.59093
42	.42346	.150452	.60693
43	.43170	.158008	.62320
44	.43997	.165857	.63976
45	.44827	.174013	.65664

$\gamma = 2.0$

φ	X	Y	T
8°	.23162	.019478	.17769
7	.17994	.012646	.14744

$\gamma = 2.0$			
φ	X	Y	T
0			
6	.14140	.008242	.12135
5	.10992	.005203	.09781
4	.08294	.003074	.07605
3	.05914	.001615	.05563
2	.03770	.000675	.03627
+1	.01811	.000160	.01778
	+	+	+
0	.00000	.000000	.00000
	−	+	−
−1	.01688	.000146	.01716
2	.03273	.000559	.03380
3	.04771	.001212	.04999
4	.06193	.002081	.06577
5	.07550	.003148	.08121
6	.08849	.004398	.09632
7	.10097	.005819	.11118
8	.11300	.007402	.12579
9	.12461	.009138	.14019
10	.13587	.011021	.15440
11	.14679	.013045	.16844
12	.15742	.015207	.18234
13	.16777	.017502	.19611
14	.17788	.019928	.20977
15	.18776	.022484	.22333
16	.19744	.025168	.23682
17	.20693	.027979	.25024
18	.21625	.030917	.26362
19	.22542	.033983	.27695
20	.23444	.037177	.29026
21	.24333	.040501	.30356
22	.25210	.043955	.31686
23	.26076	.047543	.33017
24	.26932	.051266	.34350
25	.27780	.055128	.35687
26	.28619	.059131	.37028
27	.29451	.063279	.38374
28	.30276	.067577	.39728
29	.31096	.072027	.41089
30	.31911	.076636	.42459
31	.32721	.081409	.43839
32	.33527	.086351	.45230
33	.34331	.091468	.46634
34	.35131	.096767	.48052
35	.35930	.102256	.49484
36	.36727	.107941	.50933
37	.37523	.113832	.52400
38	.38319	.119937	.53885
39	.39114	.126265	.55390

$\gamma = 2.1$			
φ	X	Y	T
0			
40	.39910	.132828	.56918
41	.40707	.139635	.58469
42	.41506	.146700	.60045
43	.42306	.154033	.61649
44	.43109	.161650	.63280
45	.43914	.169564	.64942

$\gamma = 2.1$			
φ	X	Y	T
0			
8	.24666	.021250	.18243
7	.18644	.013279	.14981
6	.14471	.008508	.12267
5	.11167	.005316	.09855
4	.08383	.003120	.07645
3	.05955	.001630	.05582
2	.03785	.000679	.03635
+1	.01814	.000161	.01779
	+	+	+
0	.00000	.000000	.00000
	−	+	−
−1	.01685	.000145	.01715
2	.03263	.000557	.03375
3	.04751	.001205	.04988
4	.06161	.002067	.06560
5	.07503	.003122	.08095
6	.08787	.004357	.09599
7	.10018	.005760	.11074
8	.11203	.007319	.12525
9	.12347	.009028	.13953
10	.13454	.010880	.15363
11	.14528	.012870	.16755
12	.15571	.014992	.18132
13	.16587	.017244	.19496
14	.17579	.019624	.20849
15	.18547	.022129	.22192
16	.19496	.024758	.23527
17	.20425	.027510	.24855
18	.21337	.030385	.26178
19	.22233	.033384	.27497
20	.23115	.036507	.28813
21	.23984	.039755	.30127
22	.24841	.043129	.31442
23	.25687	.046633	.32757
24	.26523	.050268	.34074

$\gamma = 2.2$			
φ	X	Y	T
0			
25	.27350	.054036	.35395
26	.28168	.057942	.36719
27	.28980	.061987	.38049
28	.29785	.066177	.39385
29	.30584	.070516	.40729
30	.31377	.075007	.42081
31	.32167	.079657	.43444
32	.32952	.084471	.44817
33	.33734	.089454	.46202
34	.34514	.094613	.47601
35	.35291	.099955	.49014
36	.36067	.105488	.50443
37	.36841	.111220	.51889
38	.37615	.117158	.53354
39	.38389	.123313	.54839
40	.39163	.129694	.56346
41	.39938	.136313	.57875
42	.40714	.143179	.59429
43	.41492	.150306	.61009
44	.42272	.157707	.62618
45	.43054	.165395	.64256

$\gamma = 2.2$			
φ	X	Y	T
0			
8	.26801	.023841	.18851
7	.19404	.014029	.15246
6	.14834	.008800	.12407
5	.11352	.005436	.09932
4	.08477	.003166	.07685
3	.05998	.001645	.05602
2	.03802	.000683	.03642
+1	.01817	.000161	.01781
	+	+	+
0	.00000	.000000	.00000
	−	+	−
−1	.01683	.000145	.01714
2	.03254	.000555	.03370
3	.04731	.001199	.04977
4	.06129	.002053	.06542
5	.07457	.003097	.08069
6	.08725	.004318	.09564
7	.09941	.005702	.11030
8	.11109	.007239	.12470
9	.12236	.008922	.13888

$\gamma = 2.3$			
φ	X	Y	T
0			
10	.13325	.010744	.15286
11	.14380	.012700	.16666
12	.15405	.014785	.18031
13	.16403	.016997	.19383
14	.17376	.019332	.20723
15	.18326	.021788	.22053
16	.19255	.024364	.23374
17	.20165	.027061	.24689
18	.21058	.029876	.25998
19	.21935	.032811	.27303
20	.22798	.035867	.28605
21	.23648	.039043	.29905
22	.24486	.042343	.31204
23	.25312	.045767	.32505
24	.26129	.049319	.33807
25	.26937	.052999	.35111
26	.27736	.056813	.36420
27	.28529	.060762	.37734
28	.29314	.064851	.39054
29	.30094	.069084	.40381
30	.30868	.073465	.41717
31	.31638	.077999	.43063
32	.32403	.082692	.44419
33	.33166	.087550	.45786
34	.33925	.092578	.47167
35	.34683	.097783	.48562
36	.35438	.103173	.49973
37	.36193	.108755	.51[illegible]00
38	.36946	.114539	.52846
39	.37700	.120531	.54311
40	.38453	.126743	.55798
41	.39208	.133185	.57306
42	.39963	.139867	.58839
43	.40720	.146801	.60398
44	.41478	.154001	.61985
45	.42239	.161479	.63600

$\gamma = 2.3$			
φ	X	Y	T
0			
7	.20318	.014950	.15552
6	.15236	.009129	.12559
5	.11550	.005566	.10012
4	.08575	.003216	.07727
3	.06043	.001662	.05622
2	.03818	.000687	.03649
+1	.01821	.000162	.01782

$\gamma = 2.3$			
φ	X	Y	T
°			
0	.00000	.000000	.00000
	—	+	—
—1	.01680	.000145	.01712
2	.03244	.000553	.03365
3	.04712	.001191	.04967
4	.06097	.002038	.06525
5	.07412	.003072	.08045
6	.08666	.004278	.09530
7	.09865	.005645	.10987
8	.11018	.007161	.12417
9	.12127	.008819	.13824
10	.13200	.010613	.15211
11	.14238	.012537	.16580
12	.15245	.014586	.17934
13	.16225	.016758	.19273
14	.17180	.019050	.20601
15	.18112	.021460	.21918
16	.19023	.023987	.23227
17	.19916	.026631	.24529
18	.20791	.029389	.25824
19	.21650	.032264	.27116
20	.22495	.035256	.28404
21	.23326	.038365	.29690
22	.24146	.041593	.30975
23	.24955	.044943	.32261
24	.25753	.048415	.33549
25	.26543	.052013	.34839
26	.27324	.055740	.36133
27	.28098	.059599	.37431
28	.28866	.063593	.38736
29	.29627	.067726	.40048
30	.30383	.072004	.41367
31	.31134	.076430	.42697
32	.31881	.081010	.44036
33	.32625	.085749	.45387
34	.33366	.090654	.46751
35	.34105	.095731	.48128
36	.34842	.100988	.49521
37	.35577	.106430	.50931
38	.36312	.112067	.52358
39	.37046	.117908	.53805
40	.37781	.123961	.55272
41	.38516	.130237	.56761
42	.39251	.136747	.58274
43	.39988	.143501	.59813
44	.40727	.150513	.61378
45	.41468	.157795	.62973

$\gamma = 2.4$			
φ	X	Y	T
°			
7	.21464	.016130	.15914
6	.15685	.009501	.12726
5	.11760	.005706	.10098
4	.08675	.003269	.07772
3	.06087	.001680	.05643
2	.03834	.000692	.03658
+1	.01824	.000162	.01785
	+	+	+
0	.00000	.000000	.00000
	—	+	—
—1	.01677	.000145	.01711
2	.03235	.000551	.03360
3	.04693	.001186	.04957
4	.06066	.002025	.06508
5	.07368	.003048	.08020
6	.08607	.004241	.09498
7	.09792	.005590	.10945
8	.10928	.007085	.12365
9	.12022	.008719	.13762
10	.13078	.010485	.15139
11	.14099	.012378	.16497
12	.15090	.014394	.17839
13	.16053	.016528	.19167
14	.16991	.018779	.20482
15	.17906	.021145	.21787
16	.18800	.023625	.23084
17	.19675	.026217	.24373
18	.20533	.028922	.25656
19	.21375	.031740	.26934
20	.22203	.034670	.28209
21	.23018	.037716	.29482
22	.23820	.040876	.30754
23	.24612	.044155	.32027
24	.25393	.047553	.33300
25	.26165	.051073	.34546
26	.26930	.054718	.35856
27	.27686	.058491	.37140
28	.28436	.062395	.38430
29	.29180	.066435	.39726
30	.29919	.070615	.41031
31	.30653	.074939	.42345
32	.31383	.079412	.43669
33	.32109	.084041	.45004
34	.32833	.088830	.46352
35	.33554	.093786	.47713
36	.34273	.098916	.49089
37	.34991	.104227	.50481
38	.35708	.109727	.51891
39	.36424	.115425	.53320

$\gamma = 2.5$			
φ	X	Y	T
0			
40	.37140	.121330	.54769
41	.37857	.127451	.56240
42	.38575	.133799	.57734
43	.39293	.140384	.59253
44	.40013	.147220	.60799
45	.40736	.154318	.62373

$\gamma = 2.5$			
φ	X	Y	T
0			
7	.23004	.017756	.16361
6	.16193	.009927	.12907
5	.11987	.005856	.10188
4	.08781	.003322	.07816
3	.06134	.001696	.05663
2	.03851	.000695	.03665
+1	.01828	.000162	.01786
	+	+	+
0	.00000	.000000	.00000
	—	+	—
—1	.01675	.000144	.01710
2	.03225	.000548	.03355
3	.04673	.001179	.04946
4	.06035	.002011	.06491
5	.07324	.003025	.07996
6	.08549	.004204	.09465
7	.09719	.005536	.10903
8	.10841	.007012	.12314
9	.11919	.008623	.13701
10	.12959	.010362	.15067
11	.13964	.012226	.16415
12	.14939	.014208	.17746
13	.15886	.016307	.19062
14	.16808	.018519	.20367
15	.17706	.020843	.21660
16	.18584	.023277	.22945
17	.19443	.025821	.24222
18	.20285	.028475	.25493
19	.21110	.031238	.26759
20	.21922	.034111	.28021
21	.22720	.037095	.29281
22	.23506	.040192	.30540
23	.24281	.043403	.31799
24	.25047	.046730	.33060
25	.25803	.050176	.34322
26	.26550	.053743	.35588
27	.27291	.057435	.36858

$\gamma = 2.6$			
φ	X	Y	T
0			
28	.28025	.061254	.38134
29	.28752	.065206	.39417
30	.29475	.069293	.40707
31	.30192	.073520	.42006
32	.30906	.077893	.43315
33	.31616	.082416	.44635
34	.32323	.087096	.45967
35	.33028	.091939	.47312
36	.33730	.096950	.48672
37	.34431	.102138	.50049
38	.35131	.107509	.51442
39	.35830	.113073	.52854
40	.36530	.118838	.54286
41	.37229	.124813	.55739
42	.37930	.131008	.57215
43	.38631	.137435	.58715
44	.39334	.144105	.60242
45	.40038	.151030	.61797

$\gamma = 2.6$			
φ	X	Y	T
0			
6	.16780	.010425	.13110
5	.12232	.006019	.10283
4	.08892	.003379	.07863
3	.06182	.001714	.05685
2	.03869	.000699	.03674
+1	.01832	.000163	.01788
	+	+	+
0	.00000	.000000	.00000
	—	+	—
—1	.01672	.000144	.01708
2	.03216	.000547	.03350
3	.04655	.001173	.04936
4	.06005	.001999	.06475
5	.07282	.003002	.07972
6	.08493	.004168	.09433
7	.09649	.005484	.10862
8	.10756	.006940	.12264
9	.11819	.008529	.13642
10	.12844	.010243	.14998
11	.13834	.012078	.16335
12	.14793	.014029	.17655
13	.15724	.016093	.18961
14	.16630	.018268	.20254
15	.17514	.020552	.21536

$\gamma = 2.6$

φ°	X	Y	T
16	.18376	.022943	.22810
17	.19219	.025441	.24075
18	.20045	.028045	.25334
19	.20855	.030756	.26588
20	.21651	.033574	.27838
21	.22434	.036501	.29086
22	.23205	.039537	.30333
23	.23965	.042684	.31579
24	.24714	.045944	.32827
25	.25455	.049319	.34076
26	.26188	.052813	.35329
27	.26913	.056428	.36586
28	.27631	.060167	.37848
29	.28343	.064035	.39117
30	.29050	.068034	.40393
31	.29752	.072171	.41678
32	.30450	.076449	.42973
33	.31145	.080873	.44278
34	.31836	.085450	.45595
35	.32525	.090184	.46926
36	.33212	.095084	.48271
37	.33897	.100155	.49631
38	.34582	.105405	.51009
39	.35265	.110842	.52405
40	.35948	.116475	.53820
41	.36632	.122312	.55256
42	.37316	.128365	.56715
43	.38001	.134642	.58198
44	.38687	.141156	.59707
45	.39376	.147919	.61244

$\gamma = 2.7$

φ°	X	Y	T
6	.17470	.011021	.13339
5	.12496	.006198	.10386
4	.09007	.003439	.07912
3	.06230	.001732	.05707
2	.03885	.000704	.03682
+1	.01835	.000163	.01790
	+	+	+
0	.00000	.000000	.00000
	−	+	−
−1	.01669	.000144	.01707
2	.03207	.000544	.03345
3	.04636	.001167	.04927

$\gamma = 2.7$

φ°	X	Y	T
4	.05976	.001985	.06459
5	.07240	.002979	.07948
6	.08439	.004132	.09401
7	.09581	.005432	.10822
8	.10673	.006870	.12215
9	.11722	.008437	.13583
10	.12732	.010127	.14929
11	.13708	.011934	.16256
12	.14652	.013855	.17567
13	.15569	.015286	.18862
14	.16460	.018025	.20144
15	.17328	.020270	.21416
16	.18175	.022620	.22678
17	.19004	.025074	.23932
18	.19815	.027631	.25180
19	.20610	.030293	.26422
20	.21392	.033059	.27661
21	.22160	.035930	.28897
22	.22916	.038907	.30131
23	.23661	.041993	.31366
24	.24396	.045190	.32601
25	.25122	.048498	.33838
26	.25840	.051922	.35078
27	.26550	.055464	.36323
28	.27254	.059127	.37572
29	.27952	.062915	.38828
30	.28644	.066832	.40091
31	.29331	.070883	.41362
32	.30015	.075070	.42643
33	.30695	.079401	.43935
34	.31371	.083880	.45238
35	.32045	.088513	.46554
36	.32717	.093307	.47884
37	.33388	.098267	.49230
38	.34057	.103402	.50592
39	.34725	.108720	.51972
40	.35394	.114228	.53372
41	.36062	.119935	.54792
42	.36731	.125852	.56235
43	.37401	.131989	.57701
44	.38071	.138356	.59193
45	.38744	.144965	.60712

γ = 2.8			
φ	X	Y	T
0 6	.18312	.011761	.13603
5	.12786	.006395	.10493
4	.09130	.003502	.07961
3	.06282	.001751	.05728
2	.03903	.000708	.03689
+1	.01839	.000163	.01791
	+	+	+
0	.00000	.000000	.00000
	−	+	−
−1	.01667	.000143	.01706
2	.03197	.000542	.03341
3	.04618	.001161	.04917
4	.05947	.001973	.06442
5	.07199	.002957	.07925
6	.08385	.004098	.09370
7	.09513	.005383	.10783
8	.10592	.006802	.12167
9	.11627	.008348	.13526
10	.12623	.010014	.14863
11	.13584	.011795	.16180
12	.14514	.013687	.17480
13	.15416	.015687	.18765
14	.16293	.017791	.20037
15	.17147	.019999	.21298
16	.17980	.022309	.22550
17	.18794	.024721	.23793
18	.19591	.027234	.25030
19	.20373	.029848	.26261
20	.21140	.032563	.27489
21	.21894	.035382	.28713
22	.22636	.038304	.29936
23	.23367	.041332	.31159
24	.24088	.044468	.32382
25	.24800	.047713	.33608
26	.25504	.051070	.34836
27	.26201	.054543	.36068
28	.26891	.058133	.37305
29	.27574	.061846	.38548
30	.28253	.065684	.39798
31	.28926	.069652	.41057
32	.29596	.073755	.42325
33	.30262	.077996	.43603
34	.30924	.082383	.44892
35	.31584	.086919	.46195
36	.32242	.091612	.47511
37	.32898	.096469	.48842
38	.33553	.101495	.50190
39	.34208	.106699	.51555

γ = 2.9			
φ	X	Y	T
0 40	.34861	.112089	.52940
41	.35515	.117674	.54345
42	.36170	.123463	.55772
43	.36825	.129466	.57222
44	.37481	.135694	.58698
45	.38139	.142158	.60200

γ = 2.9			
φ	X	Y	T
0 6	.19388	.012730	.13921
5	.13105	.006616	.10611
4	.09258	.003570	.08015
3	.06334	.001772	.05753
2	.03921	.000712	.03699
+1	.01842	.000164	.01793
0	.00000	.000000	.00000
−1	.01664	.000143	.01704
2	.03188	.000540	.03335
3	.04600	.001155	.04906
4	.05918	.001960	.06426
5	.07158	.002935	.07902
6	.08332	.004064	.09339
7	.09448	.005335	.10744
8	.10513	.006737	.12119
9	.11534	.008263	.13469
10	.12517	.009906	.14797
11	.13464	.011661	.16104
12	.14380	.013525	.17395
13	.15269	.015494	.18670
14	.16132	.017566	.19933
15	.16972	.019738	.21183
16	.17791	.022010	.22424
17	.18592	.024381	.23657
18	.19375	.026851	.24883
19	.20143	.029420	.26104
20	.20897	.032088	.27320
21	.21637	.034856	.28534
22	.22366	.037726	.29746
23	.23083	.040698	.30958
24	.23791	.043776	.32170
25	.24490	.046960	.33383
26	.25181	.050254	.34600
27	.25864	.053660	.35820

$\gamma = 2.9$			
φ	X	Y	T
0			
28	.26541	.057182	.37045
29	.27211	.060822	.38276
30	.27876	.064585	.39514
31	.28537	.068475	.40761
32	.29193	.072496	.42016
33	.29845	.076653	.43281
34	.30495	.080951	.44558
35	.31141	.085396	.45847
36	.31786	.089994	.47150
37	.32429	.094751	.48467
38	.33070	.099674	.49801
39	.33711	.104771	.51153
40	.34351	.110049	.52523
41	.34992	.115517	.53913
42	.35632	.121185	.55325
43	.36274	.127062	.56759
44	.36916	.133158	.58219
45	.37560	.139485	.59705

$\gamma = 3.0$			
φ	X	Y	T
0			
5	.13457	.006862	.10736
4	.09393	.003641	.07068
3	.06387	.001791	.05775
2	.03939	.000717	.03707
+1	.01846	.000164	.01795
	+	+	+
0	.00000	.000000	.00000
	—	+	—
−1	.01662	.000142	.01703
2	.03179	.000538	.03331
3	.04582	.001149	.04897
4	.05890	.001948	.06411
5	.07119	.002914	.07880
6	.08280	.004031	.09310
7	.09383	.005287	.10706
8	.10436	.006672	.12074
9	.11444	.008178	.13415
10	.12413	.009799	.14733
11	.13347	.011530	.16032
12	.14250	.013367	.17313
13	.15125	.015307	.18579
14	.15975	.017346	.19831
15	.16802	.019485	.21072

$\gamma = 3.1$			
φ	X	Y	T
0			
16	.17608	.021720	.22303
17	.18396	.024053	.23526
18	.19166	.026481	.24742
19	.19921	.029007	.25952
20	.20661	.031629	.27158
21	.21389	.034349	.28361
22	.22104	.037168	.29563
23	.22810	.040088	.30763
24	.23505	.043110	.31965
25	.24191	.046236	.33167
26	.24869	.049470	.34372
27	.25539	.052813	.35581
28	.26203	.056269	.36794
29	.26861	.059841	.38014
30	.27513	.063533	.39240
31	.28161	.067348	.40474
32	.28805	.071292	.41717
33	.29444	.075368	.42970
34	.30081	.079583	.44234
35	.30715	.083941	.45510
36	.31347	.088448	.46800
37	.31977	.093110	.48105
38	.32606	.097936	.49426
39	.33234	.102930	.50763
40	.33861	.108102	.52119
41	.34489	.113460	.53495
42	.35116	.119012	.54893
43	.35745	.124769	.56313
44	.36374	.130741	.57758
45	.37004	.136938	.59229

$\gamma = 3.1$			
φ	X	Y	T
0			
5	.13855	.007143	.10875
4	.09536	.003716	.08126
3	.06442	.001812	.05799
2	.03958	.000721	.03715
+1	.01850	.000165	.01797
	+	+	+
0	.00000	.000000	.00000
	—	+	—
−1	.01659	.000142	.01701
2	.03171	.000536	.03326
3	.04564	.001143	.04887

$\gamma = 3.1$			
φ	X	Y	T
0			
4	.05862	.001936	.06395
5	.07080	.002893	.07857
6	.08229	.003999	.09280
7	.09320	.005241	.10669
8	.10360	.006610	.12028
9	.11356	.008097	.13361
10	.12312	.009697	.14670
11	.13233	.011404	.15960
12	.14123	.013214	.17232
13	.14985	.015126	.18489
14	.15823	.017135	.19732
15	.16637	.019240	.20963
16	.17431	.021441	.22184
17	.18206	.023736	.23397
18	.18964	.026125	.24603
19	.19706	.028609	.25803
20	.20434	.031187	.26999
21	.21149	.033861	.28192
22	.21852	.036632	.29383
23	.22545	.039501	.30572
24	.23228	.042470	.31764
25	.23902	.045541	.32956
26	.24567	.048717	.34150
27	.25226	.052000	.35348
28	.25878	.055393	.36550
29	.26523	.058900	.37758
30	.27164	.062524	.38973
31	.27800	.066268	.40195
32	.28431	.070138	.41427
33	.29059	.074138	.42668
34	.29684	.078273	.43920
35	.30306	.082548	.45184
36	.30925	.086969	.46462
37	.31543	.091542	.47754
38	.32160	.096273	.49061
39	.32776	.101171	.50386
40	.33391	.106242	.51729
41	.34006	.111495	.53091
42	.34622	.116937	.54475
43	.35238	.122580	.55881
44	.35854	.128433	.57311
45	.36472	.134506	.58767

$\gamma = 3.2$			
φ	X	Y	T
0			
5	.14309	.007467	.11027
4	.09689	.003798	.08185
3	.06500	.001835	.05824
2	.03977	.000726	.03724
+1	.01853	.000165	.01799
	+	+	+
0	.00000	.000000	.00000
	—	+	—
—1	.01656	.000142	.01700
2	.03162	.000535	.03321
3	.04547	.001137	.04878
4	.05835	.001924	.06380
5	.07041	.002872	.07836
6	.08179	.003967	.09251
7	.09258	.005196	.10632
8	.10286	.006548	.11983
9	.11269	.008017	.13308
10	.12213	.009596	.14609
11	.13122	.011280	.15890
12	.14000	.013066	.17153
13	.14850	.014950	.18401
14	.15675	.016929	.19635
15	.16477	.019003	.20857
16	.17258	.021170	.22069
17	.18021	.023429	.23272
18	.18767	.025781	.24468
19	.19497	.028224	.25659
20	.20213	.030760	.26845
21	.20917	.033390	.28028
22	.21608	.036115	.29209
23	.22289	.038935	.30389
24	.22961	.041854	.31569
25	.23623	.044872	.32751
26	.24277	.047993	.33935
27	.24924	.051218	.35122
28	.25564	.054551	.36314
29	.26199	.057995	.37511
30	.26828	.061554	.38715
31	.27452	.065231	.39927
32	.28072	.069030	.41147
33	.28688	.072957	.42376
34	.29301	.077016	.43617
35	.29912	.081212	.44870
36	.30520	.085550	.46135
37	.31127	.090038	.47415
38	.31732	.094680	.48710
39	.32336	.099485	.50022

$\gamma = 3.3$

φ	X	Y	T
°			
40	.32939	.104460	.51352
41	.33543	.109613	.52702
42	.34146	.114951	.54072
43	.34750	.120486	.55464
44	.35355	.126225	.56881
45	.35961	.132181	.58323

$\gamma = 3.3$

φ	X	Y	T
°			
5	.14836	.007850	.11199
4	.09850	.003885	.08249
3	.06559	.001857	.05849
2	.03996	.000730	.03733
+1	.01857	.000165	.01800
	+	+	+
0	.00000	.000000	.00000
	−	+	−
−1	.01654	.000142	.01698
2	.03153	.000532	.03317
3	.04530	.001132	.04869
4	.05808	.001912	.06365
5	.07004	.002852	.07814
6	.08130	.003936	.09223
7	.09198	.005151	.10596
8	.10214	.006488	.11940
9	.11185	.007940	.13256
10	.12117	.009499	.14549
11	.13014	.011161	.15822
12	.13880	.012922	.17076
13	.14718	.014779	.18315
14	.15531	.016731	.19540
15	.16321	.018774	.20753
16	.17091	.020909	.21956
17	.17842	.023134	.23150
18	.18576	.025449	.24337
19	.19295	.027854	.25518
20	.20000	.030350	.26694
21	.20692	.032937	.27868
22	.21372	.035617	.29039
23	.22042	.038391	.30210
24	.22702	.041261	.31380
25	.23353	.044229	.32551
26	.23997	.047296	.33725
27	.24633	.050466	.34902

$\gamma = 3.4$

φ	X	Y	T
°			
28	.25262	.053742	.36083
29	.25885	.057126	.37270
30	.26503	.060623	.38464
31	.27117	.064236	.39665
32	.27726	.067968	.40874
33	.28331	.071825	.42093
34	.28933	.075810	.43322
35	.29533	.079930	.44564
36	.30130	.084190	.45818
37	.30725	.088596	.47086
38	.31320	.093154	.48369
39	.31913	.097871	.49669
40	.32505	.102754	.50987
41	.33097	.107811	.52324
42	.33689	.113051	.53681
43	.34282	.118482	.55061
44	.34875	.124114	.56464
45	.35470	.129957	.57892

$\gamma = 3.4$

φ	X	Y	T
°			
5	.15467	.008315	.11392
4	.10023	.003979	.08314
3	.06619	.001881	.05875
2	.04015	.000735	.03742
+1	.01861	.000166	.01802
	+	+	+
0	.00000	.000000	.00000
	−	+	−
−1	.01651	.000141	.01697
2	.03144	.000531	.03312
3	.04513	.001127	.04859
4	.05781	.001901	.06349
5	.06967	.002833	.07792
6	.08082	.003906	.09194
7	.09138	.005108	.10560
8	.10143	.006430	.11896
9	.11103	.007864	.13205
10	.12023	.009404	.14490
11	.12908	.011044	.15754
12	.13763	.012782	.17000
13	.14589	.014614	.18230
14	.15391	.016538	.19446
15	.16170	.018552	.20651

$\gamma = 3.5$			
φ °	X	Y	T
16	.16928	.020655	.21845
17	.17668	.022847	.23030
18	.18391	.025127	.24208
19	.19099	.027496	.25380
20	.19793	.029953	.26548
21	.20474	.032499	.27712
22	.21144	.035136	.28873
23	.21803	.037866	.30035
24	.22452	.040689	.31196
25	.23093	.043608	.32357
26	.23725	.046625	.33522
27	.24351	.049742	.34689
28	.24969	.052963	.35860
29	.25582	.056290	.37037
30	.26190	.059727	.38220
31	.26792	.063277	.39411
32	.27391	.066945	.40609
33	.27986	.070735	.41818
34	.28577	.074652	.43036
35	.29166	.078700	.44267
36	.29753	.082885	.45510
37	.30338	.087213	.46766
38	.30921	.091690	.48038
39	.31503	.096322	.49327
40	.32085	.101117	.50632
41	.32667	.106083	.51957
42	.33248	.111228	.53302
43	.33830	.116560	.54669
44	.34412	.122089	.56060
45	.34996	.127826	.57475

$\gamma = 3.5$			
φ °	X	Y	T
4	.10210	.004080	.08383
3	.06683	.001905	.05901
2	.04036	.000740	.03750
+1	.01865	.000166	.01804
	+	+	+
0	.00000	.000000	.00000
	—	+	—
—1	.01649	.000141	.01696
2	.03135	.000529	.03307
3	.04496	.001121	.04850
4	.05755	.001890	.06335
5	.06930	.002813	.07771
6	.08035	.003876	.09166

$\gamma = 3.6$			
φ °	X	Y	T
7	.09080	.005066	.10525
8	.10074	.006374	.11854
9	.11022	.007791	.13155
10	.11931	.009311	.14432
11	.12806	.010931	.15688
12	.13649	.012646	.16926
13	.14464	.014453	.18148
14	.15255	.016351	.19356
15	.16023	.018337	.20552
16	.16770	.020410	.21737
17	.17500	.022570	.22914
18	.18212	.024816	.24083
19	.18910	.027149	.25246
20	.19593	.029569	.26405
21	.20264	.032076	.27560
22	.20923	.034672	.28713
23	.21571	.037359	.29864
24	.22210	.040137	.31016
25	.22841	.043009	.32169
26	.23463	.045978	.33323
27	.24078	.049045	.34481
28	.24687	.052213	.35643
29	.25289	.055485	.36810
30	.25887	.058865	.37983
31	.26479	.062356	.39164
32	.27068	.065962	.40352
33	.27652	.069688	.41550
34	.28234	.073538	.42759
35	.28813	.077517	.43978
36	.29389	.081631	.45811
37	.29964	.085884	.46456
38	.30537	.090283	.47717
39	.31110	.094835	.48994
40	.31681	.099546	.50289
41	.32252	.104425	.51602
42	.32823	.109478	.52935
43	.33395	.114716	.54290
44	.33967	.120147	.55668
45	.34540	.125781	.57070

$\gamma = 3.6$			
φ °	X	Y	T
4	.10410	.004190	.08457
3	.06748	.001931	.05928
2	.04056	.000745	.03760
+1	.01868	.000167	.01806
	+	+	+

γ = 3.6			
φ	X	Y	T
0			
0	.00000	.000000	.00000
	—	+	—
—1	.01646	.000141	.01695
2	.03127	.000527	.03303
3	.04479	.001116	.04840
4	.05729	.001878	.06320
5	.06894	.002794	.07750
6	.07989	.003847	.09139
7	.09023	.005025	.10491
8	.10005	.006318	.11812
9	.10943	.007719	.13105
10	.11841	.009221	.14375
11	.12705	.010821	.15623
12	.13537	.012514	.16853
13	.14342	.014298	.18067
14	.15122	.016169	.19267
15	.15879	.018128	.20454
16	.16616	.020172	.21631
17	.17335	.022301	.22800
18	.18037	.024515	.23960
19	.18724	.026813	.25115
20	.19397	.029197	.26265
21	.20058	.031667	.27411
22	.20707	.034224	.28555
23	.21346	.036869	.29698
24	.21975	.039604	.30840
25	.22595	.042432	.31984
26	.23208	.045353	.33130
27	.23813	.048371	.34278
28	.24412	.051488	.35431
29	.25005	.054708	.36588
30	.25592	.058033	.37752
31	.26175	.061467	.38923
32	.26754	.065014	.40101
33	.27329	.068679	.41289
34	.27901	.072465	.42488
35	.28471	.076378	.43697
36	.29038	.080422	.44919
37	.29603	.084604	.46155
38	.30166	.088928	.47405
39	.30729	.093403	.48671
40	.31291	.098034	.49954
41	.31852	.102829	.51256
42	.32413	.107796	.52578
43	.32975	.112944	.53921
44	.33537	.118281	.55287
45	.34101	.123817	.56677

γ = 3.7			
φ	X	Y	T
0			
4	.10627	.004311	.08536
3	.06816	.001957	.05956
2	.04076	.000750	.03769
+1	.01872	.000167	.01808
	+	+	+
0	.00000	.000000	.00000
	—	+	—
—1	.01644	.000140	.01694
2	.03119	.000525	.03299
3	.04463	.001110	.04832
4	.05704	.001868	.06306
5	.06859	.002776	.07730
6	.07943	.003819	.09112
7	.08967	.004984	.10458
8	.09939	.006264	.11771
9	.10866	.007648	.13058
10	.11754	.009133	.14320
11	.12607	.010713	.15560
12	.13429	.012385	.16782
13	.14223	.014146	.17988
14	.14993	.015993	.19180
15	.15740	.017925	.20360
16	.16467	.019941	.21529
17	.17176	.022040	.22689
18	.17868	.024223	.23841
19	.18545	.026488	.24988
20	.19209	.028837	.26129
21	.19859	.031271	.27267
22	.20499	.033790	.28402
23	.21128	.036396	.29537
24	.21748	.039090	.30671
25	.22359	.041874	.31805
26	.22962	.044751	.32942
27	.23558	.047722	.34082
28	.24147	.050791	.35225
29	.24731	.053960	.36374
30	.25309	.057232	.37528
31	.25883	.060612	.38690
32	.26453	.064103	.39859
33	.27019	.067708	.41037
34	.27581	.071433	.42226
35	.28141	.075282	.43426
36	.28699	.079261	.44638
37	.29255	.083374	.45863
38	.29809	.087627	.47103
39	.30363	.092027	.48358
40	.30915	.096582	.49631
41	.31467	.101297	.50921
42	.32019	.106181	.52232

$\gamma = 3.7$

φ	X	Y	T
0			
43	.32572	.111242	.53564
44	.33125	.116489	.54918
45	.33678	.121932	.56296

$\gamma = 3.8$

φ	X	Y	T
0			
4	.10864	.004444	.08619
3	.06886	.001984	.05985
2	.04097	.000755	.03778
+1	.01876	.000168	.01809
	+	+	+
0	.00000	.000000	.00000
	—	+	—
—1	.01641	.000141	.01693
2	.03111	.000523	.03294
3	.04448	.001105	.04823
4	.05678	.001857	.06291
5	.06824	.002757	.07710
6	.07898	.003791	.09085
7	.08912	.004945	.10424
8	.09874	.006210	.11731
9	.10791	.007580	.13010
10	.11668	.009048	.14264
11	.12511	.010609	.15498
12	.13322	.012260	.16712
13	.14107	.013998	.17911
14	.14866	.015821	.19095
15	.15604	.017728	.20266
16	.16321	.019717	.21428
17	.17020	.021787	.22580
18	.17703	.023940	.23724
19	.18370	.026173	.24862
20	.19024	.028489	.25996
21	.19666	.030888	.27125
22	.20296	.033370	.28253
23	.20916	.035938	.29378
24	.21527	.038592	.30504
25	.22128	.041334	.31630
26	.22722	.044168	.32758
27	.23309	.047094	.33889
28	.23890	.050116	.35024
29	.24465	.053236	.36164
30	.25034	.056458	.37310
31	.25599	.059785	.38462
32	.26160	.063221	.39622
33	.26717	.066770	.40792

$\gamma = 3.8$

φ	X	Y	T
0			
34	.27271	.070436	.41971
35	.27822	.074224	.43161
36	.28371	.078139	.44363
37	.28917	.082186	.45578
38	.29463	.086371	.46808
39	.30007	.090701	.48053
40	.30551	.095181	.49316
41	.31094	.099820	.50596
42	.31637	.104624	.51896
43	.32180	.109602	.53217
44	.32723	.114763	.54560
45	.33268	.120116	.55927

$\gamma = 3.9$

φ	X	Y	T
0			
4	.11126	.004592	.08709
3	.06960	.002013	.06015
2	.04118	.000761	.03788
+1	.01880	.000168	.01811
	+	+	+
0	.00000	.000000	.00000
	—	+	—
—1	.01639	.000140	.01691
2	.03102	.000521	.03289
3	.04431	.001099	.04814
4	.05654	.001846	.06277
5	.06790	.002739	.07690
6	.07854	.003763	.09059
7	.08858	.004906	.10392
8	.09810	.006159	.11691
9	.10717	.007513	.12963
10	.11584	.008964	.14211
11	.12417	.010507	.15437
12	.13219	.012138	.16644
13	.13993	.013855	.17835
14	.14743	.015655	.19011
15	.15471	.017537	.20176
16	.16179	.019499	.21329
17	.16869	.021542	.22473
18	.17542	.023665	.23610
19	.18200	.025868	.24740
20	.18845	.028152	.25866
21	.19478	.030517	.26987
22	.20099	.032964	.28107
23	.20710	.035494	.29224
24	.21312	.038110	.30342

$\gamma = 3.9$			
φ °	X	Y	T
25	.21905	.040813	.31460
26	.22490	.043604	.32580
27	.23068	.046487	.33703
28	.23640	.049464	.34829
29	.24206	.052537	.35960
30	.24767	.055711	.37097
31	.25323	.058987	.38241
32	.25875	.062371	.39392
33	.26424	.065865	.40552
34	.26969	.069474	.41722
35	.27512	.073204	.42903
36	.28052	.077057	.44096
37	.28590	.081041	.45302
38	.29127	.085161	.46522
39	.29663	.089422	.47758
40	.30198	.093832	.49010
41	.30732	.098396	.50280
42	.31266	.103124	.51570
43	.31801	.108023	.52880
44	.32336	.113101	.54212
45	.32872	.118367	.55568

$\gamma = 4.0$			
φ °	X	Y	T
4	.11417	.004759	.08807
3	.07036	.002044	.06046
2	.04140	.000766	.03797
+1	.01884	.000169	.01813
	+	+	+
0	.00000	.000000	.00000
	—	+	—
—1	.01636	.000140	.01690
2	.03094	.000519	.03285
3	.04415	.001094	.04805
4	.05629	.001836	.06263
5	.06756	.002722	.07670
6	.07811	.003737	.09033
7	.08805	.004868	.10359
8	.09747	.006108	.11652
9	.10644	.007448	.12917
10	.11502	.008883	.14158
11	.12325	.010408	.15377
12	.13117	.012019	.16577
13	.13882	.013715	.17760
14	.14623	.015493	.18929
15	.15342	.017351	.20086

$\gamma = 4.1$			
φ °	X	Y	T
16	.16040	.019288	.21232
17	.16721	.021304	.22369
18	.17385	.023399	.23498
19	.18035	.025572	.24621
20	.18671	.027824	.25739
21	.19295	.030156	.26853
22	.19907	.032569	.27964
23	.20510	.035065	.29074
24	.21103	.037643	.30183
25	.21688	.040307	.31293
26	.22264	.043059	.32405
27	.28834	.045900	.33520
28	.23398	.048833	.34638
29	.23955	.051862	.35761
30	.24508	.054988	.36889
31	.25056	.058216	.38024
32	.25600	.061549	.39167
33	.26140	.064991	.40318
34	.26677	.068546	.41479
35	.27212	.072219	.42651
36	.27744	.076014	.43835
37	.28274	.079937	.45032
38	.28802	.083993	.46242
39	.19330	.088189	.47469
40	.29856	.092530	.48711
41	.30382	.097024	.49971
42	.30908	.101678	.51251
43	.31435	.106500	.52551
44	.31961	.111498	.53872
45	.32489	.116682	.55218

$\gamma = 4.1$			
φ °	X	Y	T
4	.11746	.004949	.08914
3	.07116	.002075	.06078
2	.04162	.000772	.03807
+1	.01888	.000169	.01815
	+	+	+
0	.00000	.000000	.00000
	—	+	—
—1	.01634	.000139	.01689
2	.03085	.000517	.03281
3	.04399	.001089	.04797
4	.05605	.001825	.06250
5	.06723	.002704	.07651
6	.07769	.003710	.09008

$\gamma = 4.1$			
φ	X	Y	T
°			
7	.08753	.004831	.10328
8	.09686	.006058	.11615
9	.10573	.007383	.12873
10	.11421	.008802	.14107
11	.12235	.010310	.15319
12	.13018	.011903	.16512
13	.13774	.013578	.17688
14	.14506	.015334	.18850
15	.15215	.017169	.20000
16	.15905	.019082	.21138
17	.16577	.021072	.22268
18	.17233	.023139	.23389
19	.17874	.025283	.24505
20	.18501	.027505	.25615
21	.19117	.029806	.26722
22	.19721	.032186	.27826
23	.20315	.034647	.28928
24	.20900	.037190	.30030
25	.21477	.039817	.31132
26	.22045	.042529	.32236
27	.22607	.045330	.33342
28	.23163	.048222	.34452
29	.23712	.051207	.35567
30	.24257	.054288	.36687
31	.24797	.057469	.37814
32	.25333	.060754	.38948
33	.25865	.064145	.40091
34	.26395	.067648	.41244
35	.26921	.071266	.42407
36	.27445	.075005	.43582
37	.27967	.078870	.44770
38	.28488	.082865	.45971
39	.29008	.086998	.47188
40	.29526	.091273	.48421
41	.30044	.095699	.49672
42	.30562	.100282	.50941
43	.31080	.105031	.52231
44	.31599	.109953	.53543
45	.32118	.115057	.54878

$\gamma = 4.2$			
φ	X	Y	T
°			
4	.12122	.005169	.09032
3	.07199	.002109	.06110
2	.04185	.000778	.03817
+1	.01892	.000170	.01817
	+	+	+

$\gamma = 4.2$			
φ	X	Y	T
°			
0	.00000	.000000	.00000
	—	+	—
—1	.01631	.000139	.01687
2	.03077	.000516	.03276
3	.04384	.001085	.04788
4	.05581	.001816	.06236
5	.06691	.002687	.07632
6	.07727	.003684	.08983
7	.08703	.004795	.10296
8	.09626	.006009	.11576
9	.10504	.007321	.12828
10	.11343	.008725	.14055
11	.12148	.010216	.15260
12	.12922	.011790	.16446
13	.13669	.013446	.17616
14	.14392	.015181	.18771
15	.15092	.016993	.19913
16	.15774	.018882	.21045
17	.16437	.020847	.22167
18	.17084	.022888	.23282
19	.17717	.025004	.24390
20	.18337	.027197	.25493
21	.18944	.029468	.26592
22	.19540	.031816	.27688
23	.20126	.034243	.28783
24	.20703	.036752	.29877
25	.21272	.039342	.30972
26	.21833	.042018	.32068
27	.22387	.044780	.33167
28	.22934	.047631	.34269
29	.23476	.050574	.35376
30	.24013	.053612	.36488
31	.24546	.056748	.37607
32	.25074	.059985	.38733
33	.25599	.063328	.39868
34	.26120	.066780	.41012
35	.26639	.070346	.42167
36	.27155	.074031	.43333
37	.27670	.077839	.44512
38	.28183	.081775	.45705
39	.28695	.085847	.46913
40	.29206	.090060	.48137
41	.29717	.094420	.49378
42	.30227	.098935	.50638
43	.30737	.103612	.51919
44	.31248	.108460	.53221
45	.31760	.113488	.54545

$\gamma = 4.3$			
φ	X	Y	T
0			
4	.12561	.005431	.09165
3	.07286	.002143	.06144
2	.04207	.000783	.03827
+1	.01896	.000170	.01819
	+	+	+
0	.00000	.000000	.00000
	—	+	—
—1	.01629	.000139	.01686
2	.03070	.000514	.03271
3	.04368	.001079	.04779
4	.05558	.001805	.06222
5	.06658	.002670	.07612
6	.07686	.003659	.08958
7	.08652	.004759	.10265
8	.06566	.005962	.11539
9	.10436	.007260	.12784
10	.11266	.008649	.14004
11	.12061	.010123	.15203
12	.12827	.011680	.16383
13	.13565	.013317	.17545
14	.14279	.015031	.18693
15	.14972	.016821	.19829
16	.15644	.018687	.20953
17	.16300	.020628	.22069
18	.16939	.022643	.23176
19	.17563	.024733	.24277
20	.18175	.026898	.25373
21	.18774	.029138	.26465
22	.19363	.031456	.27554
23	.19941	.033851	.28642
24	.20510	.036326	.29729
25	.21071	.038882	.30816
26	.21625	.041521	.31905
27	.22171	.044246	.32996
28	.22711	.047058	.34091
29	.23246	.049960	.35190
30	.23775	.052956	.36295
31	.24300	.056048	.37406
32	.24821	.059240	.38524
33	.25338	.062536	.39651
34	.25852	.065940	.40787
35	.26364	.069455	.41933
36	.26873	.073087	.43091
37	.27380	.076840	.44262
38	.27886	.080721	.45446
39	.28391	.084733	.46645
40	.28894	.088885	.47860
41	.29397	.093182	.49093
42	.29900	.097631	.50343

$\gamma = 4.4$			
φ	X	Y	T
0			
43	.30403	.102241	.51614
44	.20907	.107018	.52906
45	.31411	.111972	.54222

$\gamma = 4.4$			
φ	X	Y	T
0			
3	.07378	.002180	.06180
2	.04231	.000789	.03837
+1	.01900	.000171	.01821
	+	+	+
0	.00000	.000000	.00000
	—	+	—
—1	.01626	.000139	.01685
2	.03061	.000512	.03268
3	.04353	.001075	.04771
4	.05535	.001796	.06209
5	.06627	.002654	.07594
6	.07646	.003634	.08933
7	.08603	.004724	.10235
8	.09508	.005915	.11502
9	.10369	.007200	.12741
10	.11190	.008574	.13955
11	.11977	.010033	.15147
12	.12734	.011572	.16320
13	.13464	.013190	.17476
14	.14170	.014884	.18618
15	.14854	.016654	.19747
16	.15519	.018497	.20865
17	.16166	.020414	.21973
18	.16798	.022404	.23074
19	.17414	.024468	.24168
20	.18018	.026605	.25257
21	.18610	.028817	.26342
22	.19191	.031105	.27424
23	.19762	.033469	.28504
24	.20323	.035912	.29584
25	.20877	.038434	.30664
26	.21423	.041038	.31745
27	.21962	.043727	.32829
28	.22495	.046501	.33917
29	.23022	.049364	.35009
30	.23545	.052319	.36106
31	.24062	.055370	.37209
32	.24576	.058518	.38320
33	.25086	.061768	.39439

φ	X	Y	T
$\gamma = 4.5$			
34°	.25593	.065125	.40567
35	.26098	.068592	.41705
36	.26600	.072173	.42855
37	.27100	.075874	.44017
38	.27599	.079700	.45193
39	.28096	.083656	.46384
40	.28593	.087749	.47590
41	.29089	.091985	.48814
42	.29584	.096371	.50056
43	.30080	.100914	.51317
44	.30576	.105623	.52600
45	.31073	.110505	.53906

φ	X	Y	T
$\gamma = 4.5$			
3°	.07474	.002219	.06216
2	.04255	.000795	.03848
+1	.01904	.000171	.01823
	+	+	+
0	.00000	.000000	.00000
−1	.01624	.000138	.01683
2	.03054	.000510	.03263
3	.04338	.001069	.04762
4	.05512	.001785	.06196
5	.06596	.002638	.07576
6	.07606	.003609	.08910
7	.08555	.004690	.10205
8	.09452	.005870	.11467
9	.10303	.007142	.12700
10	.11116	.008502	.13907
11	.11895	.009945	.15093
12	.12644	.011468	.16259
13	.13366	.013067	.17409
14	.14063	.014742	.18544
15	.14740	.016491	.19666
16	.15397	.018313	.20778
17	.16036	.020207	.21879
18	.16660	.022173	.22973
19	.17269	.024212	.24061
20	.17865	.026323	.25143
21	.18449	.028507	.26221
22	.19023	.030766	.27296
23	.19587	.033100	.28370
24	.20141	.035511	.29442

φ	X	Y	T
$\gamma = 4.6$			
25°	.20687	.038001	.30516
26	.21226	.040572	.31590
27	.21758	.043224	.32667
28	.22284	.045962	.33747
29	.22805	.048788	.34831
30	.23320	.051704	.35921
31	.23831	.054713	.37017
32	.24338	.057819	.38120
33	.24841	.061026	.39232
34	.25341	.064337	.40352
35	.25839	.067756	.41483
36	.26334	.071289	.42625
37	.26828	.074939	.43780
38	.27319	.078712	.44947
39	.27810	.082614	.46130
40	.28300	.086650	.47328
41	.28789	.090828	.48543
42	.29277	.095153	.49776
43	.29766	.099633	.51029
44	.30256	.104275	.52303
45	.30745	.109089	.53599

φ	X	Y	T
$\gamma = 4.6$			
3°	.07575	.002260	06255
2	.04280	.000802	.03858
+1	.01908	.000172	.01825
	+	+	+
0	.00000	.000000	.00000
	—	+	—
−1	.01622	.000138	.01682
2	.03046	.000509	.03259
3	.04324	.001065	.04754
4	.05490	.001777	.06182
5	.06565	.002621	.07557
6	.07566	.003585	.08885
7	.08507	.004656	.10175
8	.09395	.005825	.11430
9	.10239	.007085	.12657
10	.11043	.008431	.13859
11	.11814	.009859	.15038
12	.12555	.011365	.16198
13	.13268	.012947	.17342
14	.13958	.014603	.18470
15	.14627	.016332	.19586

$\gamma = 4.6$

φ^0	X	Y	T
16	.15276	.018133	.20691
17	.15908	.020005	.21786
18	.16525	.021947	.22874
19	.17127	.023961	.23954
20	.17716	.026047	.25030
21	.18293	.028205	.26101
22	.18859	.030435	.27170
23	.19416	.032741	.28236
24	.19964	.035121	.29302
25	.20503	.037580	.30369
26	.21035	.040117	.31437
27	.21560	.042736	.32507
28	.22079	.045439	.33580
29	.22593	.048228	.34657
30	.23102	.051106	.35740
31	.23606	.054076	.36829
32	.24106	.057141	.37924
33	.24603	.060305	.39028
34	.25097	.063572	.40142
35	.25588	.066946	.41265
36	.26076	.070431	.42399
37	.26563	.074033	.43546
38	.27048	.077755	.44706
39	.27532	.081604	.45880
40	.28015	.085586	.47070
41	.28497	.089706	.48277
42	.28979	.093972	.49502
43	.29461	.098391	.50746
44	.29944	.102970	.52011
45	.30427	.107717	.53298

$\gamma = 4.7$

φ^0	X	Y	T
3	.07682	.002304	.06295
2	.04304	.000808	.03869
+1	.01912	.000172	.01827
	+	+	+
0	.00000	.000000	.00000
	−	+	−
−1	.01619	.000138	.01681
2	.03038	.000507	.03255
3	.04309	.001060	.04745
4	.05467	.001766	.06170
5	.06534	.002606	.07539
6	.07528	.003562	.08862

$\gamma = 4.8$

φ^0	X	Y	T
7	.08460	.004623	.10146
8	.09340	.005781	.11396
9	.10176	.007029	.12617
10	.10972	.008362	.13812
11	.11735	.009775	.14985
12	.12468	.011265	.16139
13	.13174	.012830	.17276
14	.13856	.014468	.18399
15	.14517	.016177	.19508
16	.15159	.017958	.20607
17	.15784	.019808	.21696
18	.16393	.021728	.22777
19	.16988	.023718	.23851
20	.17570	.025779	.24920
21	.18140	.027911	.25985
22	.18700	.030114	.27047
23	.19249	.032391	.28108
24	.19790	.034743	.29167
25	.20323	.037170	.30227
26	.20848	.039676	.31288
27	.21367	.042263	.32351
28	.21879	.044931	.33417
29	.22386	.047684	.34488
30	.22888	.050526	.35563
31	.23386	.053457	.36645
32	.23880	.056483	.37734
33	.24370	.059606	.38831
34	.24858	.062831	.39937
35	.25342	.066161	.41053
36	.25824	.069600	.42180
37	.26305	.073154	.43319
38	.26783	.076828	.44471
39	.27261	.080626	.45637
40	.27737	.084554	.46819
41	.28213	.088620	.48018
42	.28689	.092828	.49234
43	.29165	.097187	.50470
44	.29641	.101704	.51727
45	.30117	.106388	.53005

$\gamma = 4.8$

φ^0	X	Y	T
3	.07795	.002351	.06336
2	.04330	.000814	.03880
+1	.01916	.000173	.01828
	+	+	+

$\gamma = 4.8$			
φ	X	Y	T
0			
0	.00000	.000000	.00000
	—	+	—
—1	.01617	.000138	.01679
2	.03030	.000506	.03250
3	.04294	.001056	.04737
4	.05445	.001758	.06157
5	.06504	.002590	.07521
6	.07490	.003539	.08838
7	.08414	.004591	.10116
8	.09286	.005738	.11361
9	.10114	.006974	.12576
10	.10902	.008294	.13765
11	.11657	.009692	.14933
12	.12382	.011167	.16081
13	.13081	.012715	.17212
14	.13756	.014336	.18328
15	.14410	.016026	.19431
16	.15044	.017787	.20524
17	.15662	.019616	.21606
18	.16264	.021514	.22681
19	.16852	.023481	.23749
20	.17427	.025517	.24812
21	.17991	.027624	.25871
22	.18544	.029801	.26927
23	.19087	.032051	.27981
24	.19621	.034374	.29034
25	.20147	.036773	.30087
26	.20666	.039248	.31141
27	.21178	.042802	.32198
28	.21685	.044437	.33258
29	.22185	.047156	.34321
30	.22681	.049962	.35390
31	.23173	.052857	.36465
32	.23660	.055844	.37547
33	.24144	.058927	.38637
34	.24625	.062111	.39736
35	.25104	.065398	.40845
36	.25580	.068793	.41964
37	.26054	.072301	.43096
38	.26526	.075927	.44240
39	.26997	.079675	.45399
40	.27468	.083553	.46573
41	.27938	.087565	.47764
42	.28407	.091719	.48973
43	.28877	.096021	.50201
44	.29346	.100479	.51449
45	.29817	.105100	.52719

$\gamma = 4.9$			
φ	X	Y	T
0			
3	.07915	.002400	.06380
2	.04356	.000821	.03892
+1	.01921	.000173	.01831
	+	+	+
0	.00000	.000000	.00000
	—	+	—
—1	.01615	.000137	.01679
2	.03022	.000504	.03247
3	.04280	.001051	.04730
4	.05423	.001748	.06145
5	.06475	.002575	.07504
6	.07453	.003516	.08816
7	.08369	.004559	.10089
8	.09233	.005696	.11328
9	.10053	.006920	.12537
10	.10834	.008227	.13721
11	.11581	.009611	.14883
12	.12299	.011071	.16025
13	.12990	.012603	.17150
14	.13658	.014206	.18260
15	.14305	.015878	.19358
16	.14933	.017619	.20444
17	.15543	.019428	.21521
18	.16139	.021305	.22589
19	.16720	.023249	.23652
20	.17288	.025262	.24708
21	.17845	.027344	.25761
22	.18392	.029496	.26811
23	.18928	.031719	.27858
24	.19456	.034015	28905
25	.19976	.036384	.29952
26	.20489	.038829	.31000
27	.20995	.041352	.32050
28	.21495	.043955	.33103
29	.21990	.046641	.34160
30	.22480	.049412	.35222
31	.22965	.052271	.36291
32	.23446	.055222	.37366
33	.23924	.058267	.38449
34	.24399	.061410	.39541
35	.24872	.064656	.40642
36	.25342	.068008	.41755
37	.25810	.071472	.42879
38	.26276	.075051	.44016
39	.26741	.078752	.45168
40	.27206	.082580	.46334
41	.27669	.086541	.47517
42	.28133	.090641	.48718

φ	X	Y	T
$\gamma = 4.9$			
0			
43	.28596	.094887	.49938
44	.29060	.099287	.51178
45	.29524	.103848	.52440

φ	X	Y	T
$\gamma = 5.0$			
0			
3	.08044	.002455	.06425
2	.04383	.000828	.03902
+1	.01925	.000174	.01832
	+	+	+
0	.000000	.000000	.00000
	—	+	—
—1	.01612	.000137	.01677
2	.03015	.000502	.03242
3	.04266	.001046	.04721
4	.05401	.001740	.06131
5	.06446	.002560	.07486
6	.07416	.003493	.08793
7	.08324	.004527	.10060
8	.09181	.005654	.11294
9	.09993	.006868	.12497
10	.10767	.008162	.13675
11	.11506	.009533	.14831
12	.12217	.010977	.15967
13	.12901	.012494	.17087
14	.13562	.014080	.18191
15	.14201	.015734	.19283
16	.14822	.017456	.20363
17	.15426	.019245	.21434
18	.16015	.021101	.22497
19	.16590	.023024	.23553
20	.17152	.025014	.24604
21	.17703	.027072	.25650
22	.18243	.029200	.26694
23	.18773	.031397	.27735
24	.19295	.033665	.28776
25	.19809	.036007	.29816
26	.20315	.038423	.30858
27	.20816	.040916	.31902
28	.21310	.043488	.32949
29	.21798	.046142	.34000
30	.22282	.048879	.35056
31	.22762	.051703	.36118
32	.23237	.054618	.37186
33	.23709	.057626	.38263
34	.24179	.060730	.39348
35	.24645	.063936	.40443
36	.25109	.067247	.41548
37	.25571	.070667	.42666
38	.26032	.074202	.43796
39	.26491	.077857	.44940
40	.26950	.081637	.46099
41	.27408	.085548	.47275
42	.27865	.089596	.48468
43	.28323	.093789	.49680
44	.28781	.098133	.50913
45	.29239	.102636	.52167

VII. TABLE OF VALUES OF $h = \frac{1}{2} gt^2 = 193.1447\, t^2$ INCHES.

t	h	t	h	t	h	t	h
"	Inches.	"	Inches.	"	Inches.	"	Inches.
0.10	1.9314	0.21	8.5177	0.32	19.778	0.43	35.713
.11	2.3371	.22	9.3482	.33	21.034	.44	37.393
.12	2.7813	.23	10.217	.34	22.328	.45	39.112
.13	3.2641	.24	11.125	.35	23.660	.46	40.869
.14	3.7856	.25	12.072	.36	25.032	.47	42.666
.15	4.3458	.26	13.057	.37	26.442	.48	44.501
.16	4.9445	.27	14.080	.38	27.890	.49	46.374
.17	5.5819	.28	15.143	.39	29.377	.50	48.286
.18	6.2579	.29	16.244	.40	30.903	.51	50.237
.19	6.9725	.30	17.383	.41	32.468	.52	52.226
.20	7.7258	.31	18.561	.42	34.071	.53	54.254

VIII. A GENERAL TABLE OF VALUES OF $\frac{c^2}{w}s$ FOR OGIVAL-HEADED SHOT.

V.	0	1	2	3	4	5	6	7	8	9
F-s.	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.
54	1 7303	7250	7197	7144	7092	7039	6987	6935	6883	6832
55	1 6780	6729	6678	6627	6577	6526	6476	6426	6376	6326
56	1 6276	6227	6178	6129	6080	6031	5982	5934	5886	5838
57	1 5790	5742	5695	5647	5600	5553	5506	5459	5413	5366
58	1 5320	5274	5228	5182	5137	5091	5046	5001	4956	4911
59	1 4866	4822	4777	4733	4689	4645	4601	4558	4514	4471
60	1 4428	4385	4342	4299	4256	4214	4171	4129	4087	4045
61	1 4003	3962	3920	3879	3838	3796	3755	3714	3674	3633
62	1 3593	3552	3512	3472	3432	3392	3353	3313	3274	3234
63	1 3195	3156	3117	3079	3040	3001	2963	2925	2886	2848
64	1 2810	2772	2735	2697	2660	2622	2585	2548	2511	2474
65	1 2437	2400	2364	2327	2291	2255	2218	2182	2146	2111
66	1 2075	2039	2004	1969	1933	1898	1863	1828	1793	1758
67	1 1724	1689	1655	1620	1586	1552	1518	1484	1450	1417
68	1 1383	1349	1316	1283	1250	1216	1183	1150	1118	1085
69	1 1052	1019	0987	0955	0922	0890	0858	0826	0794	0762
70	1 0731	0699	0667	0636	0605	0573	0542	0511	0480	0449
71	1 0418	0387	0357	0326	0296	0265	0235	0205	0174	0144
72	1 0114	0084	0055	0025	9995	9966	9936	9907	9877	9848
73	9819	9790	9761	9732	9703	9674	9646	9617	9588	9560
74	9531	9503	9475	9447	9419	9391	9363	9335	9307	9279
75	9252	9224	9197	9169	9142	9115	9087	9060	9033	9006
76	8979	8952	8926	8899	8872	8846	8819	8793	8766	8740
77	8714	8688	8662	8636	8610	8584	8558	8532	8507	8481
78	8455	8430	8404	8354	8379	8329	8303	8278	8253	8228
79	8203	8179	8154	8129	8104	8080	8055	8031	8006	7982
80	7958	7934	7909	7885	7861	7837	7813	7789	7766	7742
81	7718	7694	7671	7647	7624	7600	7577	7554	7531	7507
82	7484	7461	7438	7415	7392	7369	7347	7324	7301	7279
83	7256	7234	7211	7189	7166	7144	7122	7100	7078	7055
84	7033	7011	6990	6968	6946	6924	6902	6881	6859	6837
85	6816	6794	6773	6752	6730	6709	6688	6667	6646	6625
86	6604	6583	6562	6541	6520	6499	6478	6458	6437	6417
87	6396	6375	6355	6335	6314	6294	6274	6254	6233	6213
88	6193	6173	6153	6133	6113	6093	6074	6054	6034	6014
89	5995	5975	5956	5936	5917	5897	5878	5859	5839	5820
90	5801	5782	5763	5744	5725	5706	5687	5668	5649	5631
91	5612	5593	5575	5556	5538	5519	5501	5483	5464	5446
92	5428	5410	5392	5374	5356	5338	5321	5303	5285	5268
93	5250	5232	5215	5198	5180	5163	5146	5129	5111	5094
94	5077	5060	5044	5027	5010	4993	4976	4960	4943	4927
95	4910	4894	4847	4861	4845	4829	4812	4796	4780	4764
96	4749	4733	4717	4701	4686	4670	4654	4639	4624	4608
97	4593	4578	4562	4547	4532	4517	4502	4487	4473	4458
98	4443	4429	4414	4399	4385	4371	4356	4342	4328	4314

V.	0	1	2	3	4	5	6	7	8	9
F-s.	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.
99	4300	4285	4271	4258	4244	4230	4216	4203	4189	4176
100	4162	4149	4136	4123	4110	4097	4084	4071	4058	4045
101	4033	4020	4008	3995	3983	3970	3958	3946	3934	3921
102	3910	3898	3886	3874	3863	3851	3840	3829	3817	3806
103	3795	3784	3773	3762	3751	3740	3730	3719	3708	3698
104	3687	3677	3666	3656	3646	3636	3626	3616	3606	3596
105	3586	3576	3567	3557	3547	3538	3528	3519	3510	3501
106	3491	3482	3473	3464	3455	3446	3438	3429	3420	3411
107	3402	3394	3385	3377	3368	3360	3351	3343	3334	3326
108	3318	3310	3301	3293	3285	3277	3269	3261	3252	3244
109	3236	3228	3220	3213	3205	3197	3189	3181	3173	3165
110	3158	3150	3142	3134	3127	3119	3111	3103	3096	3088
111	3080	3073	3065	3058	3050	3043	3035	3028	3020	3013
112	3005	2998	2990	2983	2976	2968	2961	2953	2946	2939
113	2931	2924	2917	2910	2902	2895	2888	2881	2874	2867
114	2859	2852	2845	2838	2831	2824	2817	2810	2803	2796
115	2789	2782	2775	2768	2761	2754	2747	2740	2733	2727
116	2720	2713	2706	2699	2692	2686	2679	2672	2665	2659
117	2652	2645	2638	2632	2625	2618	2612	2605	2598	2592
118	2585	2579	2572	2566	2559	2552	2546	2539	2533	2526
119	2520	2513	2507	2500	2494	2488	2481	2475	2468	2462
120	2456	2449	2443	2436	2430	2424	2417	2411	2405	2399
121	2392	2386	2380	2374	2367	2361	2355	2349	2342	2336
122	2330	2324	2318	2312	2306	2299	2293	2287	2281	2275
123	2269	2263	2257	2251	2245	2239	2233	2227	2221	2215
124	2209	2203	2197	2191	2185	2179	2173	2167	2161	2155
125	2149	2143	2138	2132	2126	2120	2114	2108	2102	2097
126	2091	2085	2079	2073	2068	2062	2056	2050	2045	2039
127	2033	2028	2022	2016	2011	2005	1999	1994	1988	1982
128	1977	1971	1965	1960	1954	1948	1943	1937	1932	1926
129	1921	1915	1909	1904	1898	1893	1887	1882	1876	1871
130	1865	1860	1854	1849	1844	1838	1833	1827	1822	1816
131	1811	1806	1800	1795	1789	1784	1779	1773	1768	1762
132	1757	1752	1746	1741	1736	1730	1725	1720	1715	1709
133	1704	1699	1693	1688	1683	1678	1672	1667	1662	1657
134	1651	1646	1641	1636	1631	1625	1620	1615	1610	1605
135	1599	1594	1589	1584	1579	1574	1569	1564	1558	1553
136	1548	1543	1538	1533	1528	1523	1518	1513	1508	1503
137	1498	1493	1488	1483	1477	1472	1467	1462	1457	1452
138	1447	1442	1437	1432	1427	1422	1418	1413	1408	1403
139	1398	1393	1388	1383	1378	1373	1368	1363	1358	1353
140	1348	1344	1339	1334	1329	1324	1319	1314	1309	1304
141	1300	1295	1290	1285	1280	1275	1270	1266	1261	1256
142	1251	1246	1242	1237	1232	1227	1222	1217	1213	1208
143	1203	1198	1193	1189	1184	1179	1174	1170	1165	1160
144	1155	1151	1146	1141	1136	1132	1127	1122	1118	1113
145	1108	1103	1099	1094	1089	1085	1080	1075	1070	1066
146	1061	1056	1052	1047	1042	1038	1033	1028	1024	1019
147	1014	1010	1005	1001	996	991	987	982	977	973
148	968	963	959	954	950	945	940	936	931	927
149	922	917	913	908	904	899	894	890	885	881

V.	0	1	2	3	4	5	6	7	8	9
F-s.	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.
150	876	871	867	862	858	853	849	844	840	835
151	830	826	821	817	812	808	803	799	794	790
152	785	781	776	771	767	762	758	753	749	744
153	740	735	731	726	722	717	713	708	704	699
154	695	690	686	681	676	672	668	663	659	654
155	650	645	641	637	632	628	623	619	614	610
156	605	601	596	592	588	583	579	574	570	565
157	561	556	552	548	543	539	534	530	525	521
158	516	512	508	503	499	494	490	486	481	477
159	472	468	464	459	455	450	446	442	437	433
160	428	424	420	415	411	406	402	398	393	389
161	385	380	376	371	367	363	358	354	350	345
162	341	337	332	328	324	319	315	310	306	302
163	297	293	289	284	280	276	271	267	263	258
164	254	250	245	241	237	232	228	224	220	215
165	211	207	202	198	194	189	185	181	177	172
166	168	164	160	155	151	147	142	138	134	130
167	126	121	117	113	109	104	100	96	92	88
168	83	79	75	71	67	62	58	54	50	46
169	41	37	33	29	25	21	17	12	8	4

IX. A GENERAL TABLE OF VALUES OF $\frac{c^2}{w}t$ FOR OGIVAL-HEADED SHOT.

Stars (*) indicate that the unit figure is to be taken from the line next below.

V.	0	1	2	3	4	5	6	7	8	9
F-s.	Seconds.	Secs.	Secs.	Secs.	Secs.	Secs.	Secs.	Secs.	Secs.	Secs.
54	22.078	*.980	*.882	*.784	*.688	*.592	*.496	*.401	*.306	*.212
55	21.118	.025	*.933	*.841	*.749	*.658	*.567	*.477	*.388	*.299
56	20.210	.122	.034	*.947	*.860	*.774	*.688	*.603	*.518	*.433
57	19.349	.265	.182	.099	.017	*.935	*.854	*.773	*.692	*.612
58	18.532	.453	.374	.295	.217	.139	.062	*.985	*.908	*.832
59	17.756	.681	.606	.531	.457	.383	.309	.236	.163	.091
60	17.019	*.947	*.876	*.805	*.734	*.664	*.594	*.524	*.455	*.386
61	16.318	.249	.182	.114	.047	*.980	*.913	*.847	*.781	*.715
62	15.650	.585	.520	.456	.392	.328	.265	.201	.139	.076
63	15.014	*.952	*.890	*.829	*.768	*.707	*.647	*.586	*.526	*.467
64	14.407	.348	.290	.231	.173	.115	.057	*.999	*.942	*.885
65	13.829	.772	.716	.660	.605	.549	.494	.439	.385	.330
66	13.276	.222	.168	.115	.062	.009	*.956	*.904	*.852	*.800
67	12.748	.696	.645	.594	.543	.493	.442	.392	.342	.292
68	12.243	.194	.145	.096	.047	*.999	*.950	*.903	*.855	*.807
69	11.760	.713	.666	.619	.572	.526	.480	.434	.388	.343
70	11.297	.252	.207	.162	.118	.073	.029	*.985	*.941	*.898
71	10.854	.811	.768	.725	.682	.639	.597	.555	.513	.471

V.	0	1	2	3	4	5	6	7	8	9
F-s.	Seconds.	Secs.	Secs.	Secs.	Secs.	Secs.	Secs.	Secs.	Secs.	Secs.
72	10.429	.388	.346	.305	.264	.223	.183	.142	.102	.062
73	10.022	*.982	*.942	*.903	*.863	*.824	*.785	*.746	*.708	*.669
74	9.631	.592	.554	.516	.478	.441	.403	.366	.329	.292
75	9.255	.218	.182	.145	.109	.073	.037	.001	*.965	*.930
76	8.894	.859	.824	.789	.754	.719	.684	.650	.616	.581
77	8.547	.513	.480	.446	.412	.379	.346	.312	.279	.246
78	8.214	.181	.148	.116	.084	.052	.020	*.988	*.956	*.924
79	7.893	.861	.830	.799	.768	.737	.706	.675	.645	.614
80	7.584	.553	.523	.493	.463	.453	.404	.374	.345	.315
81	7.286	.257	.228	.199	.170	.141	.113	.084	.056	.027
82	6.999	.971	.943	.915	.887	.859	.832	.804	.777	.750
83	6.722	.695	.668	.641	.615	.588	.561	.535	.508	.482
84	6.456	.430	.404	.378	.352	.326	.300	.275	.249	.224
85	6.198	.173	.148	.123	.098	.073	.048	.024	*.999	*.974
86	5.950	.926	.901	.877	.853	.829	.805	.781	.757	.734
87	5.710	.686	.663	.640	.616	.593	.570	.547	.524	.501
88	5.478	.455	.433	.410	.388	.365	.343	.321	.298	.276
89	5.254	.232	.210	.188	.167	.145	.123	.102	.080	.059
90	5.038	.016	*.995	*.974	*.953	*.932	*.911	*.890	*.870	*.849
91	4.829	.808	.788	.768	.747	.727	.707	.687	.667	.648
92	4.628	.608	.589	.569	.550	.531	.511	.492	.473	.454
93	4.435	.417	.398	.379	.361	.342	.324	.305	.287	.269
94	4.251	.233	.215	.197	.179	.161	.144	.126	.109	.091
95	4.074	.057	.039	.022	.005	*.988	*.971	*.955	*.938	*.921
96	3.905	.888	.872	.856	.839	.823	.807	.791	.775	.759
97	3.743	.728	.712	.697	.681	.666	.650	.635	.620	.605
98	3.590	.575	.560	.546	.531	.516	.502	.487	.473	.459
99	3.444	.430	.416	.402	.389	.375	.361	.347	.334	.320
100	3.307	.294	.281	.267	.254	.241	.229	.216	.203	.190
101	3.178	.165	.153	.141	.128	.116	.104	.092	.080	.069
102	3.057	.045	.034	.022	.011	*.999	*.988	*.977	*.966	*.955
103	2.944	.933	.922	.911	.901	.890	.880	.869	.859	.849
104	2.839	.829	.819	.809	.799	.789	.780	.770	.761	.751
105	2.742	.733	.724	.714	.705	.696	.687	.679	.670	.661
106	2.652	.644	.635	.627	.618	.610	.602	.593	.585	.577
107	2.569	.561	.553	.545	.537	.529	.521	.513	.505	.498
108	2.490	.482	.475	.467	.459	.452	.444	.437	.430	.422
109	2.415	.407	.400	.393	.386	.378	.371	.364	.357	.350
110	2.343	.336	.329	.321	.314	.307	.301	.294	.287	.280
111	2.273	.266	.259	.252	.246	.239	.232	.225	.219	.212
112	2.205	.199	.192	.186	.179	.172	.166	.159	.153	.146
113	2.140	.134	.127	.121	.114	.108	.102	.095	.089	.083
114	2.076	.070	.064	.058	.052	.045	.039	.033	.027	.021
115	2.015	.009	.003	*.997	*.991	*.985	*.979	*.973	*.967	*.961
116	1.955	.949	.943	.937	.931	.926	.920	.914	.908	.902
117	1.897	.891	.885	.880	.874	.868	.863	.857	.851	.846
118	1.840	.834	.829	.823	.818	.812	.807	.801	.796	.790
119	1.785	.779	.774	.768	.763	.758	.752	.747	.742	.736

V.	0	1	2	3	4	5	6	7	8	9
F-s.	Seconds.	Secs.	Secs.	Secs.	Secs.	Secs.	Secs.	Secs.	Secs.	Secs.
120	1.731	.726	.720	.715	.710	.705	.699	.694	.689	.684
121	1.678	.673	.668	.663	.658	.653	.648	.642	.637	.632
122	1.627	.622	.617	.612	.607	.602	.597	.592	.587	.582
123	1.577	.572	.568	.563	.558	.553	.548	.543	.538	.533
124	1.529	.524	.519	.514	.509	.505	.500	.495	.490	.486
125	1.481	.476	.471	.467	.462	.457	.453	.448	.444	.439
126	1.434	.430	.425	.420	.416	.411	.407	.402	.398	.393
127	1.389	.384	.380	.375	.371	.366	.362	.357	.353	.349
128	1.344	.340	.335	.331	.327	.322	.318	.314	.309	.305
129	1.301	.296	.292	.288	.284	.279	.275	.271	.267	.262
130	1.258	.254	.250	.245	.241	.237	.233	.229	.225	.220
131	1.216	.212	.208	.204	.200	.196	.192	.188	.184	.179
132	1.175	.171	.167	.163	.159	.155	.151	.147	.143	.139
133	1.135	.131	.127	.123	.120	.116	.112	.108	.104	.100
134	1.096	.092	.088	.084	.081	.077	.073	.069	.065	.061
135	1.058	.054	.050	.046	.042	.039	.035	.031	.027	.023
136	1.020	.016	.012	.008	.005	.001	*.997	*.994	*.990	*.986
137	0.982	.979	.975	.971	.968	.964	.961	.957	.953	.950
138	.946	.942	.939	.935	.932	.928	.924	.921	.917	.914
139	.910	.907	.903	.899	.896	.892	.889	.885	.882	.878
140	.875	.871	.868	.864	.861	.857	.854	.850	.847	.843
141	.840	.836	.833	.830	.826	.823	.819	.816	.813	.809
142	.806	.802	.799	.796	.792	.789	.785	.782	.779	.775
143	.772	.769	.765	.762	.759	.755	.752	.749	.745	.742
144	.739	.736	.732	.729	.726	.722	.719	.716	.713	.709
145	.706	.703	.700	.696	.693	.690	.687	.683	.680	.677
146	.674	.671	.667	.664	.661	.658	.655	.651	.648	.645
147	.642	.639	.636	.632	.629	.626	.623	.620	.617	.614
148	.610	.607	.604	.601	.598	.595	.592	.589	.586	.583
149	.579	.576	.573	.570	.567	.564	.561	.558	.555	.552
150	.549	.546	.543	.540	.537	.534	.531	.528	.524	.521
151	.518	.515	.512	.509	.506	.503	.500	.497	.494	.491
152	.488	.485	.482	.480	.477	.474	.471	.468	.465	.462
153	.459	.456	.453	.450	.447	.444	.441	.438	.435	.432
154	.429	.427	.424	.421	.418	.415	.412	.409	.406	.403
155	.400	.398	.395	.392	.389	.386	.383	.380	.377	.375
156	.372	.369	.366	.363	.360	.358	.355	.352	349	.346
157	.343	.341	.338	.335	.332	.329	.326	.324	.321	.318
158	.315	.312	.310	.307	.304	.301	.298	.296	.293	.290
159	.287	.285	.282	.279	.276	.274	.271	.268	.265	.263
160	.260	.257	.254	.252	.249	.246	.243	.241	.238	.235
161	.232	.230	.227	.224	.222	.219	.216	.214	.211	.208
162	.205	.203	.200	.197	.195	.192	.189	.187	.184	.181
163	.179	.176	.173	.171	.168	.165	.163	.160	.157	.155
164	.152	.150	.147	.144	.142	.139	.136	.134	.131	.129
165	.126	.123	.121	.118	.116	.113	.110	.108	.105	.103
166	.100	.097	.095	.092	.090	.087	.085	.082	.080	.077
167	.075	.072	.070	.067	.064	.062	.059	.057	.054	.052
168	.049	.047	.044	.042	.039	.037	.034	.032	.029	.027
169	.024	.022	.020	.017	.015	.012	.010	.007	.005	.002

X. A GENERAL TABLE OF VALUES OF $\frac{c^2}{w} s$ FOR SPHERICAL SHOT.

V.	0	1	2	3	4	5	6	7	8	9
F-s.	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.
50	10649	0620	0592	0563	0535	0506	0478	0450	0422	0394
51	10366	0338	0310	0283	0255	0228	0201	0174	0147	0120
52	10093	0066	0040	0013	*9987	9961	9935	9909	9883	9857
53	9831	9805	9779	9754	9729	9703	9678	9653	9628	9603
54	9578	9553	9529	9504	9480	9455	9431	9407	9383	9359
55	9335	9311	9287	9263	9240	9216	9193	9169	9146	9123
56	0100	9077	9054	9031	9008	8986	8963	8941	8918	8896
57	8873	8851	8829	8807	8785	8763	8741	8719	8698	8676
58	8655	8633	8612	8591	8569	8548	8527	8506	8485	8464
59	8443	8423	8402	8381	8361	8340	8320	8300	8279	8259
60	8239	8219	8199	8179	8159	8139	8120	8100	8081	8061
61	8041	8022	8003	7983	7964	7945	7926	7907	7888	7869
62	7850	7832	7813	7794	7776	7757	7739	7720	7702	7683
63	7665	7647	7629	7611	7593	7575	7557	7539	7521	7504
64	7486	7468	7451	7433	7416	7398	7381	7364	7346	7329
65	7312	7295	7278	7261	7244	7227	7210	7194	7177	7160
66	7144	7127	7110	7094	7078	7061	7045	7029	7012	6996
67	6980	6964	6948	6932	6916	6900	6884	6868	6853	6837
68	6821	6806	6790	6775	6759	6744	6728	6713	6698	6682
69	6667	6652	6637	6622	6607	6592	6577	6562	6547	6532
70	6517	6503	6488	6473	6459	6444	6430	6415	6401	6386
71	6372	6358	6343	6329	6315	6301	6287	6273	6259	6245
72	6231	6217	6203	6189	6175	6161	6148	6134	6120	6107
73	6093	6079	6066	6052	6039	6026	6012	5999	5986	5972
74	5959	5946	5933	5920	5907	5894	5881	5868	5855	5842
75	5829	5816	5803	5790	5778	5765	5752	5740	5727	5714
76	5702	5689	5677	5665	5652	5640	5627	5615	5603	5591
77	5578	5566	5554	5542	5530	5518	5506	5494	5482	5470
78	5458	5446	5434	5423	5411	5399	5387	5376	5364	5352
79	5341	5329	5318	5306	5295	5283	5272	5260	5249	5238
80	5226	5215	5204	5193	5181	5170	5159	5148	5137	5126
81	5115	5104	5093	5082	5071	5000	5049	5038	5027	5017
82	5006	4995	4984	4974	4963	4952	4942	4931	4921	4910
83	4900	4889	4879	4868	4858	4847	4837	4827	4817	4806
84	4796	4786	4776	4765	4755	4745	4735	4725	4715	4705
85	4695	4685	4675	4665	4655	4645	4635	4625	4615	4605
86	4596	4586	4576	4566	4557	4547	4537	4528	4518	4509
87	4499	4490	4480	4471	4461	4452	4442	4433	4423	4414
88	4405	4395	4386	4377	4367	4358	4349	4340	4331	4321
89	4312	4303	4294	4285	4276	4267	4258	4249	4240	4231
90	4222	4213	4204	4195	4186	4177	4169	4160	4151	4142
91	4134	4125	4116	4107	4099	4090	4081	4073	4064	4056

V.	0	1	2	3	4	5	6	7	8	9
F-s.	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.
92	4047	4039	4030	4022	4013	4005	3996	3988	3980	3971
93	3963	3954	3946	3938	3930	3921	3913	3905	3897	3888
94	3880	3872	3864	3856	3848	3840	3832	3823	3815	3807
95	3799	3791	3784	3776	3768	3760	3752	3744	3736	3728
96	3721	3713	3705	3697	3689	3682	3674	3666	3659	3651
97	3643	3636	3628	3621	3613	3606	3598	3591	3583	3576
98	3568	3561	3553	3546	3539	3531	3524	3516	3509	3502
99	3495	3487	3480	3473	3466	3458	3451	3444	3437	3430
100	3423	3416	3409	3402	3395	3388	3381	3374	3367	3360
101	3353	3346	3339	3332	3325	3319	3312	3305	3298	3291
102	3285	3278	3271	3265	3258	3251	3245	3238	3231	3225
103	3218	3212	3205	3199	3192	3186	3179	3173	3166	3160
104	3154	3147	3141	3135	3128	3122	3116	3109	3103	3097
105	3091	3084	3078	3072	3066	3060	3054	3048	3041	3035
106	3029	3023	3017	3011	3005	2999	2993	2987	2982	2976
107	2970	2964	2958	2952	2946	2941	2935	2929	2923	2918
108	2912	2906	2900	2895	2889	2883	2878	2872	2866	2861
109	2855	2850	2844	2838	2833	2827	2822	2816	2811	2805
110	2800	2794	2789	2784	2778	2773	2767	2762	2757	2751
111	2746	2741	2735	2730	2725	2719	2714	2709	2704	2698
112	2693	2688	2683	2678	2672	2667	2662	2657	2652	2646
113	2641	2636	2631	2626	2621	2616	2611	2606	2601	2596
114	2591	2586	2581	2576	2571	2566	2561	2556	2551	2547
115	2541	2536	2531	2526	2522	2517	2512	2507	2502	2497
116	2492	2487	2483	2478	2473	2468	2464	2459	2454	2449
117	2444	2440	2435	2430	2426	2421	2416	2411	2407	2402
118	2397	2393	2388	2383	2379	2374	2369	2365	2360	2356
119	2351	2346	2342	2337	2333	2328	2323	2319	2314	2310
120	2305	2301	2296	2292	2287	2283	2278	2274	2269	2265
121	2260	2256	2252	2247	2243	2238	2234	2229	2225	2220
122	2216	2212	2207	2203	2199	2194	2190	2185	2181	2177
123	2172	2168	2164	2159	2155	2151	2146	2142	2138	2134
124	2129	2125	2121	2116	2112	2108	2104	2099	2095	2091
125	2087	2082	2078	2074	2070	2066	2061	2057	2053	2049
126	2045	2040	2036	2032	2028	2024	2020	2015	2011	2007
127	2003	1999	1995	1991	1986	1982	1978	1974	1970	1966
128	1962	1958	1954	1949	1945	1941	1937	1933	1929	1925
129	1921	1917	1913	1909	1905	1901	1897	1893	1889	1885
130	1881	1877	1873	1869	1865	1861	1857	1853	1849	1845
131	1841	1837	1833	1829	1825	1821	1817	1813	1809	1806
132	1802	1798	1794	1790	1786	1782	1778	1774	1770	1766
133	1763	1759	1755	1751	1747	1743	1739	1736	1732	1728
134	1724	1720	1716	1713	1709	1705	1701	1697	1694	1690
135	1686	1682	1678	1675	1671	1667	1663	1660	1656	1652
136	1648	1645	1641	1637	1633	1630	1626	1622	1618	1615
137	1611	1607	1603	1600	1596	1592	1589	1585	1581	1578
138	1574	1570	1567	1563	1559	1556	1552	1548	1545	1541
139	1537	1534	1530	1526	1523	1519	1516	1512	1508	1505
140	1501	1497	1494	1490	1487	1483	1479	1476	1472	1469
141	1465	1461	1458	1454	1451	1447	1444	1440	1437	1433

V.	0	1	2	3	4	5	6	7	8	9
F-s.	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.
142	1429	1426	1422	1419	1415	1412	1408	1405	1401	1398
143	1394	1391	1387	1384	1380	1377	1373	1370	1366	1363
144	1359	1356	1352	1349	1345	1342	1338	1335	1331	1328
145	1324	1321	1318	1314	1311	1307	1304	1300	1297	1293
146	1290	1287	1283	1280	1276	1273	1270	1266	1263	1259
147	1256	1253	1249	1246	1242	1239	1236	1232	1229	1225
148	1222	1219	1215	1212	1209	1205	1202	1199	1195	1192
149	1189	1185	1182	1179	1175	1172	1169	1165	1162	1159
150	1155	1152	1149	1145	1142	1139	1135	1132	1129	1126
151	1122	1119	1116	1112	1109	1106	1103	1099	1096	1093
152	1090	1086	1083	1080	1077	1073	1070	1067	1064	1060
153	1057	1053	1051	1047	1044	1041	1038	1034	1031	1028
154	1025	1022	1018	1015	1012	1009	1006	1002	999	996
155	993	990	987	983	980	977	974	971	968	964
156	961	958	955	952	949	945	942	939	936	933
157	930	927	924	920	917	914	911	908	905	902
158	899	895	892	889	886	883	880	877	874	871
159	868	864	861	858	855	852	849	846	843	840
160	837	834	831	828	825	822	818	815	812	809
161	806	803	800	797	794	791	788	785	782	779
162	776	773	770	767	764	761	758	755	752	749
163	746	743	740	737	734	731	728	725	722	719
164	716	713	710	707	704	701	698	695	692	689
165	686	683	680	677	674	672	669	666	663	660
166	657	654	651	648	645	642	639	636	633	630
167	628	625	622	619	616	613	610	607	604	601
168	598	596	593	590	587	584	581	578	575	572
169	569	567	564	561	558	555	552	549	546	544
170	541	538	535	532	529	526	524	521	518	515
171	512	509	506	504	501	498	495	492	489	487
172	484	481	478	475	472	470	467	464	461	458
173	456	453	450	447	444	442	439	436	433	430
174	428	425	422	419	416	414	411	408	405	402
175	400	397	394	391	389	386	383	380	377	375
176	372	369	366	364	361	358	355	353	350	347
177	344	342	339	336	333	331	328	325	322	320
178	317	314	311	309	306	303	301	298	295	292
179	290	287	284	282	279	276	273	271	268	265
180	263	260	257	255	252	249	246	244	241	238
181	236	233	230	228	225	222	220	217	214	212
182	209	206	204	201	198	196	193	190	188	185
183	182	180	177	174	172	169	166	164	161	158
184	156	153	150	148	145	143	140	137	135	132
185	129	127	124	122	119	116	114	111	108	106
186	103	101	98	95	93	90	88	85	82	80
187	77	75	72	69	67	64	62	59	57	54
188	51	49	46	44	41	39	36	33	31	28
189	26	23	21	18	15	13	10	7	5	3

XI. A GENERAL TABLE OF VALUES OF $\frac{c^2}{w}t$ FOR SPHERICAL SHOT.

Stars (*) indicate that the unit figure is to be taken from the line next below.

V.	0	1	2	3	4	5	6	7	8	9
F-s.	Seconds.	Secs.	Secs.	Secs.	Secs.	Secs.	Secs.	Secs.	Secs	Secs.
50	13.414	.356	.299	.242	.185	.129	.073	.017	*.962	*.907
51	12.852	.798	.744	.690	.637	.584	.531	.478	.426	.374
52	12.323	.272	.221	.170	.119	.069	.020	*.970	*.921	*.872
53	11.823	.775	.726	.679	.631	.584	.537	.490	.443	.397
54	11.351	.305	.259	.214	.169	.124	.080	.036	*.991	*.948
55	10.904	.861	.818	.775	.732	.690	.647	.605	.564	.522
56	10.481	.440	.399	.358	.318	.278	.238	.198	.158	.119
57	10.080	.041	.002	*.964	*.926	*.887	*.849	*.812	*.774	*.737
58	9.700	.663	.626	.589	.553	.517	.481	.445	.409	.374
59	9.338	.303	.268	.234	.199	.165	.130	.096	.062	.029
60	8.995	.962	.929	.895	.863	.830	.797	.765	.733	.700
61	8.669	.637	.605	.574	.542	.511	.480	.449	.419	.388
62	8.358	.327	.297	.267	.237	.208	.178	.149	.120	.090
63	8.061	.033	.004	*.975	*.947	*.919	*.890	*.862	*.834	*.807
64	7.779	.752	.724	.697	.670	.643	.616	.589	.562	.536
65	7.510	.483	.457	.431	.405	.379	.354	.328	.303	.277
66	7.252	.227	.202	.177	.153	.128	.103	.079	.055	.030
67	7.006	*.982	*.958	*.935	*.911	*.887	*.864	*.841	*.817	*.794
68	6.771	.748	.725	.703	.680	.657	.635	.613	.590	.568
69	6.546	.524	.502	.481	.459	.437	.416	.394	.373	.352
70	6.331	.310	.289	.268	.247	.227	.206	.185	.165	.145
71	6.124	.104	.084	.064	.044	.025	.005	*.985	*.966	*.946
72	5.927	.907	.888	.869	.850	.831	.812	.793	.774	.756
73	5.737	.718	.700	.681	.663	.645	.627	.609	.591	.573
74	5.555	.537	.519	.502	.484	.466	.449	.432	.414	.397
75	5.380	.363	.346	.329	.312	.295	.278	.261	.245	.228
76	5.212	.195	.179	.163	.146	.130	.114	.098	.082	.066
77	5.050	.034	.019	.003	*.987	*.972	*.956	*.941	*.926	*.910
78	4.895	.880	.865	.849	.834	.819	.805	.790	.775	.760
79	4.745	.731	.716	.702	.687	.673	.659	.644	.630	.616
80	4.602	.587	.573	.559	.545	.532	.518	.504	.490	.476
81	4.463	.449	.436	.422	.409	.395	.382	.369	.356	.342
82	4.329	.316	.303	.290	.277	.264	.251	.239	.226	.213
83	4.200	.188	.175	.163	.150	.138	.125	.113	.101	.088
84	4.076	.064	.052	.040	.028	.016	.004	*.992	*.980	*.968
85	3.957	.945	.933	.921	.910	.898	.887	.875	.864	.852
86	3.841	.829	.818	.807	.796	.784	.773	.762	.751	.740
87	3.729	.718	.707	.696	.685	.675	.664	.653	.642	.632
88	3.621	.611	.600	.590	.579	.569	.558	.548	.537	.527
89	3.517	.507	.496	.486	.476	.466	.456	.446	.436	.426
90	3.416	.406	.396	.386	.377	.367	.357	.347	.338	.328
91	3.318	.309	.299	.290	.280	.271	.261	.252	.243	.233

V.	0	1	2	3	4	5	6	7	8	9
F-s.	Seconds.	Secs.	Secs.	Secs.	Secs.	Secs.	Secs.	Secs.	Secs.	Secs.
92	3.224	.215	.206	.196	.187	.178	.169	.160	.151	.142
93	3.133	.124	.115	.106	.097	.088	.079	.071	.062	.053
94	3.044	.036	.027	.019	.010	.001	*.993	*.984	*.976	*.967
95	2.959	.951	.942	.934	.926	.919	.909	.901	.893	.885
96	2.876	.868	.860	.852	.844	.836	.828	.820	.812	.804
97	2.797	.789	.781	.773	.765	.758	.750	.742	.734	.727
98	2.719	.712	.704	.697	.689	.682	.674	.667	.659	.652
99	2.645	.637	.630	.623	.616	.608	.601	.594	.587	.580
100	2.572	.565	.558	.551	.544	.537	.530	.523	.517	.510
101	2.503	.496	.489	.482	.476	.469	.462	.456	.449	.442
102	2.436	.429	.423	.416	.409	.403	.397	.390	.384	.377
103	2.371	.365	.358	.352	.346	.339	.333	.327	.321	.315
104	2.308	.302	.296	.290	.284	.278	.272	.266	.260	.254
105	2.248	.242	.236	.231	.225	.219	.213	.207	.202	.196
106	2.190	.184	.179	.173	.167	.162	.156	.151	.145	.140
107	2.134	.129	.123	.118	.112	.107	.102	.096	.091	.085
108	2.080	.075	.070	.064	.059	.054	.049	.043	.038	.033
109	2.028	.023	.018	.013	.008	.003	*.998	*.993	*.988	*.983
110	1.978	.973	.968	.963	.958	.953	.948	.943	.938	.933
111	1.929	.924	.919	.914	.910	.905	.900	.895	.891	.886
112	1.881	.877	.872	.867	.863	.858	.854	.849	.845	.840
113	1.835	.831	.826	.822	.817	.813	808	.804	.800	.795
114	1.791	.786	.782	.778	.773	.769	.765	.760	.756	.752
115	1.747	.743	.739	.735	.730	.726	.722	.718	.714	.709
116	1.705	.701	.697	.693	.689	.684	.680	.676	.672	.668
117	1.664	.660	.656	.652	.648	.644	.640	.636	.632	.628
118	1.624	.620	.616	.612	.608	.604	.600	.596	.593	.589
119	1.585	.581	.577	.573	.569	.566	.562	.558	.554	.550
120	1.547	.543	.539	.535	.532	.528	.524	.520	.517	.513
121	1.509	.506	.502	.498	.495	.491	.487	.484	.480	.476
122	1.473	.469	.466	.462	.459	.455	.451	.448	.444	.441
123	1.437	.434	.430	.427	.423	.420	.416	.413	.409	.406
124	1.402	.399	.395	.392	.388	.385	.382	.378	.375	.371
125	1.368	.365	.361	.358	.355	.351	.348	.344	.341	.338
126	1.334	.331	.328	.325	.321	.318	.315	.311	.308	.305
127	1.302	.298	.295	.292	.289	.285	.282	.279	.276	.272
128	1.269	.266	.263	.260	.257	.253	.250	.247	.244	.241
129	1.238	.234	.231	.228	.225	.222	.219	.216	.213	.210
130	1.206	.203	.200	.197	.194	.191	.188	.185	.182	.179
131	1.176	.173	.170	.167	.164	.161	.158	.155	.152	.149
132	1.146	.143	.140	.137	.134	.131	.128	.125	.122	.120
133	1.117	.114	.111	.108	.105	.102	.099	.096	.093	.091
134	1.088	.085	.082	.079	.076	.073	.071	.068	.065	.062
135	1.059	.057	.054	.051	.048	.045	.043	.040	.037	.034
136	1.032	.029	.026	.023	.020	.018	.015	.012	.010	.007
137	1.004	.001	*.999	*.996	*.993	*.991	*.988	*.985	*.983	*.980
138	0.977	.975	.972	.969	.967	.964	.961	.959	.956	.954
139	0.951	.948	.946	.943	.940	.938	.935	.933	.930	.927
140	0.925	.922	.920	.917	.915	.912	.909	.907	.904	.902
141	0.899	.897	.894	.892	.889	.887	.884	.882	.879	.877

V.	0	1	2	3	4	5	6	7	8	9
F-s.	Seconds.	Secs.	Secs.	Secs.	Secs.	Secs.	Secs.	Secs.	Secs.	Secs.
142	0.874	.872	.869	.867	.864	.862	.859	.857	.854	.852
143	0.849	.847	.844	.842	.839	.837	.835	.832	.830	.827
144	0.825	.822	.820	.818	.815	.813	.810	.808	.806	.803
145	0.801	.798	.796	.794	.791	.789	.787	.784	.782	.780
146	0.777	.775	.773	.770	.768	.766	.763	.761	.759	.756
147	0.754	.752	.749	.747	.745	.742	.740	.738	.736	.733
148	0.731	.729	.727	.724	.722	.720	.717	.715	.713	.711
149	0.708	.706	.704	.702	.700	.697	.695	.693	.691	.688
150	0.686	.684	.682	.680	.677	.675	.673	.671	.669	.666
151	0.664	.662	.660	.658	.656	.653	.651	.649	.647	.645
152	0.643	.641	.638	.636	.634	.632	.630	.628	.626	.623
153	0.621	.619	.617	.615	.613	.611	.609	.607	.605	.602
154	0.600	.598	.596	.594	.592	.590	.588	.586	.584	.582
155	0.580	.578	.576	.574	.572	.570	.568	.565	.563	.561
156	0.559	.557	.555	.553	.551	.549	.547	.545	.543	.541
157	0.539	.537	.535	.533	.531	.529	.527	.525	.523	.521
158	0.519	.517	.515	.513	.511	.510	.508	.506	.504	.502
159	0.500	.498	.496	.494	.492	.490	.488	.486	.484	.482
160	0.481	.479	.477	.475	.473	.471	.469	.467	.465	.463
161	0.462	.460	.458	.456	.454	.452	.450	.448	.446	.445
162	0.443	.441	.439	.437	.435	.433	.432	.430	.428	.426
163	0.424	.422	.421	.419	.417	.415	.413	.411	.410	.408
164	0.406	.404	.402	.401	.399	.397	.395	.393	.392	.390
165	0.388	.386	.384	.383	.381	.379	.377	.375	.374	.372
166	0.370	.368	.367	.365	.363	.361	.360	.358	.356	.354
167	0.353	.351	.349	.347	.346	.344	.342	.340	.339	.337
168	0.335	.333	.332	.330	.328	.327	.325	.323	.321	.320
169	0.318	.316	.315	.313	.311	.309	.308	.306	.304	.303
170	0.301	.299	.298	.296	.294	.293	.291	.289	.288	.286
171	0.284	.283	.281	.279	.278	.276	.274	.273	.271	.269
172	0.268	.266	.264	.263	.261	.260	.258	.256	.255	.253
173	0.251	.250	.248	.247	.245	.243	.242	.240	.238	.237
174	0.235	.234	.232	.230	.229	.227	.226	.224	.222	.221
175	0.219	.218	.216	.215	.213	.211	.210	.208	.207	.205
176	0.203	.202	.200	.199	.197	.196	.194	.192	.191	.189
177	0.188	.186	.185	.183	.182	.180	.178	.177	.175	.174
178	0.172	.171	.169	.168	.166	.165	.163	.162	.160	.159
179	0.157	.156	.154	.152	.151	.149	.148	.146	.145	.143
180	0.142	.140	.139	.137	.136	.134	.133	.131	.130	.129
181	0.127	.126	.124	.123	.121	.120	.118	.117	.115	.114
182	0.112	.111	.109	.108	.107	.105	.104	.102	.101	.099
183	0.098	.096	.095	.093	.092	.090	.089	.088	.086	.085
184	0.083	.082	.080	.079	.078	.076	.075	.073	.072	.070
185	0.069	.068	.066	.065	.063	.062	.061	.059	.058	.056
186	0.055	.054	.052	.051	.049	.048	.047	.045	.044	.042
187	0.041	.040	.038	.037	.035	.034	.033	.031	.030	.029
188	0.027	.026	.024	.023	.022	.020	.019	.018	.016	.015
189	0.014	.012	.011	.009	.008	.007	.005	.004	.003	.001

XII. TABLE OF VALUES OF

$h = \frac{1}{2}gt^2 = 16.0954\,t^2$ FEET.

t	0	1	2	3	4	5	6	7	8	9
″	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.
1.0	16.10	16.42	16.75	17.08	17.41	17.75	18.08	18.43	18.77	19.12
1.1	19.48	19.83	20.19	20.55	20.92	21.29	21.66	22.03	22.41	22.79
1.2	23.18	23.57	23.96	24.35	24.75	25.15	25.55	25.96	26.37	26.78
1.3	27.20	27.62	28.04	28.47	28.90	29.33	29.77	30.21	30.65	31.10
1.4	31.55	32.00	32.45	32.91	33.38	33.84	34.31	34.78	35.26	35.73
1.5	36.21	36.70	37.19	37.68	38.17	38.67	39.17	39.67	40.18	40.69
1.6	41.20	41.72	42.24	42.76	43.29	43.82	44.35	44.89	45.43	45.97
1.7	46.52	47.06	47.62	48.17	48.73	49.29	49.86	50.43	51.00	51.57
1.8	52.15	52.73	53.31	53.90	54.49	55.09	55.68	56.28	56.89	57.49
1.9	58.10	58.72	59.33	59.95	60.58	61.20	61.83	62.46	63.10	63.74
2.0	64.38	65.03	65.68	66.33	66.98	67.64	68.30	68.97	69.64	70.31
2.1	70.98	71.66	72.34	73.02	73.71	74.40	75.09	75.79	76.49	77.20
2.2	77.90	78.61	79.32	80.04	80.76	81.48	82.21	82.94	83.67	84.41
2.3	85.14	85.89	86.63	87.38	88.13	88.89	89.64	90.41	91.17	91.94
2.4	92.71	93.48	94.26	95.04	95.83	96.61	97.40	98.20	98.99	99.79
2.5	100.6	101.4	102.2	103.0	103.8	104.7	105.5	106.3	107.2	108.0
2.6	108.8	109.6	110.5	111.3	112.2	113.0	113.9	114.7	115.6	116.4
2.7	117.3	118.2	119.1	120.0	120.8	121.7	122.6	123.5	124.4	125.3
2.8	126.2	127.1	128.0	128.9	129.8	130.7	131.6	132.6	133.5	134.4
2.9	135.4	136.3	137.2	138.2	139.1	140.1	141.0	142.0	142.9	143.9
3.0	144.9	145.8	146.8	147.8	148.8	149.7	150.7	151.7	152.7	153.7
3.1	154.7	155.7	156.7	157.7	158.7	159.7	160.7	161.7	162.8	163.8
3.2	164.8	165.8	166.9	167.9	169.0	170.0	171.1	172.1	173.2	174.2
3.3	175.3	176.3	177.4	178.5	179.6	180.6	181.7	182.8	183.9	185.0
3.4	186.1	187.2	188.3	189.4	190.5	191.6	192.7	193.8	195.0	196.1
3.5	197.2	198.3	199.4	200.6	201.7	202.8	204.0	205.1	206.3	207.4
3.6	208.6	209.7	210.9	212.1	213.3	214.4	215.6	216.8	218.0	219.2
3.7	220.3	221.5	222.7	223.9	225.1	226.3	227.5	228.8	230.0	231.2
3.8	232.4	233.6	234.9	236.1	237.3	238.6	239.8	241.0	242.3	243.5
3.9	244.8	246.1	247.3	248.6	249.9	251.1	252.4	253.7	255.0	256.2
4.0	257.5	258.8	260.1	261.4	262.7	264.0	265.3	266.6	267.9	269.2
4.1	270.6	271.9	273.2	274.5	275.9	277.2	278.5	279.9	281.2	282.6
4.2	283.9	285.3	286.6	288.0	289.3	290.7	292.1	293.5	294.8	296.2
4.3	297.6	299.0	300.4	301.8	303.2	304.6	306.0	307.4	308.8	310.2
4.4	311.6	313.0	314.4	315.9	317.3	318.7	320.2	321.6	323.0	324.5
4.5	325.9	327.4	328.8	330.3	331.8	333.2	334.7	336.2	337.6	339.1
4.6	340.6	342.1	343.5	345.0	346.5	348.0	349.5	351.0	352.5	354.0
4.7	355.6	357.1	358.6	360.1	361.6	363.2	364.7	366.2	367.8	369.3
4.8	370.8	372.4	373.9	375.5	377.1	378.6	380.2	381.7	383.3	384.9
4.9	386.5	388.0	389.6	391.2	392.8	394.4	396.0	397.6	399.2	400.8
5.0	402.4	404.0	405.6	407.2	408.8	410.5	412.1	413.7	415.3	416.9

t	0	1	2	3	4	5	6	7	8	9
″	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.
5.1	418.6	420.3	421.9	423.6	425.2	426.9	428.5	430.2	431.9	433.5
5.2	435.2	436.9	438.6	440.3	442.0	443.6	445.3	447.0	448.7	450.4
5.3	452.1	453.8	455.5	457.3	458.9	460.7	462.4	464.1	465.9	467.6
5.4	469.3	471.1	472.8	474.6	476.3	478.1	479.8	481.6	483.4	485.1
5.5	486.9	488.6	490.4	492.2	494.0	495.8	497.6	499.4	501.2	503.0
5.6	504.8	506.6	508.4	510.2	512.0	513.8	515.6	517.5	519.3	521.1
5.7	522.9	524.8	526.6	528.5	530.4	532.2	534.0	535.8	537.7	539.6
5.8	541.4	543.3	545.2	547.1	549.0	550.8	552.7	554.6	556.5	558.4
5.9	560.3	562.2	564.1	566.0	567.9	569.8	571.7	573.7	575.6	577.5
6.0	579.4	581.4	583.3	585.2	587.2	589.1	591.1	593.0	595.0	597.0
6.1	598.9	600.9	602.9	604.8	606.8	608.8	610.7	612.7	614.7	616.7
6.2	618.7	620.7	622.7	624.7	626.7	628.7	630.7	632.8	634.8	636.8
6.3	638.8	640.9	642.9	644.9	647.0	649.0	651.1	653.1	655.2	657.2
6.4	659.3	661.3	663.4	665.5	667.5	669.6	671.7	673.8	675.9	677.9
6.5	680.0	682.1	684.2	686.3	688.4	690.5	692.6	694.8	696.9	699.0
6.6	701.1	703.3	705.4	707.5	709.7	711.8	713.9	716.1	718.2	720.4
6.7	722.5	724.7	726.8	729.0	731.2	733.4	735.5	737.7	739.9	742.1
6.8	744.3	746.4	748.6	750.8	753.0	755.2	757.5	759.7	761.9	764.1
6.9	766.3	768.5	770.8	773.0	775.2	777.4	779.7	781.9	784.2	786.4
7.0	788.7	790.9	793.2	795.4	797.7	800.0	802.3	804.5	806.8	809.1
7.1	811.4	813.7	816.0	818.2	820.5	822.8	825.1	827.5	829.8	832.1
7.2	834.4	836.7	839.0	841.3	843.7	846.0	848.4	850.7	853.0	855.4
7.3	857.7	860.1	862.4	864.8	867.1	869.5	871.9	874.3	876.6	879.0
7.4	881.4	883.8	886.2	888.5	890.9	893.3	895.7	898.1	900.6	903.0
7.5	905.4	907.8	910.2	912.6	915.1	917.5	919.9	922.4	924.8	927.2
7.6	929.7	932.1	934.6	937.0	939.5	941.9	944.4	946.9	949.3	951.8
7.7	954.3	956.8	959.3	961.8	964.2	966.7	969.2	971.7	974.2	976.7
7.8	979.2	981.8	984.3	986.8	989.3	991.8	994.4	996.9	999.4	1002
7.9	1005	1007	1009	1012	1015	1017	1020	1023	1025	1028
8.0	1030	1033	1035	1038	1041	1043	1046	1048	1051	1053
8.1	1056	1059	1061	1064	1066	1069	1072	1074	1077	1080
8.2	1082	1085	1088	1090	1093	1095	1098	1101	1104	1106
8.3	1109	1112	1114	1117	1120	1122	1125	1128	1130	1133
8.4	1136	1138	1141	1144	1147	1149	1152	1155	1157	1160
8.5	1163	1166	1158	1171	1174	1177	1179	1182	1185	1188
8.6	1190	1193	1196	1199	1202	1204	1207	1210	1213	1216
8.7	1218	1221	1224	1227	1230	1232	1235	1238	1241	1244
8.8	1246	1249	1252	1255	1258	1261	1264	1266	1269	1272
8.9	1275	1278	1281	1284	1286	1289	1292	1295	1298	1301
9.0	1304	1307	1310	1312	1315	1318	1321	1324	1327	1330
9.1	1333	1336	1339	1342	1345	1348	1350	1353	1356	1359
9.2	1362	1365	1368	1371	1374	1377	1380	1383	1386	1389
9.3	1392	1395	1398	1401	1404	1407	1410	1413	1416	1419
9.4	1422	1425	1428	1431	1434	1437	1440	1444	1447	1450
9.5	1453	1456	1459	1462	1465	1468	1471	1474	1477	1480
9.6	1483	1486	1490	1493	1496	1499	1502	1505	1508	1511
9.7	1514	1518	1521	1524	1527	1530	1533	1536	1540	1543
9.8	1546	1549	1552	1555	1558	1562	1565	1568	1571	1574
9.9	1578	1581	1584	1587	1590	1593	1597	1600	1603	1606

APPENDIX II.

TABLE I.

Densities corresponding to different values of $W - W' + w$, in grammes.

Numbers.	0	1	2	3	4	5	6	7	8	9	Diff.
700	1.93579	551	523	496	468	441	413	385	358	330	27.6
701	303	275	247	220	192	165	137	109	082	054	27.6
702	027	$\overline{997}$	$\overline{972}$	$\overline{944}$	$\overline{917}$	$\overline{890}$	$\overline{862}$	$\overline{835}$	$\overline{807}$	$\overline{780}$	27.4
703	1.92753	725	698	670	643	616	588	561	533	506	27.4
704	479	451	424	396	369	342	314	287	259	232	27.4
705	205	177	150	123	096	069	041	014	$\overline{987}$	$\overline{960}$	27.2
706	1.91933	905	878	851	824	797	770	743	716	689	27.1
707	662	634	607	580	553	526	499	472	445	418	27.1
708	391	364	337	310	283	256	229	202	175	148	27.0
709	121	094	067	040	013	$\overline{986}$	$\overline{959}$	$\overline{932}$	$\overline{905}$	$\overline{878}$	26.9
710	1.90852	825	798	771	744	718	691	664	637	610	26.8
711	584	557	530	503	476	450	423	396	369	342	26.8
712	316	289	262	235	209	182	155	129	102	075	26.7
713	049	022	$\overline{995}$	$\overline{969}$	$\overline{942}$	$\overline{916}$	$\overline{889}$	$\overline{862}$	$\overline{836}$	$\overline{809}$	26.6
714	1.89783	756	730	703	677	651	624	597	571	544	26.5
715	518	491	465	438	412	385	359	332	306	279	26.5
716	253	226	200	173	147	121	094	068	041	015	26.4
717	1.88989	962	936	910	883	857	831	804	778	752	26.3
718	726	699	673	647	620	594	568	541	515	489	26.3
719	463	436	410	384	358	332	306	280	254	228	26.1
720	202	175	149	123	097	071	045	019	$\overline{993}$	$\overline{967}$	26.1
721	1.87941	914	888	862	836	810	784	758	732	706	26.1
722	680	654	628	602	576	550	524	498	472	446	25.9
723	421	395	369	343	317	291	265	239	213	187	25.9
724	162	136	110	084	058	033	007	$\overline{981}$	$\overline{955}$	$\overline{929}$	25.8
725	1.86904	878	852	826	800	775	749	723	697	671	25.8
726	646	620	594	568	543	517	491	466	440	414	25.7
727	389	363	337	311	286	260	234	209	183	157	25.7
728	133	107	082	056	031	005	$\overline{980}$	$\overline{954}$	$\overline{929}$	$\overline{893}$	25.6
729	1.85878	852	827	801	776	750	725	699	674	648	25.5
730	623	598	573	547	522	495	471	446	420	395	25.4

Table I.—Continued.

Numbers.	0	1	2	3	4	5	6	7	8	9	Diff.
731.............	1.85369	344	318	293	267	243	217	192	167	142	25.2
732.............	116	091	066	041	015	$\overline{989}$	$\overline{973}$	$\overline{939}$	$\overline{914}$	$\overline{890}$	24.9
733.............	1.84863	839	813	786	762	737	714	687	653	637	25.7
734.............	612	587	562	536	511	486	461	436	411	389	25.0
735.............	361	336	311	286	260	235	210	185	150	135	25.0
736.............	110	085	060	035	010	$\overline{985}$	$\overline{960}$	$\overline{935}$	$\overline{910}$	$\overline{885}$	25.0
737.............	1.83860	835	811	786	761	736	711	685	661	636	25.0
738.............	612	586	560	536	510	487	461	437	412	388	25.0
739.............	362	338	313	288	264	239	214	189	165	140	25.0
740.............	114	090	064	041	016	$\overline{991}$	967	$\overline{942}$	$\overline{917}$	$\overline{893}$	25.0
741.............	1.82868	843	819	794	769	745	720	695	670	645	24.6
742.............	621	596	572	547	523	498	474	449	425	400	24.5
743.............	376	351	326	302	277	253	228	203	179	154	24.6
744.............	130	105	081	056	032	008	$\overline{983}$	$\overline{959}$	$\overline{934}$	$\overline{910}$	24.6
745.............	1.81886	861	837	812	788	764	739	715	691	666	24.4
746.............	642	617	593	569	544	520	496	471	447	423	24.3
747.............	399	374	350	326	302	278	253	229	205	181	24.2
748.............	157	132	108	084	060	036	011	$\overline{987}$	$\overline{963}$	$\overline{939}$	24.2
749.............	1.80915	890	866	842	818	794	770	746	722	698	24.1
750.............	674	649	625	601	577	553	529	505	481	457	24.1
751.............	433	409	385	361	337	313	289	265	241	217	24.0
752.............	193	169	145	121	097	073	049	025	001	$\overline{977}$	24.0
753.............	1.79953	929	905	881	857	833	809	785	761	737	23.9
754.............	714	690	666	642	619	595	571	548	524	500	23.7
755.............	477	453	429	405	382	358	334	311	287	263	23.7
756.............	240	216	192	168	145	121	097	074	050	026	23.7
757.............	003	$\overline{979}$	$\overline{955}$	$\overline{931}$	$\overline{908}$	$\overline{884}$	$\overline{860}$	$\overline{837}$	$\overline{813}$	$\overline{789}$	23.7
758.............	1.78766	742	719	695	672	648	625	601	578	554	23.5
759.............	531	507	484	460	437	413	390	366	343	319	23.5
760.............	296	272	249	225	202	179	155	132	108	085	23.4
761.............	062	039	015	$\overline{992}$	$\overline{968}$	$\overline{945}$	$\overline{921}$	$\overline{898}$	$\overline{874}$	$\overline{851}$	23.4
762.............	1.77828	804	781	758	734	711	688	664	641	618	23.4
763.............	595	571	548	525	502	479	455	432	409	386	23.2
764.............	363	339	316	293	270	247	223	200	177	154	23.2
765.............	131	107	084	061	038	015	$\overline{992}$	$\overline{969}$	$\overline{946}$	$\overline{923}$	23.1
766.............	1.76900	876	853	830	807	784	761	738	715	692	23.1

TABLE I.—Continued.

Numbers.	0	1	2	3	4	5	6	7	8	9	Diff.
767..............	1.76669	646	623	600	577	554	531	508	485	462	23.0
768..............	439	416	393	370	347	324	301	278	255	232	22.9
769..............	210	187	164	141	118	095	072	049	026	003	22.9
770..............	1.75981	958	935	912	889	866	843	820	797	774	22.9
771..............	752	729	706	683	661	638	615	593	570	547	22.7
772..............	525	502	479	456	434	411	388	366	343	320	22.7
773..............	298	275	252	227	207	184	161	139	116	093	22.7
774..............	071	048	025	003	$\overline{980}$	$\overline{958}$	$\overline{935}$	$\overline{912}$	$\overline{890}$	$\overline{867}$	22.6
775..............	1.74845	822	800	777	755	732	710	687	665	642	22.5
776..............	620	597	575	552	530	507	485	463	440	418	22.5
777..............	395	372	350	327	305	283	260	238	215	193	22.4
778..............	171	148	126	104	081	059	037	014	$\overline{992}$	$\overline{970}$	22.3
779..............	1.73948	925	903	881	858	836	814	791	769	747	22.3
780..............	725	702	680	658	635	613	591	568	546	524	22.3
781..............	502	479	457	435	413	391	368	346	324	302	22.2
782..............	280	257	235	213	191	169	147	125	103	081	22.1
783..............	059	036	014	$\overline{992}$	$\overline{970}$	$\overline{948}$	$\overline{926}$	$\overline{904}$	$\overline{882}$	$\overline{860}$	22.1
784..............	1.72838	815	793	771	749	729	705	683	661	639	22.1
785..............	617	595	573	551	529	507	485	463	441	419	21.9
786..............	398	376	354	332	310	288	266	244	222	200	21.9
787..............	179	157	135	113	091	070	048	026	004	$\overline{982}$	21.8
788..............	1.71961	939	917	895	873	852	830	808	786	764	21.8
789..............	743	721	699	677	656	634	612	591	569	547	21.7
790..............	526	504	482	460	439	417	395	374	352	330	21.7
791..............	309	287	265	243	222	200	178	157	135	113	21.7
792..............	092	070	049	027	006	$\overline{984}$	$\overline{963}$	$\overline{941}$	$\overline{920}$	$\overline{898}$	21.5
793..............	1.70887	855	833	812	790	769	747	725	704	682	21.6
794..............	661	639	618	596	575	554	532	511	489	468	21.4
795..............	447	425	404	382	361	340	318	297	275	254	21.4
796..............	233	211	190	168	147	126	104	083	061	040	21.4
797..............	019	$\overline{997}$	$\overline{976}$	$\overline{954}$	$\overline{933}$	$\overline{912}$	$\overline{890}$	$\overline{869}$	$\overline{847}$	$\overline{826}$	21.3
798..............	1.69806	784	763	742	721	700	679	658	639	616	21.1
799..............	595	573	552	531	509	488	467	445	424	403	21.2
800..............	382	360	339	318	297	276	254	233	212	191	21.1
801..............	170	149	128	107	086	065	044	023	002	$\overline{981}$	21.0
802..............	1.68959	938	917	896	875	854	833	812	791	770	21.0

TABLE I.—Continued.

Numbers.	0	1	2	3	4	5	6	7	8	9	Diff.
803.............	1.68749	728	707	686	665	644	623	602	581	560	21.0
804.............	539	518	497	476	455	434	413	392	371	350	21.0
805.............	329	308	287	266	245	224	203	182	161	140	20.9
806.............	120	099	078	057	036	015	$\overline{994}$	$\overline{973}$	$\overline{952}$	$\overline{932}$	20.9
807.............	1.67912	891	870	849	828	808	787	766	745	724	20.8
808.............	704	683	662	641	621	600	579	559	538	517	20.7
809.............	497	476	455	434	414	393	372	352	331	310	20.7
810.............	290	269	248	228	207	187	166	145	125	104	20.6
811.............	084	063	042	022	001	$\overline{981}$	$\overline{960}$	$\overline{939}$	$\overline{919}$	$\overline{898}$	20.6
812.............	1.66878	857	837	816	796	775	755	734	714	693	20.5
813.............	673	652	632	611	591	570	550	529	509	488	20.5
814.............	468	447	427	406	386	366	345	325	304	284	20.4
815.............	264	243	223	203	182	162	141	121	101	080	20.4
816.............	060	039	019	$\overline{999}$	$\overline{978}$	$\overline{958}$	$\overline{938}$	$\overline{917}$	$\overline{897}$	$\overline{877}$	20.3
817.............	1.65857	836	816	796	775	755	735	714	694	674	20.3
818.............	654	633	613	593	573	553	533	512	492	472	20.2
819.............	452	431	411	391	371	351	330	310	290	270	20.2
820.............	250	229	209	189	169	149	129	109	089	069	20.1
821.............	049	028	008	$\overline{988}$	$\overline{968}$	$\overline{948}$	$\overline{928}$	$\overline{908}$	$\overline{888}$	$\overline{868}$	20.1
822.............	1.64848	828	808	788	768	748	728	708	688	668	20.0
823.............	648	628	608	588	568	548	528	508	488	468	20.0
824.............	448	428	408	388	368	348	328	308	288	268	19.9
825.............	249	229	209	189	169	149	129	109	089	069	19.9
826.............	050	030	010	$\overline{990}$	$\overline{970}$	$\overline{950}$	$\overline{930}$	$\overline{910}$	$\overline{890}$	$\overline{870}$	19.9
827.............	1.63851	831	811	791	771	752	732	712	692	672	19.8
828.............	653	633	613	593	574	554	534	515	495	475	19.7
829.............	456	436	416	396	377	357	337	318	298	278	19.7
830.............	259	239	219	200	180	161	141	121	102	082	19.6
831.............	063	043	023	004	$\overline{984}$	$\overline{965}$	$\overline{945}$	$\overline{925}$	$\overline{906}$	$\overline{886}$	19.6
832.............	1.62867	847	827	808	788	769	749	729	710	690	19.6
833.............	671	651	632	612	593	573	554	534	515	495	19.5
834.............	476	456	437	417	398	379	359	340	320	301	19.4
835.............	282	262	243	223	204	184	165	145	126	106	19.5
836.............	087	067	048	029	009	$\overline{990}$	$\overline{971}$	$\overline{951}$	$\overline{932}$	$\overline{913}$	19.3
837.............	1.61894	874	855	836	816	797	778	758	739	720	19.3
838.............	701	681	662	643	623	604	585	565	546	527	19.3

Table I.—Continued.

Numbers.	0	1	2	3	4	5	6	7	8	9	Diff.
839..............	1.61508	488	469	450	431	412	392	373	354	335	19.2
840..............	316	296	277	258	239	220	200	181	162	143	19.2
841..............	124	104	085	066	047	028	009	$\overline{990}$	$\overline{971}$	$\overline{952}$	19.1
842..............	1.60933	913	894	875	856	837	817	798	779	760	19.2
843..............	741	722	703	684	665	645	627	608	589	570	19.0
844..............	551	532	513	494	475	456	437	418	399	380	19.0
845..............	361	342	323	304	285	266	247	228	209	190	18.9
846..............	172	153	134	115	096	077	058	039	020	001	19.0
847..............	1.59982	963	944	925	906	888	869	850	831	812	18.8
848..............	794	775	756	737	718	700	681	662	643	624	18.8
849..............	606	587	568	549	530	512	493	474	455	436	18.8
850..............	418	399	380	361	342	324	305	286	267	248	18.8
851..............	230	211	192	174	155	137	118	099	081	062	18.6
852..............	044	025	006	$\overline{987}$	$\overline{969}$	$\overline{950}$	$\overline{931}$	$\overline{913}$	$\overline{894}$	$\overline{875}$	18.7
853..............	1.58857	838	820	801	783	764	746	727	709	690	18.5
854..............	672	653	634	615	597	578	559	541	522	503	18.7
855..............	485	466	448	429	411	392	374	356	337	319	18.5
856..............	300	281	263	244	226	208	189	171	152	134	18.4
857..............	116	097	079	060	042	023	005	$\overline{986}$	$\overline{968}$	$\overline{949}$	18.5
858..............	1.57931	912	894	875	857	839	820	802	783	765	18.4
859..............	747	728	710	692	673	655	637	618	600	582	18.3
860..............	564	545	527	509	490	472	454	435	417	399	18.3
861..............	381	362	344	326	307	289	271	252	234	216	18.3
862..............	198	179	161	143	125	107	088	070	052	034	18.2
863..............	016	$\overline{997}$	$\overline{979}$	$\overline{961}$	$\overline{943}$	$\overline{925}$	$\overline{907}$	$\overline{889}$	$\overline{871}$	$\overline{853}$	18.1
864..............	1.56835	816	798	780	762	744	725	707	689	671	18.2
865..............	653	634	616	598	580	562	544	526	508	490	18.1
866..............	472	454	436	418	400	382	364	346	328	310	18.0
867..............	292	273	255	237	219	201	183	165	147	129	18.1
868..............	111	093	075	057	039	021	003	$\overline{985}$	$\overline{967}$	$\overline{949}$	17.9
869..............	1.55932	914	896	878	860	842	824	806	788	770	17.9
870..............	753	735	717	699	681	663	645	627	609	591	17.9
871..............	574	556	538	520	502	485	467	449	431	413	17.8
872..............	396	378	360	342	324	307	289	271	253	235	17.8
873..............	218	200	182	164	146	129	111	093	075	051	17.8
874..............	040	022	004	$\overline{986}$	$\overline{969}$	$\overline{951}$	$\overline{933}$	$\overline{916}$	$\overline{898}$	$\overline{880}$	17.7

Table I.—Continued.

Numbers.	0	1	2	3	4	5	6	7	8	9	Diff.
875..............	1.54863	845	827	809	792	774	756	739	721	703	17.7
876..............	686	668	650	633	615	598	580	562	545	527	17.6
877..............	510	492	474	457	439	422	404	386	369	351	17.6
878..............	334	316	298	281	263	246	228	210	193	175	17.6
879..............	158	140	123	105	083	070	052	034	017	$\overline{999}$	17.6
880..............	1.53982	964	947	929	912	895	877	860	842	825	17.4
881..............	808	790	773	755	738	721	703	686	668	651	17.4
882..............	634	616	599	581	564	547	529	512	494	477	17.4
883..............	460	442	425	407	390	373	355	338	320	303	17.4
884..............	286	268	251	234	216	199	182	164	147	130	17.3
885..............	113	095	078	061	043	026	009	$\overline{991}$	$\overline{974}$	$\overline{957}$	17.3
886..............	1.52940	922	905	888	871	854	836	819	802	785	17.2
887..............	768	750	733	716	699	682	664	647	630	613	17.2
888..............	596	578	561	544	527	510	492	475	458	441	17.2
889..............	424	406	389	372	355	338	321	304	287	270	17.1
890..............	253	235	218	201	184	167	150	133	116	099	17.1
891..............	082	064	047	030	013	$\overline{996}$	$\overline{979}$	$\overline{962}$	$\overline{945}$	$\overline{928}$	17.1
892..............	1.51911	894	877	860	843	826	809	792	775	758	17.0
893..............	741	724	707	690	673	656	639	622	605	588	16.9
894..............	572	555	538	521	504	487	470	453	436	419	17.0
895..............	402	385	368	351	334	317	300	283	266	249	16.9
896..............	233	216	199	182	165	149	132	115	098	081	16.8
897..............	065	048	031	014	$\overline{997}$	$\overline{981}$	$\overline{964}$	$\overline{947}$	$\overline{930}$	$\overline{913}$	16.8
898..............	1.50897	880	863	846	829	813	796	779	762	745	16.8
899..............	729	712	695	678	661	645	628	611	594	577	16.8
900..............	561	544	527	510	494	477	460	444	427	410	16.7
901..............	394	377	360	343	327	310	293	377	260	243	16.7
902..............	227	210	193	177	160	144	127	110	094	077	16.6
903..............	061	044	027	011	$\overline{994}$	$\overline{978}$	$\overline{961}$	$\overline{944}$	$\overline{928}$	$\overline{911}$	16.6
904..............	1.49895	878	862	845	829	812	796	779	763	746	16.5
905..............	730	713	696	680	663	647	630	613	597	580	16.6
906..............	564	547	531	514	498	481	465	448	432	415	16.5
907..............	399	382	366	349	333	317	300	284	267	251	16.4
908..............	235	218	202	185	169	152	136	119	103	086	16.5
909..............	070	053	037	021	004	$\overline{988}$	$\overline{972}$	$\overline{955}$	$\overline{939}$	$\overline{923}$	16.3
910..............	1.48907	890	874	857	841	825	809	792	776	760	16.4

TABLE II.

Table for the reduction of grammes and tenths of grammes to grains.

[From 700 grammes to 910 grammes.]

Numbers.	0	1	2	3	4	5	6	7	8	9
700..................	10801.00	02.5	04.1	05.6	07.2	08.7	10.3	11.8	13.4	14.9
701..................	16.43	17.9	19.5	21.0	22.6	24.1	25.7	27.2	28.8	30.3
702..................	31.9	33.4	35.0	36.5	38.1	39.6	41.2	42.7	44.3	45.8
703..................	47.3	48.8	50.4	51.9	53.5	55.0	56.6	58.1	59.7	61.3
704..................	62.7	64.2	65.8	67.3	68.9	70.4	72.0	73.5	75.1	76.6
705..................	78.2	79.7	81.3	82.8	84.4	85.9	87.5	89.0	90.6	92.1
706..................	93.6	95.1	96.7	98.2	99.8	01.3	02.9	04.4	06.0	07.5
707..................	10909.0	10.5	12.1	13.6	15.2	16.7	18.3	19.8	21.4	22.9
708..................	24.4	25.9	27.5	29.0	30 6	32.1	33.7	35.2	36.8	38.3
709..................	39.9	41.4	43.0	44.5	46.1	47.6	49.2	50.7	52.3	53.8
710..................	55.3	56.8	58.4	59.9	61.5	63.0	64.6	66.1	67.7	69.2
711..................	70.7	72.2	73.8	75.3	76.9	78.4	80.0	81.5	83.1	84.6
712..................	86.2	87.7	89.3	90.8	92.4	93.9	95.5	97.0	98.6	00.1
713	11001.6	03.1	04.7	06.2	07.8	09.3	10.9	12.4	14.0	15.5
714..................	17.0	18.5	20.1	21.6	23.2	24.7	26.3	27.8	29.4	30.9
715..................	32.5	34.0	35.6	37.1	38.7	40.2	41.8	43.3	44.9	46.4
716..................	47.9	49.4	51.0	52.5	54.1	55.6	57.2	58.7	60.3	61.8
717..................	63.3	64.8	66.4	67.9	69.5	71.0	72.6	74.1	75.7	77.2
718..	78.7	80.2	81.8	83.3	84.9	86.4	88.0	89.5	91.1	92.6
719..................	94.2	95.7	97.3	98.8	00.4	01.9	03.5	05.0	06.6	08.1
720..................	11109.6	11.1	12.7	14.2	15.8	17.3	18.9	20.4	22.0	23.5
721..................	25.0	26.5	28.1	29.6	31.2	32.7	34.3	35.8	37.4	38.9
722..................	40.5	42.0	43.6	45.1	46.7	48.3	49.9	51.4	53.0	54.5
723..................	55.9	57.4	59.0	60.5	62.1	63.6	65.2	66.7	68.3	69.8
724..................	71.3	72.8	74.4	75.9	77.5	79.0	80.6	82.1	83.7	85.3
725..................	86.8	88.3	89.9	91.4	93.0	94.5	96.1	97.6	99.2	00.7
726..................	11202.2	03.7	05.3	06.8	08.4	09.9	11.5	13.0	14.6	16.1
727..................	17.6	19.1	20.7	22.3	23.8	25.3	26.9	28.4	30.0	31.5
728..................	33.0	34.5	36.1	37.6	39.2	40.7	42.3	43.8	45.4	46.9
729..................	48.5	50.0	51.6	53.1	54.7	56.2	57.8	59.3	60.9	62.4
730..................	63.9	65.4	67.0	68.5	70.1	71.6	73.2	74.7	76.3	77.8

TABLE II.—Continued.

Numbers.	0	1	2	3	4	5	6	7	8	9
731	11279.3	80.8	82.4	83.9	85.5	87.0	88.6	90.1	91.7	93.2
732	94.8	96.3	97.9	99.4	$\overline{0}1.0$	$\overline{0}2.5$	$\overline{0}4.1$	$\overline{0}5.6$	$\overline{0}7.2$	$\overline{0}8.7$
733	11310.2	11.7	13.3	14.8	16.4	17.9	19.5	21.0	22.6	24.1
734	25.6	27.1	28.7	30.2	31.8	33.3	34.9	36.4	38.0	39.5
735	41.0	42.5	44.1	45.6	47.2	48.7	50.3	51.8	53.4	54.9
736	56.5	58.0	59.6	61.1	62.7	64.2	65.8	67.3	68.9	70.4
737	71.9	73.4	75.0	76.5	78.1	79.6	81.2	82.7	84.3	85.8
738	87.3	88.8	90.4	91.9	93.5	95.0	96.6	98.1	99.7	$\overline{0}1.2$
739	11402.8	04.3	05.9	07.4	09.0	10.5	12.1	13.6	15.2	16.7
740	18.2	19.7	21.3	22.8	24.4	25.9	27.5	29.0	30.6	32.1
741	33.6	35.1	36.7	38.2	39.8	41.3	42.9	44.4	46.0	47.5
742	49.1	50.6	52.2	53.7	55.2	56.8	58.4	59.9	61.5	63.0
743	64.5	66.0	67.6	69.1	70.7	72.2	73.8	75.3	76.9	78.4
744	79.9	81.4	83.0	84.5	86.1	87.6	89.2	90.7	92.3	93.8
745	95.4	96.9	98.5	$\overline{0}0.0$	$\overline{0}1.6$	$\overline{0}3.1$	$\overline{0}4.7$	$\overline{0}6.2$	$\overline{0}7.8$	$\overline{0}9.3$
746	11510.8	12.3	13.9	15.4	17.0	18.5	20.1	21.6	23.2	24.7
747	26.2	27.7	29.3	30.8	32.4	33.9	35.5	37.0	38.6	40.1
748	41.6	43.1	44.7	46.2	47.8	49.3	50.9	52.4	54.0	55.5
749	57.1	58.6	60.2	61.7	63.3	64.8	66.4	67.9	69.5	71.0
750	72.5	74.0	75.6	77.1	78.7	80.2	81.8	83.3	84.9	86.4
751	87.9	89.4	91.0	92.5	94.1	95.6	97.2	98.7	$\overline{0}0.3$	$\overline{0}1.8$
752	11603.4	04.9	06.5	08.0	09.6	11.1	12.7	14.2	15.8	17.3
753	18.8	20.3	21.9	23.4	25.0	26.5	28.1	29.6	31.2	32.7
754	34.2	35.7	37.3	38.8	40.4	41.9	43.5	45.0	46.6	48.1
755	49.7	51.2	52.8	54.3	55.9	57.4	59.0	60.5	62.1	63.6
756	65.1	66.6	68.2	69.7	71.3	72.8	74.4	75.9	77.5	79.0
757	80.5	82.0	83.6	85.1	86.7	88.2	89.8	91.3	92.9	94.4
758	95.9	97.4	99.0	$\overline{0}0.5$	$\overline{0}2.1$	$\overline{0}3.6$	$\overline{0}5.2$	$\overline{0}6.7$	$\overline{0}8.3$	$\overline{0}9.8$
759	11711.4	12.9	14.5	16.0	17.6	19.1	20.7	22.2	23.8	25.3
760	26.8	28.3	29.9	31.4	33.0	34.5	36.1	37.6	39.2	40.7
761	42.2	43.7	45.3	46.8	48.4	49.9	51.5	53.0	54.6	56.1
762	57.7	59.2	60.8	62.3	63.9	65.4	67.0	68.5	70.1	71.6
763	73.1	74.6	76.2	77.7	79.3	80.8	82.4	83.9	85.5	87.0
764	88.5	90.0	91.6	93.1	94.7	96.2	97.8	99.3	$\overline{0}0.9$	$\overline{0}2.4$
765	11803.9	05.4	07.0	08.5	10.1	11.6	13.2	14.7	16.3	17.8
766	19.4	20.9	22.5	24.0	25.6	27.1	28.7	30.2	31.8	33.3

TABLE II.—Continued.

Numbers.	0	1	2	3	4	5	6	7	8	9
767..................	11834.8	36.3	37.9	39.4	41.0	42.5	44.1	45.6	47.2	48.7
768..................	50.2	51.7	53.3	54.8	56.4	57.9	59.5	61.0	62.6	64.1
769..................	65.7	67.2	68.8	70.3	71.9	73.4	75.0	76.5	78.1	79.6
770..................	81.1	82.6	84.2	85.7	87.3	88.8	90.4	91.9	93.5	95.0
771..................	96.5	98.0	99.6	01.1	02.7	04.2	05.8	07.3	08.9	10.4
772..................	11911.9	13.4	15.0	16.5	18.1	19.6	21.2	22.7	24.3	25.8
773..................	27.4	28.9	30.5	32 0	33.6	35.1	36.7	38.2	39.8	41.3
774..................	42.8	44.3	45.9	47.4	49.0	50.5	52.1	53.6	55.2	56.7
775..................	58.25	59.8	61.4	62.9	64.5	66.0	67.6	69.1	70.7	72.2
776..................	73.68	75.2	76.8	78.3	79.9	81.4	83.0	84.5	86.1	87.6
777..................	89.1	90.6	92.2	93.7	95.3	96.8	98.4	99.9	01.5	03.0
778..................	12004.5	06.0	07.6	09.1	10.7	12.2	13.7	15.3	16.9	18.4
779..................	19.9	21.4	23.0	24.5	26.1	27.6	29.2	30.7	32.3	33.8
780..................	35.4	36.9	38.5	40.0	41.6	43.1	44.7	46.2	47.8	49.3
781..................	50.8	52.3	53.9	55.4	57.0	58.5	60.1	61.6	63.2	64.7
782..................	66.3	67.8	69.4	70.9	72.5	74.0	75.6	77.1	78.7	80.2
783..................	81.7	83.2	84.8	86.3	87.9	89.4	91.0	92.5	94.1	95.6
784..................	97.1	98.6	00.2	01.7	03.3	04.8	06.4	07.9	09.5	11.0
785..................	12112.6	14.1	15.7	17.2	18.8	20.3	21.9	23.4	25.0	26.5
786..................	28.0	29.5	31.1	32.6	34.2	35.7	37.3	38.8	40.4	41.9
787..................	43.4	44.9	46.5	48.0	49.6	51.1	52.7	54.2	55.8	57.3
788..................	58.8	60.3	61.9	63.4	65.0	66.5	68.1	69.6	71.2	72.7
789..................	74.3	75.8	77.4	78.9	80.5	82.0	83.6	85.1	86.7	88.2
790..................	89.7	91.2	92.8	94.3	95.9	97.4	99.0	00.5	02.1	03.6
791..................	12205.1	06.6	08.2	09.7	11.3	12.8	14.4	15.9	17.5	19.0
792..................	20.6	22.1	23.7	25.2	26.8	28.3	29.9	31.4	35.0	34.5
793..................	36.0	37.5	39.1	40.6	42.2	43.7	45.3	46.9	48.5	50.0
794..................	51.4	52.9	54.5	56.0	57.6	59.1	60.7	62.2	63.8	65.3
795..................	66.9	68.4	70.0	71.5	73.1	74.6	76.2	77.9	79.3	80.8
796..................	82.3	83.8	85.4	86.9	88.5	90.0	91.6	93.1	94.7	96.2
797..................	97.7	99.2	00.8	02.3	03.9	05.4	07.0	08.5	10.1	11.6
798..................	12313.1	14.6	16.2	17.7	19.3	20.8	22.4	23.9	25.5	27.0
799..................	28.6	30.1	31.7	33.2	34.8	36.3	37.9	39.4	41.0	42.5
800..................	44.0	45.5	47.1	48.6	50.2	51.7	53.3	54.8	56.4	57.9
801..................	59.4	60.9	62.5	64.0	65.6	67.1	68.7	70.2	71.8	73.3
802..................	74.9	76.4	78.0	79.5	81.1	82.6	84.2	85.7	87.3	88.8

Table II.—Continued.

Numbers.	0	1	2	3	4	5	6	7	8	9
803	12390.3	91.8	93.4	94.9	96.5	98.0	99.6	$\overline{0}1.1$	$\overline{0}2.7$	$\overline{0}4.2$
804	12405.7	07.2	08.8	10.3	11.9	13.4	15.0	16.5	18.1	19.6
805	21.2	22.7	24.3	25.8	27.4	28.9	30.5	32.0	33.6	35.1
806	36.6	38.1	39.7	41.2	42.8	44.3	45.9	47.4	49.0	50.5
807	52.0	53.5	55.1	56.6	58.2	59.7	61.3	62.8	64.4	65.9
808	67.4	68.9	70.5	72.0	73.6	75.1	76.7	78.2	79.8	81.3
809	82.9	84.4	86.0	87.5	89.1	90.6	92.2	93.7	95.3	96.8
810	98.3	99.8	$\overline{0}1.4$	$\overline{0}2.9$	$\overline{0}4.5$	$\overline{0}6.0$	$\overline{0}7.6$	$\overline{0}9.1$	$\overline{1}0.7$	$\overline{1}2.2$
811	12513.7	15.2	16.8	18.3	19.9	21.4	23.0	24.5	26.1	27.6
812	29.2	30.7	32.3	33.8	35.4	36.9	38.5	40.0	41.6	43.1
813	44.6	46.1	47.7	49.2	50.8	52.3	53.9	55.4	57.0	58.5
814	60.0	61.5	63.1	64.6	66.2	67.7	69.3	70.8	72.4	73.9
815	75.5	77.0	78.6	80.1	81.7	83.2	84.8	86.3	87.9	89.4
816	90.9	92.4	94.0	95.5	97.1	98.6	$\overline{0}0.2$	$\overline{0}1.7$	$\overline{0}3.3$	$\overline{0}4.8$
817	12606.3	07.8	09.4	10.9	12.5	14.0	15.6	17.1	18.7	20.2
818	21.7	23.2	24.8	26.3	27.9	29.4	31.0	32.5	34.1	35.6
819	37.2	38.7	40.3	41.8	43.4	44.9	46.5	48.0	49.6	51.1
820	52.6	54.1	55.7	57.2	58.8	60.3	61.9	63.4	65.0	66.5
821	68.0	69.5	71.1	72.6	74.2	75.7	77.3	78.8	80.4	81.9
822	83.5	85.0	86.6	88.1	89.7	91.2	92.8	94.3	95.9	97.4
823	98.9	$\overline{0}0.4$	$\overline{0}2.0$	$\overline{0}3.5$	$\overline{0}5.1$	$\overline{0}6.6$	$\overline{0}8.2$	$\overline{0}9.7$	$\overline{1}1.3$	$\overline{1}2.8$
824	12714.3	15.8	17.4	18.9	20.5	22.0	23.6	25.1	26.7	28.2
825	29.7	31.2	32.8	34.3	35.9	37.4	39.0	40.5	42.1	43.6
826	45.2	46.7	48.3	49.8	51.4	52.9	54.5	56.0	57.6	59.1
827	60.6	62.1	63.7	65.2	66.8	68.3	69.9	71.4	73.0	74.5
828	76.0	77.5	79.1	80.6	82.2	83.7	85.3	86.8	88.4	89.9
829	91.5	93.0	94.6	96.1	97.7	99.2	$\overline{0}0.8$	$\overline{0}2.3$	$\overline{0}3.9$	$\overline{0}5.4$
830	12806.9	08.4	10.0	11.5	13.1	14.6	16.2	17.7	19.3	20.8
831	22.3	23.8	25.4	26.9	28.5	30.0	31.6	33.1	34.7	36.2
832	37.8	39.3	40.9	42.4	44.0	45.5	47.1	48.6	50.2	51.7
833	53.2	54.7	56.3	57.8	59.4	60.9	62.5	64.0	65.6	67.1
834	68.6	70.1	71.7	73.2	74.8	76.3	77.9	79.4	81.0	82.5
835	84.1	85.6	87.2	88.7	90.3	91.8	93.4	94.9	96.5	98.0
836	99.5	$\overline{0}1.0$	$\overline{0}2.6$	$\overline{0}4.1$	$\overline{0}5.7$	$\overline{0}7.2$	$\overline{0}8.8$	$\overline{1}0.3$	$\overline{1}1.9$	$\overline{1}3.4$
837	12914.9	16.4	18.0	19.5	21.1	22.6	24.2	25.7	27.3	28.8
838	30.3	31.8	33.4	34.9	36.5	38.0	39.6	41.1	42.7	44.2

TABLE II.—Continued.

Numbers.	0	1	2	3	4	5	6	7	8	9
839..................	12945.8	47.3	48.9	50.4	52.0	53.5	55.1	56.6	58.2	59.7
840..................	61.2	62.7	64.3	65.8	67.4	68.9	70.5	72.0	73.6	75.1
841..................	76.6	78.1	79.7	81.2	82.8	84.3	85.9	87.4	89.0	90.5
842..................	92.1	93.6	95.2	96.7	98.3	99.8	01.4	02.9	04.5	06.0
843..................	13007.5	09.0	10.6	12.1	13.7	15.2	16.8	18.3	19.9	21.4
844..................	22.9	24.4	26.0	27.5	29.1	30.6	32.2	33.7	35.3	36.8
845..................	38.4	39.9	41.5	43.0	44.6	46.1	47.7	49.2	50.8	52.3
846..................	53.8	55.3	56.9	58.4	60.0	61.5	63.1	64.6	66.2	67.7
847..................	69.2	70.7	72.3	73.8	75.4	76.9	78.5	80.0	81.6	83.1
848..................	84.6	86.1	87.7	89.2	90.8	92.3	93.9	95.4	97.0	98.5
849..................	13100.1	01.6	03.2	04.7	06.3	07.8	09.4	10.9	12.5	14.0
850..................	15.5	17.0	18.6	20.1	21.7	23.2	24.8	26.3	27.9	29.4
851..................	30.9	32.4	34.0	35.5	37.1	38.6	40.2	41.7	43.3	44.8
852..................	46.4	47.9	49.5	51.0	52.6	54.1	55.7	57.2	58.8	60.3
853..................	61.8	63.3	64.9	66.4	68.0	69.5	71.1	72.6	74.2	75.7
854..................	77.2	78.7	80.3	81.8	83.4	84.9	86.5	88.0	89.6	91.1
855..................	92.7	94.2	95.8	97.3	98.9	00.4	02.0	03.5	05.1	06.6
856..................	13208.1	09.6	11.2	12.7	14.3	15.8	17.4	18.9	20.5	22.0
857..................	23.5	25.0	26.6	28.1	29.7	31.2	32.8	34.3	35.9	37.4
858..................	38.9	40.4	42.0	43.5	45.1	46.6	48.2	49.7	51.3	52.8
859..................	54.4	55.9	57.5	59.0	60.6	62.1	63.7	65.2	66.8	68.3
860..................	69.8	71.3	72.9	74.4	76.0	77.5	79.1	80.6	82.2	83.7
861..................	85.2	86.7	88.3	89.8	91.4	92.9	94.5	96.0	97.6	99.1
862..................	13300.7	02.2	03.8	05.3	06.9	08.4	10.0	11.5	13.1	14.6
863..................	16.1	17.6	19.2	20.7	22.3	23.8	25.4	26.9	28.5	30.0
864..................	31.5	33.0	34.6	36.1	37.7	39.2	40.8	42.3	43.9	45.4
865..................	46.9	48.4	50.0	51.5	53.1	54.6	56.2	57.7	59.3	60.8
866..................	62.4	63.9	65.5	67.0	68.6	70.1	71.7	73.2	74.8	76.3
867..................	77.8	79.3	80.9	82.4	84.0	85.5	87.1	88.6	90.2	91.7
868..................	93.2	94.7	96.3	97.8	99.4	00.9	02.5	04.0	05.6	07.1
869..................	13408.7	10.2	11.8	13.3	14.9	16.4	18.0	19.5	21.1	22.6
870..................	24.1	25.6	27.2	28.7	30.3	31.8	33.4	34.9	36.5	38.0
871..................	39.5	41.0	42.6	44.1	45.7	47.2	48.8	50.3	51.9	53.4
872..................	55.0	56.5	58.1	59.6	61.2	62.7	64.3	65.8	67.4	68.9
873..................	70.4	71.9	73.5	75.0	76.6	78.1	79.7	81.2	82.8	84.3
874..................	85.8	87.4	89.0	90.5	92.1	93.6	95.2	96.7	98.3	99.8

TABLE II.—Continued.

Numbers.	0	1	2	3	4	5	6	7	8	9
875	13501.2	02.7	04.3	05.8	07.4	08.9	10.5	12.0	13.6	15.1
876	16.7	18.2	19.8	21.3	22.9	24.4	26.0	27.5	29.1	30.6
877	32.1	33.6	35.2	36.7	38.3	39.8	41.4	42.9	44.5	46.0
878	47.5	49.0	50.6	52.1	53.7	55.2	56.8	58.3	59.9	61.4
879	63.0	64.5	66.1	67.6	69.2	70.7	72.3	73.8	75.4	76.9
880	78.4	79.9	81.5	83.0	84.6	86.1	87.7	89.2	90.8	92.3
881	93.8	95.3	96.9	98.4	$\bar{0}0.0$	$\bar{0}1.5$	$\bar{0}3.1$	$\bar{0}4.6$	$\bar{0}6.2$	07.7
882	13609.3	10.8	12.4	13.9	15.5	17.0	18.6	20.1	21.7	23.2
883	24.7	26.2	27.8	29.3	30.9	32.4	34.0	35.5	37.1	38.6
884	40.1	41.6	43.2	44.7	46.3	47.8	49.4	50.9	52.5	54.0
885	55.6	57.1	58.7	60.2	61.8	63.3	64.9	66.4	68.0	69.5
886	71.0	72.5	74.1	75.6	77.2	78.7	80.3	81.8	83.4	84.9
887	86.4	87.9	89.5	91.0	92.6	94.1	95.7	97.2	98.8	$\bar{0}0.3$
888	13701.8	03.3	04.9	06.4	08.0	09.5	11.1	12.6	14.2	15.7
889	17.3	18.8	20.4	21.9	23.5	25.0	26.6	28.1	29.7	31.2
890	32.7	34.2	35.8	37.3	38.9	40.4	42.0	43.5	45.1	46.6
891	48.1	49.6	51.2	52.7	54.3	55.8	57.4	58.9	60.5	62.0
892	63.6	65.1	66.7	68.2	69.8	71.3	72.9	74.4	76.0	77.5
893	79.0	80.5	82.1	83.6	85.2	86.7	88.3	89.8	91.4	92.9
894	94.4	95.9	97.5	99.0	$\bar{0}0.6$	$\bar{0}2.1$	$\bar{0}3.7$	$\bar{0}5.2$	$\bar{0}6.8$	$\bar{0}8.3$
895	13809.9	11.4	13.0	14.5	16.1	17.6	19.2	20.7	22.3	23.8
896	25.3	26.8	28.4	29.9	31.5	33.0	34.6	36.1	37.7	39.2
897	40.7	42.2	43.8	45.3	46.9	48.4	50.0	51.5	53.1	54.6
898	56.1	57.6	59.2	60.7	62.3	63.8	65.4	66.9	68.5	70.0
899	71.6	73.1	74.7	76.2	77.8	79.3	80.9	82.4	84.0	85.5
900	87.0	88.5	90.1	91.6	93.2	94.7	96.3	97.8	99.4	$\bar{0}0.9$
901	13902.4	03.9	05.5	07.0	08.6	10.1	11.7	13.2	14.8	16.3
902	17.9	19.4	21.0	22.5	24.1	25.6	27.2	28.7	30.3	31.8
903	33.3	34.8	36.4	37.9	39.5	41.0	42.6	44.1	45.7	47.2
904	48.7	50.2	51.8	53.3	54.9	56.4	58.0	59.5	61.1	62.6
905	64.2	65.7	67.3	68.8	70.4	71.9	73.5	75.0	76.6	78.1
906	79.6	81.1	82.7	84.2	85.8	87.3	88.9	90.4	92.0	93.5
907	95.0	96.5	98.1	99.6	$\bar{0}1.2$	$\bar{0}2.7$	$\bar{0}4.3$	$\bar{0}5.8$	$\bar{0}7.4$	$\bar{0}8.9$
908	14010.4	11.9	13.5	15.0	16.6	18.1	19.7	21.2	22.8	24.3
909	25.9	27.4	29.0	30.5	32.1	33.6	35.2	36.7	38.3	39.8
910	41.3	42.8	44.4	45.9	47.5	49.0	50.6	52.1	53.7	55.2

TABLE III.

Density of mercury at different temperatures. (*Centigrade.*)

Temperature.	Density.	Temperature.	Density.	Temperature.	Density.
0°	13.59600	14½°	13.56148	23°	13.54095
1	13.59355	15	13.56025	23½	13.53952
2	13.59110	15½	13.55903	24	13.53830
3	13.58865	16	13.55780	24½	13.53707
4	13.58620	16½	13.55658	25	13.53585
5	13.58375	17	13.55536	25½	13.53463
6	13.58130	17½	13.55413	26	13.53340
7	13.57885	18	13.55290	26½	13.53217
8	13.57640	18½	13.55178	27	13.53095
9	13.57395	19	13.55055	27½	13.52973
10	13.57150	19½	13.54933	28	13.52850
11	13.56905	20	13.54810	28½	13.52728
12	13.56760	20½	13.54688	29	13.52606
12½	13.56638	21	13.54565	29½	13.52483
13	13.56515	21½	13.54443	30	13.52361
13½	13.56393	22	13.54320		
14	13.56270	22½	13.54197		

TABLE IV.

Reduction of Fahrenheit to Centigrade scale.

Fahrenheit.	Centigrade.	Fahrenheit.	Centigrade.	Fahrenheit.	Centigrade.	Fahrenheit.	Centigrade.
2°......	0°	49°.....	9° 4-10	66°.....	18° 9-10	83°.....	28° 3-10
3......	5-10	50.....	10	67.....	19 4-10	84.....	28 9-10
34......	1 1-10	51.....	10 5-10	68.....	20	85.....	29 4-10
35......	1 6-10	52.....	11 1-10	69.....	20 5-10	86.....	30
36......	2 2-10	53.....	11 6-10	70.....	21 1-10	87.....	30 5-10
37......	2 7-10	54.....	12 2-10	71.....	21 6-10	88.....	31 1-10
38......	3 3-10	55.....	12 7-10	72.....	22 2-10	89.....	31 6-10
39......	3 9-10	56.....	13 3-10	73.....	22 7-10	90.....	32 2-10
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