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ENGINEERING FACTS AND FIGURES

FOR 1864.

AN

ANNUAL REGISTER OF PROGRESS IN MECHANICAL ENGINEERING AND CONSTRUCTION.

EDITED BY

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PREFACE.

A VARIETY of circumstances—amongst others the lengthened and serious illness of the Editor—has prevented the earlier issue of the present volume of "Engineering Facts and Figures." While, on some accounts, this delay in its issue may be deemed matter for regret, it is right to say that it does not in any way lessen the practical value of the work. For although, as part of its plan, it takes up and records the published experience and facts of the year, this experience and those facts do not partake of the ephemeral nature of what may be called "news of the day," but possess, on the contrary, the valuable characteristic of permanent value. It is thus that the records of any one year may be consulted with advantage long after their issue, dealing chiefly, as they do, with principles and details of practice applicable at all times. It is doubtless so far advantageous to have a regular issue; and, to secure this, arrangements have been made for future volumes; for present failure in this respect it is to be hoped that under the circumstances the consideration claimed will be readily conceded by the reader.

From the numerous and gratifying evidences which have from time to time been obtained from various quarters—both from the press and from private sources—with respect to the first volume, the Editor has been confirmed estimate of the practical purposes which he believed it and still believes it will, serve. For the suggestions he received he is grateful, and some of them are em in the present volume. At the same time, in view class of suggestions which have been offered for hi sideration, it is deemed necessary here to repeat wh stated in the preface to the first volume, that the w *not* designed to embody the opinions of the Editor. is wanted, he believes, are opinions of those who, eit their theoretical investigation or by their practical are enriching the art and the practice of engineerin which opinions have been publicly recorded. Suc ginal remarks, then, given here and there in the of the work, must be taken for what they are wort must be looked upon as introductory to, or corrob of, those of others, and as in no way interfering w to be taken as substitutes for, the recorded opinions thorities. Scattered here and there through the pa publications issued both in this and in other countrie therefore not always within the reach of practical men, opinions of authorities, and their detailed experien practice, find in some measure a permanent and re accessible position in the pages of a work like the pr and which is therefore calculated—as it is believed projectors—to be a valuable companion to the worksh study of the practical man. Nor is it out of place h record the gratification with which they have receive roborative evidence of this from so many and such infl quarters.

In the present volume a few papers are given which

ithin the period of time named in the title-page; but
lthough post- and in one or two instances ante-
vere thought to be of such importance that a place for
re was deemed necessary. For the matter of these
the other papers of which the volume is composed,
tor has to acknowledge his special obligations to the
g Journals published in this country, all of which
ducted with admirable ability, and contain a vast
of valuable facts and papers. He can only regret
limited space at his disposal has prevented him from
the attention of his readers to other subjects dis-
in their pages: — The Engineer; the Mechanics'
ne; the Practical Mechanics' Journal; the Engi-
d Architect's Journal; the Building News; the
; the Chemical News; the Scientific American, pub-
t New York; and the Transactions and Reports of
ntific Societies and Associations.

st, 1865.

CONTENTS.

DIVISION FIRST.

Page.

Boilers, &c.,—

DIVISION SECOND.

Steam Engines,—

DIVISION THIRD.

Steam Fire-engines, &c.,—

DIVISION FOURTH.

team Hammers and Forging Machines,—

DIVISION FIFTH.

Cables, Chains, and Anchors,—

DIVISION SIXTH.

Railways,—

DIVISION SEVENTH.

Ships,—

DIVISION EIGHTH.

Metals used in Construction,—

DIVISION NINTH.

Miscellaneous Notes upon the modes of Working and Using of Iron, &c.,—

DIVISION TENTH.

Page.

Building Materials,—

DIVISION ELEVENTH.

Bridges—Roofs—Reservoirs,—

DIVISION TWELFTH.

Agricultural Machinery,—

DIVISION THIRTEENTH.

Miscellaneous—Machinery in General—Machine Construction,—

DIVISION FOURTEENTH.

Page.

Miscellaneous,—

ENGINEERING

FACTS AND FIGURES FOR 1864.

DIVISION FIRST.

BOILERS AND VESSELS FOR CONTAINING STEAM AND OTHER FLUIDS UNDER HIGH PRESSURE.

1. THE engineering year, of which the following pages are a record, offers in this department of its labours more, perhaps, of novelty, if not of practical utility, than was offered by the year which has passed, for the consideration of those interested in the improvement of certainly not the least important appliance of steam-engine mechanism. It has been one of the characteristic features of — as some, indeed, have deemed it to be a reproach to — modern engineering, that while the most pointed attention was paid to the steam engine, the improvement of old, the bringing out of altogether new forms, and the perfecting of their details, aided by the finest and most accurate workmanship attainable by a system of workshop economy and mechanism remarkable for efficiency, comparatively little attention was paid to the Boiler, upon which the operation of the engine depended. This reproach, however closely it may have been—as we do not, however, hesitate to say it was—applicable to steam-engine boiler-makers at a period dating but a ery few years back, is, we are glad to say, not existent, or, if xisting, only so in a greatly lessened and modified degree. The ommon-sense view of the matter, so long ignored, has at last een taken up and carried out more or less completely by those

interested in the improvement of steam-engine mechanism ; tha view which maintains it to be an inversion of correct principles—no less correct in the physiology of the steam engine tha in that of the human body—where every attention is paid t the arrangement and construction of the body, while the lungs upon which it depends for life, are left altogether, or nearly uncared for; for as the lungs to the human system, so is th boiler to the steam engine. This return to common-sense principles was sure to result—as it has, indeed, already to a larg extent resulted—in a close and philosophical attention being paid to all the circumstances or principles affecting the form o boilers, the materials of which they are constructed, and to the best, the safest, and the most economical manner of working them. But while much has been done, there is doubtless much yet to be done ; more, probably, than some may be disposed to admit, if the dictum be true, which is almost universally held by competent authorities, that "the explosion of a boiler is rather due to the weakness of the boiler than to the strength of the steam contained in it;" or, as put by Mr. Robert Stephenson, "There are but few cases which do not exhibit undue weakness in some part of the boiler." That this, it must be confessed, rather unsatisfactory condition of matter exists, need not, however, be wondered at, if we consider, what, indeed, is too often lost sight of in the discussion of the question of boiler improvement, that the Engineer has to deal with a variety of conflicting circumstances which come into operation in the practical working of boilers, many of which could scarcely have been expected to occur, and the causes of which are occult, being utterly beyond the reach of ocular inspection. Conjectures as to causes of explosion are in many cases all that is left to the Engineer, and where doubt exists because certainty is not within reach, it need not be cause of wonder that, like doctors in similar circumstances, Engineers differ, and differences in theory lead of necessity either to tardiness in improvement or to uncertainty of practice. It is to be hoped, however, that where at present darkness is, or, at best, but a feeble and faint glimmering of light, the full flame of scientific truth will shine leading, as a highly-to-be-wished-for result, to precision in practice. At present, unfortunately, the Engineer is greatly dis turbed, and often baffled, by "a very complex train of mechanical, chemical, and physico-chemical forces," which lead to the "deterioration and consequent destruction of a steam boiler; and it is probable that no other metallic structure is subjected to *such complicated conditions*." The reader, then, will join with us that it cannot be a useless, as we think it is impossible to be otherwise than an interesting, task to glance as briefly as may be at the published results of the inquiries and practical labours of Engineers and men of science interested in the real progress of this most important department of engineering economics, results which have either been published through the medium of our ably-conducted professional papers, or through that of the transactions and journals of our leading scientific associations. To aid in this task, and to give us all the benefit of a ready reference, we purpose to throw these published results under one or other of the following heads:—*a.* Forms of Boilers; the theoretical and practical considerations affecting them. *b.* Materials of which Boilers are made; their nature, strength, and economical practical application. *c.* The working and testing of Boilers. *d.* The explosion of Boilers; and lastly, *e*, the Customs and Legislative enactments connected with the use of Boilers on land and sea. In accordance, then, with this arrangement, we take up the consideration of

2. *a. Forms of Boilers; the Theoretical and Practical Considerations affecting them.*—The greatest novelty of the year we are recording—if not, as named by some authorities, the greatest novelty hitherto introduced into boiler engineering—is the Cast-iron Sphere Boiler, the invention of Mr. Joseph Harrison of Philadelphia, United States. It is scarcely necessary to inform the practical reader that the marked tendency of modern engineering has been to increase the pressure of the contained steam in Boilers—a tendency which, more than any other cause, probably has forced on improvements, or attempted improvements, in boiler construction. From a pressure, for instance, of 50 lbs., at which, in 1830, the locomotives of the Manchester and Liverpool Railway worked, the increase has been gradually progressive, till it has now reached the usual pressure of 130 lbs., and the occasional one of 160 lbs.; while for land engines a pressure of 100 lbs. is by no means uncommon, and is likely soon to be superseded by

one much higher. It has, then, been the aim of Engineers to meet the demand for a greatly-increased pressure of steam by forms of boilers calculated safely and economically to raise it; and amongst those distinguished for the experiments they carefully made, is to be named the gentleman alluded to above. By far the most complete account yet published of the form of boiler invented by Mr. Harrison is that from the pen of Zerah Colburn, Esq., C.E., read before the Institution of Mechanical Engineers, in May 1864, and of which we give the following abstract:—"It was the object of the inventor, Mr. Joseph Harrison, of Philadelphia, U.S., to provide great strength against bursting, and to obtain also a large extent of heating surface in proportion to the weight and external dimensions of the boiler. It was important, moreover, to obtain perfect circulation for the water. An experience of several years in America, and for upwards of two years in London and Manchester—in one case with a boiler supplying steam to the extent of 200 indicated horse-power—has proved that these objects, as well as other important advantages, have been secured. It will not be necessary to describe now the forms which the parts of the boiler received in the earlier experiments several years ago, but these led to the adoption of hollow cast-iron spheres, connected by hollow necks, and secured together by bolts. Each of the castings includes four spheres, each 8 inches in external diameter, $\frac{3}{8}$ths of an inch thick, and connected by necks of 3-inch opening. Each of these castings is called a 'unit.' Each 'unit' of four spheres has eight openings, 3 inches in internal diameter, the edges of these openings being faced up to a true surface so as to bear fairly upon the corresponding faced surfaces of the adjoining 'units.' Each joint has a shoulder and socket, so as to 'steady' the units in their place, and steam-tight caps are provided to cover the external openings, while the whole series of units, forming a slab of rectangular or other form, are held together by bolts of $1\frac{1}{4}$-inch diameter, these bolts passing inside the 'units,' and through the water or steam which they contain. Although the arrangement is simple, it will be better understood from the drawings (not given here), and from the units exhibited to the meeting, than from a purely literal description. Each slab, of whatever number of units it may be rmed, may be regarded as a separate vessel, throughout which the water or steam can circulate freely, both vertically and longitudinally. Any number of slabs may be placed side by side in the same fireplace, and they are connected together by a feed water-pipe at the bottom, and by a steam-pipe at the top. There are eight slabs in the width of the boiler. The water level is usually maintained, so that about two-thirds of the whole number of spheres will be constantly filled with water, the remaining spheres forming a steam space. The full force of the heat is not allowed to come upon those of the spheres which contain only steam, but small fire-brick screens are so placed between the slabs a little below the water level, as to confine the direct action of the heat chiefly to the spheres filled with water. The upper spheres are at the same time enveloped in an atmosphere so hot as to ensure the complete drying of the steam. The slabs are fixed with an amount of inclination, in the direction of their length, sufficient to ensure the complete drainage of all the spheres when the boiler is blown out. This inclination serves, at the same time, to bring the largest body of water to where the action of the heat is most direct, and to provide the largest steam space over that part of the boiler where ebullition is probably the least active. The earlier experiments have shown that, although the 'units' may be bolted together into slabs of a total length of even 20 feet, a length of 9 feet is preferable, as the strain upon the bolts is correspondingly less, and as, in the latter case, there is no observable tendency to sag, the complete tightness of the joints is thereby insured.

"The spheres weigh each about 22½ lbs., a 'unit' of four spheres weighing rather more than 3 cwt. Thus there are, as nearly as may be, one hundred spheres to the ton, and it has been the habit, thus far, to rate the boilers by their weight, as a 4-ton boiler, an 18-ton boiler, &c. The nominal horse power of the cast-iron boiler may be generally taken as three times its weight in tons. Thus, a 10-ton boiler may be rated as of 30 nominal horse power, nd from experiments it appears that a boiler of this weight may e counted upon to evaporate 40 cubic feet of water per hour, orresponding to about 80 indicated horse power. Each sphere ontains seven pints of water, a 'unit' of four spheres containing ½ gallons. The external surface of each sphere is rather more than 1¼ square foot, and *the internal* surface a little more than

$1\frac{1}{8}$ square foot. In round numbers it may be said that each sphere presents a square foot of heating surface, and contains a gallon of water; while a ton of 100 spheres represents three nominal horse power, the proportion of weight to power being about the same as in Lancashire boilers of the ordinary type.

"It cannot be said that cast-iron is, in itself, a strong material for boilers, yet it will appear that, in the form already described, it affords greater absolute strength against bursting than is possessed by any form of plate-iron boiler now in use. The 'units' are cast upon green sand cores, so placed that they cannot alter their position in the flasks by any force short of what would be sufficient to crush them to pieces. The thickness of metal in the spheres is, therefore, everywhere uniform, as has been proved by breaking great numbers of 'units' taken at random. In a unit of four spheres, each sphere having an internal diameter of $7\frac{1}{4}$ inches, the whole area of the plane in which a bursting pressure would act is 220 square inches, while the least section of iron resisting this pressure, in the same plane, is $27\frac{1}{2}$ square inches. The iron employed is an equal mixture of Glengarnock, Carnbroe, and scrap, a mixture selected for its free running quality, and which is much used for small machinery castings. Its tensile strength may be safely taken as $5\frac{1}{2}$ tons per square inch. At this rate the bursting strength of the units would be 1,540 lbs., or nearly 14 cwt. per square inch. The first experiments actually made to test the bursting strength of the units was made upwards of two years ago, in Brussels, at the request of the Belgian Minister of Public Works. In this case a pressure of 98 atmospheres, or 1,440 lbs. per square inch, was applied. This was as high as the force pump employed could go, but the spheres were not burst. When recently in Manchester, the author desired that a further series of experiments might be made with the same object. The arrangements for this purpose could not be completed before he was compelled to return to London, but Mr. Beyer kindly allowed the experiments to be made at the Gorton Foundry, and he deputed Mr. R. H. Burnett, then engaged in that establishment, but who is now Locomotive Superintendent of the Metropolitan Railway, to conduct them. The first of these experiments need t be recorded, as it was made with a hydraulic press gauge, stering up to 4 tons per square inch, but which was subsequently found to be most incorrect. A high-pressure gauge of Schaffer and Budenberg's, graduated to 1,000 lbs., was then attached to one of the units to which the caps had been accurately ground, and a water pressure was then applied by means of a force pump. The pointer of the gauge passed the 1,000 lbs. mark to an extent indicating from 1,150 lbs. to 1,200 lbs., but the spheres did not burst. The Schaffer gauge was then compared with a Bourdon gauge, marked to 500 lbs., and up to this point the gauges agreed within 10 lbs. per square inch. From a calculation of the weight applied to the force-pump lever, and from the dimensions of the pump, Mr. Burnett estimated that the total force applied was about 1,470 lbs. per square inch. Another casting of four spheres was afterwards tested in the same way, the pointer of the Schaffer gauge passing far beyond the 1,000 lbs. mark. In this instance, three men instead of two, as in the first trial, were put to work the pump, but the spheres did not burst. The castings were subsequently broken with a sledge, and showed a uniform thickness, and a good quality of iron.

"A safety-valve was then arranged with the intention of ascertaining the bursting strength of the spheres. The valve was square $\frac{1}{2}$ inch on a side, and therefore of $\frac{1}{4}$th square inch area. Its head was $1\frac{1}{4}$ inch in diameter, and was ground carefully to its seat. The spheres were burst at a pressure calculated at 1,850 lbs. per square inch, but on comparing the safety-valve with a pressure gauge, it appeared that water must have worked its way over the ground seating of the valve, and that the true pressure could have hardly been so much. The seat of the valve was then turned to a diameter of $\frac{7}{8}$ths of an inch, and the spheres were burst at a calculated pressure of 1,650 lbs. per square inch. Even here it was found that some water must have worked under the valve seating, thus exerting its pressure upon an area greater than one-fourth of 1 square inch. The experiments with the safety-valve were not, therefore, altogether satisfactory, but there appeared no reason to doubt that the bursting pressure was not far short of 1,500 lbs. per square inch. All these experiments were made upon castings having their covering-caps ground carefully to them, and the bolts were only about 9 inches long between the caps covering the opposite openings of the units. When, however, a slab of perhaps 100 spheres is bolted together, the bolts being upwards of 9 feet in length, the application of a strain considerably below the bursting pressure so stretches the bolts as to cause the joints to open everywhere and relieve the pressure. In this way every joint becomes a safety-valve. This never occurs with any practicable steam pressure, but it did take place in many of the earlier experiments made to burst the spheres, although leakage seldom commenced until a strain of nearly or quite half a ton per square inch had been applied.

"All these experiments were made with new castings, and at the time they were made no other spheres could be had which had been more than twelve months in use; and the condition of these was clearly the same as when new. It would appear, therefore, that the boiler now described possesses the same factor of safety under a pressure of 225 lbs. per square inch as a 7-feet Lancashire boiler under a pressure of 50 lbs. If, however, one of the units of the cast-iron boiler should burst, it could not do more than empty itself, and open one or more 3-inch apertures into the units adjacent to it. If, however, an ordinary boiler, containing, say, 20 tons of highly-heated water in one compartment, should burst, the consequences would be most disastrous.

* * * * *

"Mr. Harrison had, from the first, counted upon entire freedom from corrosion of the spheres, and the experience thus far has borne out this anticipation. Cast-iron, as is well known, endures much better than wrought-iron under the action of flame, water, and other corrosive influences. It need hardly be said that plate iron would, if employed for gas retorts, be immediately burnt through, yet until the introduction of clay retorts, cast-iron answered very well. The pipes for heating the blast of blast furnaces were originally made by Mr. Neilson of plate-iron, but, although the blast was then heated to but 350°, it became immediately necessary to resort to cast-iron heating-pipes. The superior durability of cast-iron forge tuyeres, especially where made hollow and lined with water, is well known. Mr Jaffrey, the engineer to Messrs. Thomas Richardson & Sons, of Hartlepool, has employed cast-iron superheaters with much success, and he has informed the author that four superheaters upon his plans, fitted on board the steam-colliers Berwick, Killingworth, Wearmouth, and Earl of Elgin, showed no sign of corrosion when examined in October last, after four years of almost constant service. Mr. Jaffrey's assistant reported to him that the superheaters 'looked almost as well as on the day they were put in; there was not the slightest sign of external corrosion, and the pipes, when cleaned, looked like new castings. The cast-iron connections of the Earl of Elgin are just the same; the heat does not seem to have taken any effect on them.' Mr. Jaffrey adds, 'I am quite satisfied in my own mind as to the value of cast-iron where a strong heat is applied, as these and kindred instances establish.' In the case of the Harrison boiler, many castings have been purposely removed and examined, but their weight is the same as when they went in, and the joints show no degradation of their original surface.

"The point in connection with the boiler now described, which caused most apprehension in the first instance, was that of maintaining a clean surface within the spheres. The cast-iron boiler may be said to belong to the family of water-tube boilers, or those having small water cells. The water-tube boiler is at least sixty years old, for Arthur Woolf fitted one in Meux's brewery in London in the year 1804. In the same year, John C. Stevens of New York worked a small screw steamboat on the river Hudson, the engine of which vessel was made by Boulton & Watt, while the boiler had eighty-one water tubes 1 inch in diameter and 2 feet long. From the first, however, water-tube boilers have generally failed on account of defective circulation, and from the difficulty of keeping the tubes free from internal deposit. Many attempts have been made to remove this difficulty. Mr. William Henry James long ago proposed to employ circulating pumps, in addition to the ordinary feed-pump, to maintain a constant circulation of water through the tubes. The boilers of the first American steam fire-engines were thus constructed, and Mr. Spencer, and Mr. Russell some time since, gave descriptions of such a boiler to this Institution. Other forms of water-tube boilers have been made with different means for promoting a circulation of the water, but in all cases the whole of the inorganic matter contained in the feed water must remain in the boiler, unless it be blown on while working; and in the case of some salts held in solution by ordinary boiler waters, these are inevitably, and almost *irremovably, deposited* upon some part of the internal surfaces. The Harrison boiler forms no exception to the general experience in this respect. The water with which Messrs. Hetheringtons', and, indeed, most boilers in Manchester, are fed, is such as to form a hard scale, $\frac{1}{8}$th of an inch thick, after a few weeks' time. A tool had been contrived with steel scrapers, so hinged, that it might be entered through any of the openings in the cast-iron boiler, and be then forced out to the internal circumference of the spheres. By then working this tool within the sphere, the scale would be removed, so that it could afterwards be blown out. Unexpectedly, however, no occasion has arisen for the use of this tool. It was found that the supply of steam continued good without it, and that none of the spheres were overheated or leaking. The boiler was regularly blown out at the end of every week. After ten months' work it was desired to increase the boiler power at Messrs. Hetheringtons', and as the large cast-iron boiler then in use there was formed of units having only two spheres each, it was thought best to replace it with a new boiler having four spheres in each unit, with the exception of those employed for breaking joint, which had two spheres as before. On taking down the old boiler little or no scale was found in any of the spheres, some of which, in the same condition as when taken down, are now exhibited to the meeting. . . . The fact that the spheres of the Harrison boiler shed their scale is not referrible, therefore, to the material of which they are made. It might, perhaps, be argued that the water is occasionally driven from the internal surfaces, and that the consequent expansion of the spheres, and their subsequent contraction on the return of the water, would account for the loosening and breaking of the scale. But the spheres show no evidence—as in this case they might be expected to do—of the irregular action of the fire, and, too, those of the spheres which are placed far behind, where the action of the heat is moderated, are equally free from scale. It appears to be more probable that, as the spheres expand at all parts, and, in cooling, contract equally at the same parts, the scale is detached and crushed in this process of contraction. If this conjecture be correct, the unexpected separation of the scale may be attributed to the form and dimensions of the spheres themselves. Whatever explanation may be offered, it is certain that, with foul water, and with such as gives much trouble with other boilers, the scale breaks freely off, and into small pieces, in the cast-iron boiler now described. This is, perhaps, one of its most valuable properties; but it was quite unforeseen. It would not be prudent to anticipate the result in the case of the application of the Harrison boiler to marine purposes; but with all the land boilers upon the plan now described, it has been found that, with a blowing off once a-week, they may be worked indefinitely without any formation of scale. The description already given will show how readily the cast-iron boiler may be laid open for examination, and it was recently thought expedient to open the large boiler at Messrs. Hetheringtons' for this purpose. A small quantity of loose and broken scale—perhaps a tablespoonful—was found in each of the spheres examined, but their internal surfaces, so far as they could be seen, were entirely clear.

"The evaporative efficiency of the cast-iron boiler depends, as in the case of all other boilers, upon the amount of heating surface exposed in proportion to the consumption of a given weight of fuel in a given time. The boiler, by which Messrs. Hetheringtons' works are now driven, supplies an amount of steam which a single Lancashire boiler, 7 feet in diameter, 30 feet long, and weighing 14 tons, was found inadequate to produce. Both the original and the present boiler are in connection with a chimney 165 feet high, and which affords an excellent draught. The Lancashire boiler had two flues, 2½ feet each in diameter, and enlarged at the fireplace to 3 feet. The area of the fire-bars was 36 square feet, and the total run of the heat was 90 feet in length. The cast-iron boiler now in use has about 1,800 spheres, weighing 18 tons, and presenting about 1,600 square feet of surface in the water spheres, and about 700 square feet in the steam spheres. The area of fire-grate is 33 square feet. The usual quantity of water carried is 147 cubic feet, or rather more than 4 tons, the quantity usually carried in the former Lancashire boiler being nearly 20 tons. The external dimensions of the present boiler are considerably less than those of the Lancashire boiler formerly employed. Rather more than 3 cwt. of coal are now required in raising 50 lbs. of steam from cold water, and the time occupied is about half-an-hour. . . . .

"In conclusion, it is believed that the boiler now described possesses several important advantages. It is believed to be absolutely secure from explosion, and, so far as experience has gone, free from any liability to choke with scale. It is durable, easily taken apart and put together, and it may be erected in almost any form, adapted to that of the space in which it may be necessary to place it. The parts are very portable, and they may be taken through any opening where a boy can pass. Any part of a boiler upon this construction may be readily renewed if necessary, and an existing boiler may be at any time readily enlarged, and to an indefinite extent, by adding to the number of slabs either at the sides or at the back. The economy of the boiler in first cost is obvious, and with proper proportions between the fire-grate and heating surfaces, as high an evaporative efficiency may be had as with most other forms of boilers. The quantity of water carried being comparatively small, steam may be raised with a small quantity of fuel, and in a short space of time. Water may be left standing in the boiler for almost any length of time without injury. Every part of the boiler is at all times under ready observation, without disturbing the connections, and the spheres may be easily swept on their outside. The setting of the boiler is such, also, that the steam may be dried to any extent desired in the spheres themselves, without any other provision for superheating. It is thought that this boiler especially meets the increasing tendency to use high pressure steam, and that the description now given will, therefore, prove interesting to the members of this Institution."

3. A very able paper in the "Engineer" (October 21st, 1864) describes the "*properties of the hollow sphere*," which forms the principal feature of the " Harrison Boiler " described in last par. This we extract below, and request the particular attention of the reader to some of the very suggestive points contained in it. "The properties of the hollow sphere have not, until very recently, received any considerable amount of attention in connection with boiler engineering, and so little, indeed, are they yet understood that one of the most eminent men in our profession lately asked, when he was shown a boiler formed entirely of hollow spheres, "Why are not these made as cylinders?" The ength of a hollow sphere to resist internal pressure is exactly ice that of a hollow cylinder of the same diameter, material,

and thickness; and it can be shown that even a cast-iron sphere, 7 ft. in diameter, and $\frac{7}{16}$ths inch thick, is as strong as the shell of a Cornish boiler of the same dimensions. The plane in which rupture, if it happen at all, will take place in a hollow sphere, is the largest plane that can be drawn through it, and the metal, resisting the strain tending to cause rupture, is the whole section of metal bounding that plane. Thus, in a hollow metal sphere 2 ft. in diameter, the plane upon which an internal pressure of steam, for example, is exerted, is $3\frac{1}{7}$ square feet in extent, while the section of the metal resisting the strain will be the circumference of the sphere multiplied by the thickness of the metal, or, say, with a 2 ft. sphere and a $\frac{1}{2}$in. plate, about 38 square inches. In a hollow cylinder, the area upon which the greatest pressure tending to cause rupture will be exerted, is that represented by the product of the length into the diameter of the cylinder. And the metal which would be torn across in a complete separation of the cylinder into two halves would be that bounding the sides and ends of the plane just defined. But the ends of the cylinder oppose no resistance to a pressure about to rupture it at the middle of its length, at least where this length is equal to the diameter of the cylinder. And as, in the case of boilers, a rupture may lead to, and is commonly equivalent to, an explosion, we must dismiss from our consideration of the strength of the cylinder the resistance of the metal forming the heads or ends. Taking the metal in the sides only of the hollow cylinder we shall find that, with a diameter of 2 ft. and a thickness of metal of $\frac{1}{2}$in., as in the case of the hollow sphere already considered, an internal plane of $3\frac{1}{7}$ square feet will occupy but about 19 in. of the length of the cylinder, and the metal bounding the sides of that plane will have a section of but 19 square inches, instead of 38 as in the case of the hollow sphere. And as long as the diameter and thickness of the hollow sphere and the hollow cylinder are the same, it will be found that but one-half as much metal is opposed to the pressure exerted upon a given area in the latter as in the former; the cylinder, therefore, being but half as strong as the sphere.

"The fact that a 7 ft. cast-iron sphere, $\frac{1}{2}$in. thick, may be as strong as a riveted wrought-iron cylinder of the same dimensions may be easily explained, *it* being understood that, in this case, only the strength to resist internal fluid or steam pressure is considered. The average tensile strength of wrought-iron may be taken as 22 tons per square inch, and that of cast-iron as a little more than 6 tons. But in punching and single rivetting boiler work nearly one-half, or, to take the results of Mr. Fairbairn's experiments, 44 per cent. of the strength of the metal is destroyed, by the loss of iron punched out, and the slight injury done to the iron remaining between the rivet holes, injury which Mr. Fairbairn's experiments have proved to be committed. Thus iron of a strength of 22 tons is really weakened to less than $12\frac{1}{2}$ tons in a single riveted boiler, for this is the ultimate strength along the joints; and the excess of strength elsewhere is of no service, unless to give stiffness, and to resist corrosion. Having thus brought the strength of the wrought-iron down to $12\frac{1}{2}$ tons per square inch, the cast-iron, of $6\frac{1}{4}$ tons, having no riveted seams, will, in the form of the hollow sphere, have exactly the same strength to resist bursting as the wrought-iron cylinder. Not that any one would propose to employ a cast-iron sphere of such dimensions as a high-pressure boiler, but it is as well, nevertheless, to know its real powers of resistance, and the comparison will at least show that small cast-iron spheres are practically unburstable.

"The great strength of the hollow sphere is obtained without any sacrifice of weight; or, in the case of boilers, of external surface. A row of spheres, say 1 ft. in diameter and ten in number, will, if close together, present the same surface as a cylinder 1 ft. in diameter and 10 ft. long, leaving out of consideration only the two ends of the cylinder, which are generally useless as heating surface. And so of any space, it can be filled with spheres in straight rows, which shall present the same surface as cylinders of the same diameter and length. If the spheres are placed as in a pile of cannon balls, the total surface to be arranged within a given space is, of course, much increased. And with the same thickness of metal in each case the weight is exactly as the surface presented. In the case of a boiler a close row of spheres of a given diameter will contain but two-thirds the quantity of wa- er which would be contained by a cylinder of the same length diameter. This, perhaps, is rather an advantage than other- , as, with the exception of multitubular boilers, most land boilers contain far more water than is desirable, except for the purpose of keeping the heating surfaces covered.

"The advantages of the hollow sphere are best secured in cast metal, which, it is needless to say, can be readily and cheaply moulded into almost any form whatever. But for the practical difficulties in the way of working plate metal into the spherical form, that would be the best for all boilers. Where, then, cast-iron is adopted, as in the case of the boilers for working the machinery of the Dublin Exhibition, the cylindrical form is objectionable, because, not only is one-half of the strength of the material thrown away, so to speak, but no arrangement of small cylindrical water spaces has yet been known to give a complete circulation in a boiler. Besides, while it is known that boiler scale, lodged upon the internal surfaces of cast-iron boiler spheres, is periodically loosened and thrown off by a natural process, it is also known from the experience with the early forms of cast-iron boilers, and from the water tubes of the 'Economisers' in use in Lancashire, that it adheres firmly to the interiors of cast-iron cylinders, defying removal, except by mechanical means. Cast-iron cylinders, too, cannot be cast without some danger of the core floating in the mould so as to cause an unequal thickness of metal on opposite sides, and if either head be cast in, there is a strain left in the casting, on its cooling in the foundry. Nor can any arrangement of cast-iron cylinders be contrived in which the expansion and contraction due to irregularities of temperature can expend itself freely. These considerations are of great practical consequence, and while so decided a tendency is being manifested to return to cast-iron as a material for the construction of steam boilers, the many advantages of the hollow sphere should be fully considered and turned to account. Its self-scaling property, when used in a boiler fed with hard water, *is one of the most remarkable discoveries in boiler engineering*, and as this property is not known to be possessed by any other form, it seems sufficient, if there were no other advantages, to decide the question of cast-iron pheres *v.* cast-iron cylinders for steam boilers."

4. The science of Engineering abounds, like that of other ciences, with "vexed questions," and of these probably the one oncerned with "tubular" as against other forms of boilers, has een discussed with the utmost pertinacity of opinionativeness;

and with not a little of that warmth which is most appropriately suggestive of the subject. This is well hit off in the introduction to an article on "Tubular Boilers" in the "Mechanics' Magazine" for July 22d, 1864, which, conveying so much that is practically valuable as to details at present adopted, as well as much that is suggestive of future improvement, we do the reader a service by giving *in extenso.*

"There is not a question," says the author, "connected with the steam engine or the employment of steam power, which has not at one time or another been made the subject matter for bitter discussion. The value of the heating surface of tube flues, in particular, stands forth prominently, as one of the most fertile soils for the production of this kind of argument that has yet been cultivated. We question if two men of science who have given any thought to the matter, can be found at this moment who will agree even on the conditions under which the tubular boiler can be worked to the most advantage. As to its comparative abstract value, it seems all but hopeless to expect an unanimity of opinion. Very many and very elaborate experiments have been conducted from time to time, but, regarded in the proper light, these experiments impart very little information. As a rule, they have been two-fold in their object. In the first place, they have been instituted to determine the value of flue surface as compared with fire-box surface in the same boiler; and, secondly, they have now and again been employed to determine the value of the tubular as compared with the Cornish or the externally fired boiler. As to the first, it is somewhat remarkable that there are no recorded instances of experiments conducted under other than abnormal conditions, that is to say, the generator has never been employed as generators of the class would be in actual work. As to the second, we are at a loss to find an instance wherein precisely the same coals, the same stack and draught, and the same water supply, were employed in each case, and it is yet more difficult still, to find an instance wherein all parties were not previously impressed with the superiority of one or other class of boiler over that with which it has been compared. In spite of the utmost conscientiousness on the part of the experimentalist, such a bias is certain to produce results on which it is difficult to place implicit reliance.

"The truth of the matter is this: apart from its economical value, the tubular boiler possesses certain constructive advantages which have brought it into high favour. No other practical generator—by which we mean one moderately cheap and not likely soon to get out of order—will bear a moment's comparison with the tubular in its powers of making steam, weight for weight, and size for size. Lighter boilers may be found of equal power, but they are inevitably larger; smaller boilers may be found, but they are sure to be heavier. And, beside all this, the shape of the tubular boiler of the best type is, above all others, that best adapted for a locomotive carriage supported on more than one pair of wheels, and intended to travel at high speeds. This fact in itself is enough to render its popularity for railway purposes a thing which needs no further explanation. Again, for marine purposes, nothing more convenient than the return flue system exists, and without tubes it is not easy to carry out this principle of construction with any success.

"Every tube flue has three purposes to fulfil at least. Occasionally it may have to perform a fourth, to which we shall refer further on. The first is to permit the passage of its own proportions of the products of combustion from the furnace to the chimney. The second, to transmit through its walls the greatest allowable quantity of the heat of these products to the water; and the third purpose is, under the given conditions, to fulfil its duties better and more economically than any other device. We shall consider the last first, because it is impossible to put a flue to work until it is made, and on its material a great deal of its value will ultimately depend. The first tubes used appear to have been of copper. The tubular boiler proper was employed in France, before it came into favour, even in the idea, here. The first instance of its actual use on record appears to have occurred in the case of two of Stephenson's locomotive engines, fitted in 1828 with the tubular boilers by M. Marc Seguin, engineer of the St. Etienne railway. Stephenson used copper flues in the first instance in the 'Rocket.' Shortly afterwards their use became habitual in America, especially for wood-burning engines, and they are used in that country still, although rarely. Now copper appears at first sight to be a very excellent material for flue tubes. It can be easily drawn into pipes; hard solder may be employed to make up the joints; its ductility is such that the tube expand under the action of the ferrules in the tube plates, and is, therefore, very easily fitted into place without any necessity for nic workmanship; and, above all, the metal is one of the best conductors of heat known, the relative thermal resistance of iron an copper being as 96 to 40. No wonder, therefore, that the us of copper flues was habitual for some time after the railway system, as applied to the conveyance of passengers, came into operation. But, with the good qualities that we have named, all tha is good about copper tubes begins and ends, and very little practice proved that the particles of flying coke cut them up so rapidly that they required continual replacement at a very heav expense. It is well to bear in mind, therefore, that copper, theoretically the best, is practically the worst material ever used to make tubular flues. After the failure of copper, brass was introduced in 1833, as a material for locomotive flues, on the Liverpool and Manchester railway; as far as we can learn, at the suggestion of Mr. Dixon, then resident engineer of that line. The copper flues lasted on an average three months; the brass two years at least. Brass possesses many of the constructive advantages of copper, while its superior hardness imparts to it the quality of permanence so desirable. Hundreds of tons of brass tubes are used, therefore, yearly, for locomotive purposes. Iron tubes, though rather more difficult to set, apparently remain tight longer, and are as a rule more durable than brass; they are a great deal cheaper as well, and in consequence they are extensively used; indeed, it is questionable if they may not one day turn brass out of the market. Thus we see that either iron or brass are better calculated to answer the third great purpose of a flue than any other material. Steel may yet play an important part, of course; but, in the absence of extended experience in the use of steel flues, it would be premature to speak positively as to their value.

"The second great purpose to be fulfilled by a flue, is the transmission of heat to the water with which, in common parlance, it is in contact. It may be said that this is really the first object, but such is not the fact, because it is impossible that the tube should have any heat to transmit, unless the products of combustion can pass freely through it in the first instance; and the neglect of the principle involved in this statement has been the cause, time and again, of great disappointment. We can state, without hesitation, that the material of which a flue is composed does not practically exert the smallest influence on its evaporative powers. It is true that both brass and copper are very much better conductors of caloric than iron. Yet iron flues are quite as efficient and as economical, in all that concerns the use of fuel, as either the one or the other of the dearer metals we have named. Why this should be so has excited a great deal of unnecessary and useless speculation. In point of fact, the water within a tubular boiler is never in contact with the metal of the tube. The same holds true of the heated gases. A coating of deposit of greater or lesser thickness collects after the first few days of the active life of a new boiler on the exterior of the flues, and a coating of soot forms within. The conducting powers of these two substances really measure the calorificent value of the tube. When experiments are conducted in the laboratory on this subject, the metallic surfaces are all kept clean, perhaps bright. Could the flues of a locomotive be kept bright also, there is no doubt that the results obtained in the laboratory would be verified in practice. Thus we find that, during the first few days, a brass-flued boiler always makes more steam than one the flues of which are of iron. With the appearance of a little deposit this superiority becomes evanescent. Deposit is one of the most perfect non-conductors of heat in existence, and so greatly does it obstruct the passage of caloric, that the difference between the relative values of copper and iron is as nothing, when compared with the relative values of iron, and copper, and deposit, as conductors. While each tube is enveloped in a second strongly adherent to it, and formed of lime and clay, it is a matter of very little consequence of what the tube itself is made. Even with surface condensation it is impossible, practically impossible, to keep the inside of a boiler clean. If there is not sulphate of lime, there is certain to be oxide of iron arising from the decay and corrosion of the plates. No laboratory experiments have yet been undertaken to determine the relative value of encrusted flues of different metals; simply, we presume, because it was evident beforehand that no appreciable difference would be found to exist. To put the fact in the simplest light, it is the deposit which directly imparts heat to the water with which it, and not the tube, is in contact. All that the metal of the flue can possibly do is involved in the transmission of caloric to the deposit in the first instance.

"We have stated that a great number of experiments have been undertaken to determine the relative value of tube and fire-box surface. The results of these have been presented to the world as conclusive. Yet they are, one and all, untrustworthy, and to a certain extent fallacious. In 1830 Stephenson took the top off a locomotive boiler; a tube-plate separated the water in the fire-box shell from that in the barrel of the boiler. A fire was lit in the box, and the results obtained went to show that one foot of fire-box was equivalent to three of tube surface. In 1840, Mr. Dewrance performed the same experiment with a difference. He divided a small tubular boiler into seven distinct compartments, the first being fire-box, the second 6 inches of tube, and the remaining five, a foot each of tube. From this experiment it was deduced that the first six inches of tube were equal, square foot for square foot, to the fire-box surface; the second compartment was about one-third as effective; and for the rest, Mr. Dewrance stated that the evaporation was so small as to be practically useless. Mr. Wye Williams, not many years ago, fitted up a tube five feet long, and three inches in diameter, in his laboratory. This tube passed through a vessel divided into five compartments, each a foot long; the heat was applied by means of a ring of gas jets fitted in one end of the tube, turned down at right angles. The temperature of the waste heat was said to have been 800 degrees, yet the boiling point was never once reached in the compartment furthest from the source of heat. Not one of these experiments possesses much in common with the conditions under which a tube works in a locomotive boiler, simply because the influence of the blast in the chimney has invariably been neglected. The caloric to be derived by conduction from heated air is very trifling, because hot air parts with caloric with great reluctance. With true flame the case is altogether different; the most intense heats known in the arts are the result of flame. The blow pipe, the lime light, nay, even the combustion of gas in a common paraffin lamp, are illustrations of the truth of this proposition. None ever attempted with success to fuze platinum, or decompose the diamond, with a jet of heated air; flame has alone proved equal to the task. It is certain that water takes up heat very slowly from a gas unless in actual contact with it, and the absolute quantity of caloric which will penetrate a metal plate apparently varies nearly as the cube of the intensity of the sensible heat. Why this should be so we know not; and the entire problem has been very much overlooked by experimentalists. The relative calorific value, then, of flame is transcendent as compared with hot air, and this indisputable fact once admitted, there is no longer any difficulty in seeing wherein Stephenson's, Dewrance's, and Wye Williams' experiments were defective. The belief obtained then, as it does now, that flame would not enter a small tube. The inventor of a safety lamp depending on this principle for its success was not likely to dispute the question; especially with the example of the Davy lamp—a far more perfect invention—before his eyes. We are told nothing of a forced draught in Mr. Dewrance's experiments, and from the nature of those conducted by Mr. Williams it is simply impossible that flame could enter the tube he used. In the case of a locomotive burning coal, or even a gaseous coke, there is no doubt whatever that, with a powerful blast, flame does traverse the tubes in whole or in part of their length; the distance depending on their diameter and the force of the draught. As a datum from which deductions may be drawn, we may state that flame—true bright flame—will traverse a tube $2\frac{3}{4}$ in. diameter, and 6 ft. long, at each stroke of the piston, and we feel very little doubt that in coal-burning engines the tube surface invariably possesses a higher economic value in proportion to the fire-box than when coke is burned. We said there was a fourth purpose which the tube flue might fulfil; and it is involved in permitting the combustion of gas, and the consequent production of flame, to go on within it. Certainly, it is somewhat remarkable that, while Mr. Williams could not make water boil by means of air heated to 800 degrees, steam of half the same temperature will, if conveyed through a worm, cause water to boil freely in an open vessel. is known that locomotives with long flues of small dia- eter are unable to make steam without a tremendous blast. e cause has been sought in the friction of the air against the les of the pipes. *Doubtless, there* is a certain amount of truth in this, but not all the truth. Flame will not enter a very small tube very far, except under strong compulsion, and there is little doubt that in such cases the value of the tube surface falls off so much in consequence of the absence of flame within them, that the evaporative powers of the boiler suffer considerably. A great number of small tubes are never so efficient individually as a smaller number of large ones. As to the relative durability, absence of priming, and efficacy, the over-flued boiler will bear no comparison with its rival.

"The first great purpose of a flue is the conveyance of the products of combustion to the smoke box. The concluding sentences of the last paragraph state nearly all that can be said on this branch of the subject. The proportion which the calorimeter of a boiler—in other words, the area of its flues or tubes—should bear to the area of grate bar, is a question of considerable importance. In the case of the locomotive, it is intimately connected with the position of the blast pipe, its area, and the mode in which it is fitted. In the marine boiler the cubic contents of the furnace, the power of the draught, the quantity of the coals, &c., all exercise a considerable influence."

5. Among the papers read in the "Mechanical Section" of the last meeting of the British Association for the advancement of science, not the least valuable was one by Mr. Z. Colburn on "*Steam Boilers*," the first portion of which we give here, omitting the last part which described the "Harrison Boiler," of which a full account will be found in par. 2.

"The rate at which heat may be transmitted through an iron boiler plate, without injury to its substance, has never been precisely ascertained. About 70,000 units of heat per hour, equal to the evaporation in that time of one cubic foot of water from 60 deg., is believed to be the utmost per square foot of plate of ordinary thickness. But, in order to approximately apply the *whole* heat of a furnace to the purposes of evaporation, a much larger area of heating surface, per unit of work done, is requisite. Watt fixed the proportion of one square yard of heating surface per cubic foot of water evaporated per hour, and this has been sanctioned by modern practice. But the average depth—or, in other words, the thickness of the stratum—of water thus boiled by is only $1\frac{1}{3}$ inch per hour, $\frac{1}{45}$th inch per minute, or $\frac{1}{2700}$th inch per second, over the whole heating surface. From ten to twelve seconds are thus occupied in evaporising a *couche* of water, no thicker than a single leaf of the paper upon which books are commonly printed. If, in proportion to the evaporation, an insufficient extent of heating surface be provided, there is not only a direct waste of heat,—the products of combustion escaping at a temperature corresponding, perhaps, to that of incandescent iron —but the furnace plates may be burnt. Notwithstanding the active convection of heat in water, an intense flame, directed against the sides or roof of a boiler furnace, will, in time, crack or blister the iron. It is not certain that this result occurs from the inability of the metal to transmit the heat, for it is more likely that, under vigorous vaporization, the gravity of the liquid water (and it is its gravity only that brings it to the heating surfaces) is insufficient to bear down effectively against the rising volumes of steam. If, by powerful mechanical means, the water could be constantly maintained in contact with the heating surfaces, it is possible that the rate of evaporation upon a given area could be increased without injury to the plate. In the hardening of anvil faces and of steel dies, the requisite rapidity of cooling is obtained, not merely by immersion in water, but by its forcible descent, in a strong jet, upon the heated metal.

"Under the conditions, however, of ordinary practice, no restriction of the heating surface is permissible. This surface is sometimes that of the exterior only of the boiler, but it is more usual, and on most accounts preferable, to dispose it internally by means of fire boxes, flues, or tubes. The external surface of a boiler can only be increased by increasing its length or its diameter, or by increasing both of these together. Plain cylindrical boilers 90 ft., and in one or two instances 104 ft. in length, have been employed, but, even apart from any consideration of the great amount of space which they occupy, they are mechanically objectionable, and they are now no longer made. In increasing the external surface of a boiler by enlarging its diameter, it is weakened exactly in proportion to the increase, the bursting pressure, for a given thickness of plates, being inversely as the diameter. The danger attending the presence of a large quantity of heated water in a boiler is now well understood, and, such as it is, it increases as the square of the diameter, so that, in a boiler of a given length, the elements of weakness and danger are collectively related to the cube of the diameter. External heating surface may be provided for in a number of smaller vessels, as in the retort boilers by Mr. Dunn, but these are of the water-tube family, which, heretofore, has been found subject to choking with the solid matter deposited by the water.

"Next are the boilers with internal heating surfaces. Internal fire tubes were in use in steam boilers in the last century, and they were applied within a cylindrical barrel by the Cornish engineers, among whom was Trevithick, who employed both the straight flue and the return flue, and who made the fireplace within the flue. The Cornish boiler, in this form, was improved by Mr. Fairbairn and the late Mr. Hetherington, who added another fire tube, thus making the two-flued boiler now so extensively employed in Lancashire. The two flues, although somewhat smaller than the single flue, afforded a greater extent of heating surface, besides securing increased regularity in firing. The principle of subdividing the flame and heated products of combustion, so as to obtain greatly increased heating surface within a barrel of given diameter, was fully carried out in the multitubular boiler invented by Neville, of London, in 1826, employed by Seguin, in France, in 1828, and subsequently in the Liverpool and Manchester locomotives, from which it has been handed down to the present practice of engineers. Not since Watt's time, however, has the evaporative power of a square foot of heating surface been increased, the improvement in the plan of steam boilers being that, chiefly, of enclosing a greater extent of surface within a given space. The heating surface, in the boilers of the Great Eastern steamship, is equal to the entire area of her vast main deck, that in the Adriatic measures more than three-fourths of an acre, while the Warrior and the Black Prince have in their boilers 2,500 square yards of surface of tubes, the aggregate length of which is more than 5½ miles. But it is only where, as in steamships and in locomotive engines, the dimensions and weight of boilers must be the least possible, that the multitubular arrangement is even to be tolerated. It is costly, nd subject to rapid decay. In steamships, especially, the life multitubular boilers is comparatively short. The boilers in r Majesty's vessels of war are found to last but from five to seven years; those of the West Indian Royal Mail ships last, according to Mr. Pitcher, of Northfleet, six years only, and those of the Dover and Calais packets, taking the testimony of the former mail contractor, Mr. Churchward, need to be renewed every three and a-half or four years. On land, multitubular boilers, working under constant strain, and, in most cases, as constantly concentrating a saturated solution of sulphate of lime, are nearly out of the question for the purposes of manufactories, although there are instances of their employment, even in spinning mills. A boiler rated at 40 nominal horse power will ordinarily evaporate 60 cubic feet of water per hour, or upwards of 100 tons of water per week of sixty hours. And feed water containing as much as 40 grains of solid matter per gallon is often regarded as very good, not only when the inorganic impurity consists of the deliquescent salts of soda, but even when it is neither more nor less than an obdurate carbonate or sulphate of lime. Whatever the solid matter contained in the water may be, it is never carried over with the steam, but is left behind in the evaporating apparatus, and 100 tons of the water, fed in a single week to a boiler in the manufacturing districts, commonly contains a hundredweight or more of dissolved gypsum or marble, and of which all that is not held in solution is deposited in a calcareous lining upon the internal metallic surfaces. This fact will explain why not only water-tube, but multifire tube, boilers cannot be economically employed under the ordinary circumstances of steam generation. The consideration of deposit or scaling, as well as that of workmanship, imposes a limit to the subdivision of heating surface among a great number of small tubes. In ordinary boiler-making the geometrical advantage of the sphere cannot be turned to account. It cannot be produced economically in plate iron, nor, if made in plate iron, could it be advantageously applied in a steam boiler. The hollow sphere has this property, to wit: with a given thickness of metal it has twice the strength of a hollow cylinder of the same diameter. This is upon the assumption (which is correct where the cylinder of a length greater than its own diameter), that the ends of e cylinder offer no resistance to a bursting pressure exerted gainst the circumference. Under over-pressure, a closed cylin-er would take the sh*ape of* a barrel, and if of homogeneous material and structure it would burst at the middle of its length, and in the direction of the circumference. The circumference of a sphere of a diameter of 1 being always 3·14159, the sum of the length of the two sides of a cylinder of the same diameter, and having a plane of rupture of the same area, is 1·5708, or exactly half as much. And not only are the boiler heads of no service in resisting the strain in the direction of the circumference of the cylinder, and not only are they weak in themselves, except when of a hemispherical form, or when well stayed, but, furthermore, the whole pressure against them is exerted to produce a strain of the sides of the cylinder in the direction of its length, and where there are no through stay-rod between the opposite heads this strain is necessarily equal to one-half of that exerted in the direction of the circumference.

"The bursting pressure of steam boilers is commonly calculated from the average tensile strength of wrought-iron plates. This strength is very variable, however, and it would be more logical to take the minimum. The most extensive series of experiments upon the strength of iron plates is that made by Mr. Kirkaldy for Messrs. Napier, of Glasgow. The number of samples of each description of iron tested was not large, yet the tensile strength ranged between very wide limits. That of Yorkshire iron varied between 62,544 lb. per square inch and 40,541 lb., both specimens being from the same makers. Staffordshire plates varied between 60,985 lb. and 35,007 lb., and Lanarkshire plates between 57,659 lb. and 32,450 lb. The conclusion cannot be resisted that engineers are frequently dealing with boiler plates of a tensile strength not greater than from 16 tons to 18 tons per square inch, notwithstanding that the average strength may be 22 tons, and the maximum 27 tons. And the loss of this strength in punching the rivet holes is not merely that of the iron cut out, but the punch is found to sensibly injure that which remains. Mr. Fairbairn's well-known and frequently verified ratio of 56 to 100, as the strength of a single riveted joint to that of the unpunched plate, must be always admitted in calculations of the strength of riveted boilers. The 40-horse Lancashire boiler, 7 ft. in diameter, will thus be often found to ave an ultimate strength not greater, when new, than that cor- onding to a pressure of from 210 lb. to 235 lb. per square inch. This, however, is without taking account of the strain exerted longitudinally upon the shell of the boiler by the pressure on the ends, and it is upon the assumption, which is hardly tenable, that the boiler heads, and especially the flues, are of the same strength as the cylindrical body or shell. Without the angle-iron strengthening recommended by Mr. Fairbairn, the collapsing pressure of the flues of large boilers was found, in that gentleman's experiments, to be sometimes as little as 87 lb. per square inch. The strain resulting from the circumferential and longitudinal components, in the outer shell, is one-eighth greater than that calculable for the circumference alone, so that, even if the heads and flues were stayed to the strength of the shell, this would correspond to a pressure of but from 190 lb. to 210 lb., instead of 210 lb. to 235 lb., as just supposed. But these estimates are for the strength of the boiler when new. In the experience of the officers of the Manchester Boiler Association, with from 1,300 to 1,600 boilers always under their care, one boiler out of every seven, and, in some years, as in 1862, nearly one of every four, became defective by corrosion alone, while of every eight boilers examined in the course of a year seven are found to be defective in some respects. Thus, in 1862, with 1,376 boilers under inspection, 85 positively dangerous, and 987 objectionable defects, were discovered, 37 dangerous and 270 objectionable cases of corrosion alone having been reported. As a boiler malady, corrosion corresponds in its comparative frequency and fatality to the great destroyer of human life—consumption. It is the one great disease. It is frequently internal, in consequence of the presence of acid in the water; but it is still oftener external, and it is most insidious and certain wherever there is the least leakage of steam into the brickwork setting. Condensed steam, or distilled water, is an active solvent of iron, as well as of lead, and peaty water, which, so far as *inorganic* matter is concerned, is very pure, and distilled water from surface condensers, and, indeed, any water that is quite soft, is known to eat rapidly into the substance of the boiler in which it is used. A trickling, however slight, of condensed steam, down the outside of a boiler, will infallibly cause corrosion, and to this was directly traced a large number of the forty-seven boiler explosions *which occurred* in the United Kingdom in it, and not the tube, is in contact. All that the metal of the flue can possibly do is involved in the transmission of caloric to the deposit in the first instance.

"We have stated that a great number of experiments have been undertaken to determine the relative value of tube and firebox surface. The results of these have been presented to the world as conclusive. Yet they are, one and all, untrustworthy, and to a certain extent fallacious. In 1830 Stephenson took the top off a locomotive boiler; a tube-plate separated the water in the fire-box shell from that in the barrel of the boiler. A fire was lit in the box, and the results obtained went to show that one foot of fire-box was equivalent to three of tube surface. In 1840, Mr. Dewrance performed the same experiment with a difference. He divided a small tubular boiler into seven distinct compartments, the first being fire-box, the second 6 inches of tube, and the remaining five, a foot each of tube. From this experiment it was deduced that the first six inches of tube were equal, square foot for square foot, to the fire-box surface; the second compartment was about one-third as effective; and for the rest, Mr. Dewrance stated that the evaporation was so small as to be practically useless. Mr. Wye Williams, not many years ago, fitted up a tube five feet long, and three inches in diameter, in his laboratory. This tube passed through a vessel divided into five compartments, each a foot long; the heat was applied by means of a ring of gas jets fitted in one end of the tube, turned down at right angles. The temperature of the waste heat was said to have been 800 degrees, yet the boiling point was never once reached in the compartment furthest from the source of heat. Not one of these experiments possesses much in common with the conditions under which a tube works in a locomotive boiler, simply because the influence of the blast in the chimney has invariably been neglected. The caloric to be derived by conduction from heated air is very trifling, because hot air parts with caloric with great reluctance. With true flame the case is altogether different; the most intense heats known in the arts are the result of flame. The blow pipe, the lime light, nay, even the combustion of gas in a common paraffin lamp, are illustrations of the truth of this proposition. No one ever attempted with success to fuze platinum, or decompose of fuel is to be had in more ways than one; the use of steam being quite distinct from its generation. A good engine may give very fair results with even a bad boiler; and a bad engine may get on very creditably, provided the generator which supplies it with steam possesses more than the average amount of good qualities; on the union of that which is best in both, depends the highest economical result. Nevertheless, it is often not only advisable, but absolutely necessary, to sacrifice many things, good in themselves, in order to attain others yet more desirable. The marine boiler may be taken as an instance: its shape is regulated to a great extent by circumstances, which have no relation whatever to its steaming powers, while its dimensions are in nearly all cases limited to the available space on board ship at the disposal of the engineer. Under these conditions, it is not wonderful that a certain form or pattern of marine boiler has become almost universal in its adoption with us; the rectangular shape, the long narrow grate, the return flues, may be met with in almost every steamship which sails from a British port. The now old-fashioned flue boiler, properly so called, is, it is true, met with commonly enough still; but the external form of this so nearly resembles that of the tubular boiler, that we may consider one general type as being by consent deemed most suitable for a place on board ship.

"If we exclude the adoption of the locomotive pattern of boiler, which possesses some qualities pointing it out as admirably suited to marine service, it remains doubtful if any other important change in external form will become popular in our mercantile marine—indeed, we do not see the want for such a change. High-pressure steam, if not generated within a fire-box boiler of the kind met with on our railways, must be raised in boilers built up of a number of tubes or stayed chambers, forming one whole, and there is no valid objection to the form of the entire structure assimilating more or less nearly to that of the boilers at present in use. These last, as a rule, answer their purpose pretty well; and the defects in our machinery lie far more in the methods employed for using, than generating steam. Perhaps the most common error committed is that of so designing boilers, that, while regard is had for economy of fuel, no care whatever is exercised to maintain their efficiency. Hard firing follows as a matter of course, and waste instead of saving is the result. In order that a few pints more of water may be evaporated per pound of coal burned, grate and furnace area is reduced, in order that heating surface may be extended, and the heat better absorbed from the escaping gases. If the vessel fails to attain the required speed, the furnaces are filled beyond their proper capacity; imperfect combustion ensues; and the very means intended to produce economy, conduce to the most opposite result. A couple of boilers more, put on board, might overcome the objection. Most shipowners would consider the remedy worse than the disease, however. The best marine boiler is not that alone which burns least fuel, but that which can produce most steam in a certain time, weighs least, and evaporates a fair quantity of water per pound of coal.

"The quantity of heat actually communicated to the water within a boiler, in a given time, is the direct measure of its steaming powers. Now, it by no means follows as a matter of course, that this should be measured, in turn, by the quantity of coal consumed. There are two or three points deserving of careful attention in considering this question. Care must be taken to secure the necessary conditions both without and within the boiler—we use the words "without" and "within" in rather a peculiar sense. The furnaces and flues are, it is true, inside as regards the external superficies of the generator, but they are outside as regards the water and steam space; within, then, the paramount object must be to secure a good circulation of the water, in order that the heated metal may never be out of contact with it for a moment. Steam possesses a very powerful tendency to cling to vertical surfaces. A constant moderate current of water is the best possible means of removing it. Ample water spaces are thus a desideratum to be obtained, even at the expense of a certain amount of heating surface. Flues are seldom or never put too closely together in the marine boiler; and there is little fault to be found with the arrangement generally adopted. We wish we could say as much of the water spaces between furnaces, which are frequently reduced to the very limit where safety ends and danger commences; not only is economy, but efficiency, sacrificed. Furnace plates get burned, come down, leak, and do all manner of objectionable things, as a consequence of a disregard for that common-sense rule which tells us, that a heated plate should always be covered with water enough to keep that heat from becoming excessive and injurious. Ample water spaces conduce powerfully to the production of dry steam; and, were it for no other reason than this, their use is extremely desirable.

"The relation between the area of the flues and of the grate surface, is a matter of vital importance, in which our present practice is very defective. As a rule all marine boilers have too many flues. They tower up row upon row from the very crowns of the furnaces, taking up space invaluable for other purposes. It is by no means an easy thing to get the products of combustion equally diffused through all the flues of a boiler in their passage to the smoke stack. They will, whether we like it or not, take the shortest way to the up-take; and, setting aside the very peculiar eddies which manifest themselves in some boilers, we are certain to find that the gases desert some of the tubes, wholly or partially, in favour of others. The only means of preventing this lies in making their area so contracted in proportion to the aggregate spaces between the grate bars, that all the air entering under the influence of the draught cannot escape without permeating each and every one of them. What this proportion should be, is hardly so well settled as we could desire. It apparently lies between one-seventh and one-eighth. In order to secure a large number of tubes, a great proportion of which are practically useless, we find, every now and then, furnaces so reduced in height that perfect combustion is practically out of the question. The deeper a furnace is, the better—that is, the higher the crown plate is from the bars, the better the opportunity for burning the ascending gases. Locomotive fire-boxes have been made as much as 5 ft. 4 in. deep, with advantage for burning coal spread rather thinly, too, on a large grate. The distance between the grate bars and crown plate of a marine boiler furnace should never be less anywhere than 20 in.; 30 in. would probably be better. This would be tantamount in many cases to the suppression of, at least, two rows of tubes; but the increased steaming powers of the boiler, and the more perfect combustion of the fuel, would leave no room for regret at their loss. A roomy combustion chamber at the back, or furnace up-take, as it is sometimes termed, is always of value; and tubes might often be shortened 3 in. or 4 in. with advantage in order to obtain it. Flame once produced in quantity here, will, under the influence of a strong draught, find its way for 5 ft. or 6 ft. into a 3-in. tube; whereas, if space is not afforded for the ignition of the gases before they enter the tubes, they escape to the chimney, carrying carbon with them in suspension, and pour forth as a volume of black smoke, hanging for hours athwart the sky. Unless a fire-box is roomy and lofty, it is absurd to speak of admitting air above the burning fuel. Shallow furnaces are usually packed as full as they can hold, and combustion must be, to the last degree, imperfect."

7. The two following articles will appropriately enough conclude this section of the work; the first, entitled "Horses Power of Boilers," is taken from the work, which we cordially recommend to our readers as being a very practically valuable one, entitled "Mills and Millwork" (Longmans, London), by the eminent Engineer, William Fairbairn. The second, in par. 8, is from the "Scientific American," and is suggestive on some points, the value of which is frequently overlooked:—

"*The horses power of boilers* is dependent in part on the capacity of the boiler itself, in part on the heating surface, and in part on the area of grate and the consumption of coal per hour. The common rule for estimating the horse power is as follows:— Calculate the 'effective section' of the boiler by adding to the diameter of the boiler the diameters of any internal flues, and multiplying by the length of the boiler, and divide the product by the constant 5·5, 5·75, or 6, according to the practice of different engineers.

"For condensing engines I have usually allowed about 12 square feet of 'effective section' for each nominal horse power of the engine, although in practice many conditions necessitate the alteration of this proportion to suit circumstances. Now, as engines are at present constructed, working at from two to three times their nominal horses power, this is equivalent to an allowance of 5 square feet of 'effective section' per indicated horse power, and hence agrees approximately with the rule given above. But this empirical rule is not at all to be relied upon, as it gives erroneous results with boilers of different forms and proportions.

"The true method of calculating the proper proportion of boiler for any given engine is, however, to estimate the actual amount of steam required, which can easily be done with the aid of the tables, already given, of the weight and density of steam. Then provide a boiler capable of evaporating that weight of water, according to the data obtained in experiments with boilers of the particular construction employed. Some data of this kind will be given below. It being borne in mind that more heat is required, and less water evaporated with a given weight of coal, the higher the pressure at which the steam is employed.

"*Area of Heating Surface.*—The total area of metal exposed to the flame and hot gases is called the total heating surface of the boiler, and is usually expressed in terms of the 'grate-bar surface.' This unit of comparison has, however, been rendered ambiguous by the employment of another unit, called 'the efficient heating surface.' The efficient heating surface is obtained by deducting from the total heating surface one-half the area of vertical portions, and one-half the area of horizontal cylindrical flues, on the supposition that the vertical heating surfaces, and the under side of flues and tubes, act less efficiently in absorbing heat than horizontal surfaces above the flame.

"A common allowance of effective heating surface for stationary boilers has been 10 to 15 square feet per square foot of grate area, and 1 square foot of grate is required per nominal horse power of the engine. I have usually allowed 16 or 17 square feet of effective heating surface; and in Cornish boilers 25 square feet is allowed. In general practice it will, however, be found that such a proportion as 17 will better serve the interests of the employers of steam engines than the extreme limits of 1 in 10 or 1 in 25; at least this is the best proportion for cylindrical-flued boilers. The limits which define the amount of efficient heating surface, are, on the one hand, the temperature of the gases escaping into the chimney, which should be as low as possible, and on the other the temperature of the boiler bottom, at which soot is deposited. If the gases escape at a higher temperature than is necessary to create a sufficient draught, heat is wasted by dissipation in the atmosphere, in consequence of insufficient heating surface. On the other hand, if the boiler is unduly increased, so that part of the heating surface is coated with soot, and the absorption of heat prevented, not only is boiler space wasted, but heat is lost by radiation.

"In the Saltaire boilers the proportions of the heating surface may be estimated as follows:—

	Total heating surface in sq. ft.	Efficient heating surface in sq. ft.
Furnaces,	135	68
Mixing chambers,	102	51
Vertical tubes,	28	14
Three-inch tubes,	550	275
Exterior flues,	285	192
	1,100	600

Area of fire-grate, 33·5 square feet.

That is, 17 square feet of effective, and 32 square feet of total heating surface per square foot of grate.

"Again; in a double-flued tubular boiler, 30 feet long, 7 feet diameter, with two flues each 2 feet 8 inches in diameter, we have the following proportions:—

	Total heating surface.	Efficient heating surface.
Internal flues,	504	252
Exterior flues,	390	318
	894	570

Area of grates = 33 square feet.

Hence there would be 27 square feet of total heating surface, and 17 feet of effective heating surface, per square foot of grate area.

"*Boiler Capacity.*—In my practice I have always advocated large boilers. I have said before that boilers of limited capacity, when overworked, must be forced, and this forcing is the gangrene which corrupts and festers the whole system of operations. Under such circumstances perfect combustion is out of the question, and every attempt at economy fails. Usually with flued boilers I have allowed 15 to 20 cubic feet of boiler space per indicated horse power after deducting the flues. Mr. Armstrong contends for 27 cubic feet, of which one-half is steam, and the other half water room. I have allowed one-third for steam and two-thirds for water where the boiler is fitted with a dome. When the steam room is too small, the boiler primes, or water is carried over from the boiler with the steam.

the diamond, with a jet of heated air; flame has alone proved equal to the task. It is certain that water takes up heat very slowly from a gas unless in actual contact with it, and the absolute quantity of caloric which will penetrate a metal plate apparently varies nearly as the cube of the intensity of the sensible heat. Why this should be so we know not; and the entire problem has been very much overlooked by experimentalists. The relative calorific value, then, of flame is transcendent as compared with hot air, and this indisputable fact once admitted, there is no longer any difficulty in seeing wherein Stephenson's, Dewrance's, and Wye Williams' experiments were defective. The belief obtained then, as it does now, that flame would not enter a small tube. The inventor of a safety lamp depending on this principle for its success was not likely to dispute the question; especially with the example of the Davy lamp—a far more perfect invention—before his eyes. We are told nothing of a forced draught in Mr. Dewrance's experiments, and from the nature of those conducted by Mr. Williams it is simply impossible that flame could enter the tube he used. In the case of a locomotive burning coal, or even a gaseous coke, there is no doubt whatever that, with a powerful blast, flame does traverse the tubes in whole or in part of their length; the distance depending on their diameter and the force of the draught. As a datum from which deductions may be drawn, we may state that flame—true bright flame—will traverse a tube 2¾ in. diameter, and 6 ft. long, at each stroke of the piston, and we feel very little doubt that in coal-burning engines the tube surface invariably possesses a higher economic value in proportion to the fire-box than when coke is burned. We said there was a fourth purpose which the tube flue might fulfil; and it is involved in permitting the combustion of gas, and the consequent production of flame, to go on within it. Certainly, it is somewhat remarkable that, while Mr. Williams could not make water boil by means of air heated to 800 degrees, steam of half the same temperature will, if conveyed through a worm, cause water to boil freely in an open vessel. It is known that locomotives with long flues of small diameter are unable to make steam without a tremendous blast. The cause has been sought in the friction of the air against the sides of the pipes. Doubtless, there is a certain amount of truth is maintained. The general formula embodying these revelations is $F = C \frac{H^2}{G}$, in which F is the quantity of fuel consumed per hour, H the area of heating surface, G the grate area, and C a constant varying for each kind of boiler.

"Grates for burning wood require to be constructed on different principles from those for the consumption of coal. In this case, from the rapid ignition of the material, the furnace must be constructed capaciously, while at the same time the area for the admission of air must be reduced. In Russia, where nearly the whole of the coal used in manufacture is imported from this country, it is usual to have the boilers constructed on the same principle as has already been described. It, however, sometimes happens, as in the case of the late war, that the supply of coal ceases, and the owners of mills are in this emergency under the necessity of burning wood, which even in Russia at the present time is more expensive than imported coal. When driven to its use, all that is done is to remove the coal grate and furnace bars, and substitute an iron gridiron, laid on the bottom of the internal flues, which increases the capacity of the furnace and decreases the grate area. The boiler is then as efficient with wood as it was before with coal. In other cases the wood is supplied by a hopper, in which it descends as it burns away at the bottom."

8. *Faulty construction of steam boilers.*—"It is palpable to the close professional observer of the manner in which steam boilers are generally constructed, that there is not only great need of reform in the actual workmanship, but that a large proportion of the accidents arising from the use of steam can be traced directly to faulty construction. It is a truism that "the strength of any structure is exactly that of the weakest part;" but who can say where the weakest part of a steam boiler is, as they are ordinarily made? Take a simple cylinder boiler, for instance: the sheets are run through the rolls and bent to the proper radius; when the riveting gang get to work, they close up the rivets with great rapidity, but when the holes come out of line with each other, the drift pin is resorted to, and the sheets are literally stretched until the rivets can be inserted; when the drift pin is knocked out, the sheet goes back to its place, and there is already, without a pound of steam pressure, strain enough

to cut the rivets off. Repeat this performance through twenty or thirty feet, the length of an ordinary cylinder boiler, and who can say where the weakest point of the structure is? Suppose such a boiler to be made of silk, for instance, or any flexible material, what shape would it be in? It would be full of puckers, folds, seams, and gathers, and represent most accurately the various trials to which that most abused of all modern engineering apparatuses—the boiler—is exposed.

"The case is aggravated, not benefited, when we construct a square boiler, for this shape seems, by general consent, to have been adopted for marine service. When the angles or flanges of the sheets are not broken by the flange turners, they are cracked out by the drift pin of the riveting gang, and it ought to be made a capital offence to have such a tool on the premises of any boiler-works. New boilers burst under the most mysterious circumstances; old boilers are patched and then burst; and we are told gravely that 'putting new cloth into old garments' is the solution of the trouble. On each occasion the Coroner examines a host of 'experts,' who proceed to declare that 'the iron was burnt,' 'the water low,' 'the stays insufficient,' 'the water changed into explosive gases," &c.; but it never occurs to these worthies that the actual strength of the boilers was in many cases unknown, and that the boilers may have been at the bursting point for days, weeks, or months, until at length it gave way.

"It may be argued against this view of the matter that, if hydrostatic pressure is applied, it makes no difference where the strain comes, for the boiler is, as we have admitted, just as strong as the weakest point. It must be borne in mind, however, that it is natural or only reasonable to infer, in theory at all events, that every square inch of the boiler sustains an equal strain; with faulty construction this is impossible, for there may be, as we have shown, almost a rending force without a pound of steam in the boiler. It is ridiculous to suppose that safety is secured by *neat-looking* rivet heads, handsomely calked seams, and extra-heavy iron; the best materials and the finest workmanship in other respects are of no use so long as rivet-holes shut past each other so much that some rivets we once took from a boiler were offset nearly half their diameters. Holes will come out of truth with the utmost care, *especially in* such hap-hazard work as punching is generally made, and when they do so, the only safe way is to rivet all the true holes first, rim all the faulty ones to one size, and then put rivets in that fit, just as a machinist turns bolts to fit true holes in a bed-plate or cylinder. This method is no doubt costly, and will never be adopted, but it has the merit of common sense if no other. There is a great deal of carelessness in caulking seams also; for when the chipper chamfers the edge of the plate, the lower side of the chisel bears on the sheet and leaves a furrow, not very deep, it is true, but sufficient to cut through the skin of the iron, which is the strongest part. Neither are the braces properly set, for some draw all one way, while others don't draw or hold at all, and are perfectly loose; thus a portion do all the work, and the rest are idle, they impart no strength and are an element of weakness, for the engineer relies upon them when they are doing no good. We are confident that a great deal of attention can profitably be given to the mere workmanship of steam boilers; they are not tanks or receptacles for boiling water, but great magazines wherein a tremendous power is stored, the safe custody of which is of paramount importance to all in the vicinity."

9. *b. Materials of which boilers are made* (see end of par. 1.)—If the reader will turn to p. 73 of the first volume of this work (1863) he will there find described the recent introduction of *steel* as a material for boilers, and a statement of the advantages claimed for it. This was considered—as, indeed, by many it is still considered—a great advance, bearing the same relation to the use of wrought or plate iron as that bore to the use of cast-iron as employed in boiler construction in the early days of steam engineering. There is nothing, perhaps, more striking in the outline of engineering discussion of the year we are now recording, than the attention which has been drawn to the use of cast-iron in the making of boilers, as being likely, in the estimation of some, to supersede wrought-iron and steel, more especially the latter. So true is it, apparently, that certain systems revolve in cycles, in full operation at one period, then dying out, and again viving. The proposal to use cast-iron for boiler purposes is exemplification of this. The following are articles, or parts icles, which have appeared in the pages of our leading on this most interesting subject. "Simple as the

art of working," says an editorial article in the Mechanics' Magazine, under date May 27th, 1864, "in plate-iron may appear, it is not the less certain that the practice of this art is of very recent date. Half a century ago the conversion of the product of the smelting furnace into plates, sheets, or slabs of malleable iron was little understood, and practised by few ironmasters. Bars and rods there were in abundance, of good quality, too; perhaps better than those habitually met with now; but even in the present day, with all the aids of machinery and the teachings of experience, it is very well known that the production of thoroughly good boiler plate is a far more difficult task than the manufacture of square, round, or flat bars of moderate scantling. Fifty years ago the construction of rolls capable of taking a plate 5 or 6 feet wide within their gripe taxed the skill of the mechanician in no ordinary degree. Lathes suitable for giving a true surface to such rolls had no existence. We have examined very many specimens of old boiler plate in excellent preservation, but we have been unable to find any pretending to an equality of thickness over even a few superficial feet; and though this iron has been for the most part good and tough, still the grain has taken a more prominent place than is at all desirable. In short, the material is not that which the modern boiler-maker would select to exercise his skill on in the formation of anything like finished work. Old plates, too, were almost invariably different in quality and quantity at the edges, coming from such rolls as then existed, ragged and poor to a degree which rendered it imperative that a very considerable selvage, so to speak, should be removed before the plates could be properly worked up.

"If the art of making such plates was imperfect, the art of working them up into boilers or tanks was very little better understood. A punching-press, calculated to drive a fair hole through a half-inch plate, was something worth making a pilgrimage to see, while shearing was a thing not to be lightly undertaken. For the most part, boiler plates—for girders and the like were unknown—were heated red hot and cut into shape in the forge. Rivets were all made by hand. It is very doubtful when the simple rivet-anvil, now so much used in small shops, was first introduced. Before its advent each rivet had to be made as a nailer turns out each nail, by a certain amount of skilled labour necessary to its manufacture. With the rivet-anvil any ordinary labourer can make rivets all of the same length, almost as quickly as he can strike with the hammer, half a dozen blows being sufficient to complete each, while a seventh on the trigger-bar throws out the headed rivet. Simple as this invention was, it is certain that its introduction must have wrought a great change in the practice of working in plate-iron. Something more was still wanting, however, even when plate-making and bending rolls had become habitual, and when punching and shearing machines had been brought to moderate perfection; and this something was good rivet iron of exactly the same diameter, not alone through one bar, but through hundreds or thousands of bars, and, strange as it may seem, we can assure our readers that the manufacture of bars of round iron fulfilling this condition, is not a thing of the past, but of the present.

"The progress of the steam engine has been isochronous with the progress of the iron manufactures of the world. With each improvement in the means of obtaining power for raising ores, for draining pits, and for blowing furnaces, we find that enterprising men adventured upon new schemes. It is not too much to say that, in return, the steam engine has profited largely by every advance in the art of working in iron. These advantages and benefits have been reflective so far, and it is likely that such will continue to be the case so long as iron is forged, or steam used to supply motive power to the machines which forge it; but we must expect, on looking back to the past, to find that, in the infancy of the art of working in iron, expedients which we would now regard as very exceptional, were commonly resorted to in the construction of steam machinery; and, perhaps, in no department is this fact more apparent than in the history of the development of steam generators.

"The first engines ever made were employed in the mining districts, and it is by no means easy to say in what district first. As this is a question of little importance, however, we need not dwell on it. When the first wrought-iron generator was made is a matter of more interest. Savary used cast-iron; Newcomen, his successor, used wrought-iron; but it is worth noticing that, while Savary raised steam of 30 lbs. to 45 lbs. above the atmosphere, Newcomen never employed pressures of more than 1 or

2 lbs. In the first place, as his engine did not work by the direct action of the steam, higher pressures would have availed him nothing; and, in the second, it is extremely doubtful if any wrought iron boiler could in his day have been made tight under higher pressures. With the introduction of low pressure steam, we find that many strange schemes for the construction of boilers were produced, all intended to obviate the difficulties of working in plate-iron. Thus, Watt proposed boilers made of wood hooped, with a cast-iron furnace within; and others, boilers of stone, or lead, or copper, which last could be brazed, were actually used. In fact, until the comparatively recent introduction of the locomotive engine, it was by no means easy to procure wrought-iron boilers tight under high pressures; for low pressures, they soon became popular in the mining districts, and old punching and shearing machines, of a pattern now seldom or never used, once employed in their repair or construction, may still be seen lying neglected and overgrown with grass and weeds by the roadside in the 'Black country.'

"There is an old French proverb in existence, which, being translated, says that we always return to our first love; and it is by no means unlikely that this will be verified in boiler engineering. At one period it is beyond question that cast-iron boilers were habitually used for generating very high pressures, and they were used simply because the material possessed constructive advantages which were not then believed to reside in wrought-iron; and if these advantages are found to reside in it still, under a principle of construction modified to meet existing demands, there is surely no good reason why it should not be habitually employed. Cast-iron is really far better adapted to meet the ordeal of fire and water to which a boiler is exposed, than the best wrought-iron plate ever manufactured. As to strength, we all know, or we all ought to know, that that is a matter of proportion quite as much as a matter of material. There is nothing like practical illustration to bring such truths home to the mind. Let us suppose, then, the case of two boilers, one made of plates half an inch thick, the other of plates one quarter of an inch thick; if each of these boilers is, say, 6 feet in diameter, the first-mentioned will possess as nearly as may be double the strength *of the other if* we neglect all considerations connected with the process of riveting. In order to render both of equal strength, it is only necessary to reduce the thinnest of the two to half the diameter of the thickest. In the same way it is certain that a cast-iron tube of a given diameter may be made quite as strong as one made of wrought-iron of the same thickness, provided their diameters are proportioned the one to the other in the ratio of their tensile strength. It is only a fallacy to consider cast-iron as a material wholly unsuitable for the construction of generators in the abstract; and even in the practical, there is no difficulty whatever in adopting such a system of construction as will enable cast-iron to excel wrought in all those qualities which constitute a thoroughly efficient generator for even the highest pressures.

"That the arguments adduced against the use of cast-iron are many and powerful we do not pretend to deny; but that they are invariably applicable, or that, in other words, it is impossible to devise a boiler which shall elude these objections, is false. We daily see cast-iron employed to carry enormous pressures with the utmost confidence. Water mains are abundant 30 inches in diameter, carrying pressures due to heads varying from 100 to 240 feet, or from 50 to 120 lbs. to the square inch. Its tensile strength may always be brought, in one sense, up to that of wrought-iron, by using enough of it. It has thus beaten wrought-iron in the form of guns many times. Indeed, it is still doubtful if the best guns which Sir William Armstrong can turn out on his system equal the Rodman cast-iron ordnance in their powers of endurance. There are two methods of increasing the strength of any vessel, or, in other words, its powers of resisting either internal or external pressure. The one consists in increasing the thickness, the other in reducing the diameter of the globe or cylinder tested. As a boiler has something more to do than passively withstand a certain pressure, like a water main—having to transmit heat freely, in order that it may not become oxidized or 'burned'—it is obvious that cast-iron can only be employed in the form of small tubes or chambers, inasmuch as larger vessels should necessarily be of such a thickness that heat would pass through them very slowly indeed; but this fact in no way militates against either the safety, efficiency, or economy of a generator. Perhaps the present system of employing wrought-iron boilers of colossal dimensions in our every-day practice has been productive of more injury to property, and of a greater loss of life, than can be fairly laid at the door of the engineer on any other grounds. To Dr. Alban, of Plau, in Mecklenburgh, is due the credit of first enunciating the grand principle, that "*all boilers should be so constructed that their explosion may not be dangerous.*" In order to carry out this principle, it is absolutely necessary to adopt some method of construction by which the water and steam space shall be subdivided as much as possible. We will not here dwell on the objections urged from time to time against water-tube or 'tubulous' boilers. We may probably treat of such generators at another time; at present it is sufficient to say that these objections are many and well-founded—so well founded that such boilers have never become popular as yet, and it is very improbable that the constructive difficulties which now render them exceedingly expensive ever will be overcome; while from the nature of their form, and the material of which they are made, they have hitherto been found not only costly to make, but difficult to maintain at any price in fair working order on a large scale."

On the same subject, the "Engineer," in a leading article, has the following, entitled "*Cast-Iron Heating Surfaces:*"—

"The change now going on, from wrought-iron, copper, and brass, to cast-iron, as a material for steam boilers, is one of the most remarkable in modern engineering. It has been so long the custom to regard cast-iron as a brittle material, hardly to be trusted under pressure, that it requires some amount of reflection to perceive wherein it possesses manifest advantages over wrought-iron. It is often lost sight of that, according to the careful experiments of Mr. Fairbairn and others, nearly one-half of the ultimate strength of plate-iron is lost in the single riveted seams of ordinary boilers. Here, at one step, the best Yorkshire or Staffordshire plates are brought down to nearly the limit of tensile resistance of the best cast-iron, and it would indeed be easy to prepare cast-metal by repeated melting, and by keeping it melted two or three hours at each fusion, to make it absolutely stronger than the best wrought-iron single-riveted boiler. Cast-iron boilers may, however, be made of any required strength without either boiling the iron or increasing the thickness of the metal. It is only *necessary to* keep the diameter to moderate dimensions to secure an unburstable boiler, the ascertained bursting pressure of the cast-iron boiler spheres now in use (upon Mr. Harrison's patent)* being no less than 1,500 lb. per square inch, notwithstanding that the metal is hardly more than $\frac{3}{8}$in. thick. And even should one or more spheres burst, whether from external injury or otherwise, the small quantity of water which they contain would prevent anything like a disastrous boiler explosion. The fact that it is still a question whether cast-iron, properly treated, is not the best material for cannon, under all the incidents of enormous pressure, great heat, and considerable friction, leaves but little room for doubting its entire applicability to boilers. Practice, on the great scale, has, indeed, placed this fact beyond question; or, more strictly, it has shown that, so far as liability to explosion is concerned, and with respect to the consequences in case of failure, the cast-iron boiler, as now made, is altogether safer than any combination of wrought-iron or copper for the same purpose. A little reflection, indeed, will show that an 8 in. cast-iron sphere is safer under a pressure of even 200 lb. per square inch than a 7 ft. single-riveted boiler of the same thickness, under a pressure of no more than 50 lb.

"The resisting strength and safety of a properly made cast-iron boiler were, indeed, calculable, and a good *à priori* case could have been made out in their favour long ago. It was not so easy, however, to foresee that a great number of permanently steam-tight and water-tight joints might be made in a cast-iron boiler, and maintained by the direct tension only of a single bolt. Yet the result, once known, is quite explicable. An ordinary riveted boiler has, perhaps, some thousands of what are really joints, under the heads, of as many rivets. In many of these there are only two edges, or exceedingly narrow surfaces in contact, tightness being secured by caulking or burring. But in the cast-iron boiler the bearing surfaces of the joints are everywhere three-sixteenths of an inch in width, and they are finished with a truth of surface not surpassed in the best steam-engine valves. The machinery employed in making these joints produces a surface in a manner nearer than any other to that which Mr. Whitworth has done so much to bring into favour. The tool begins

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* See par. 2, p. 3; also par. 3, p. 12.

with a deep cut, and finishes by lightly and truly scraping the surface exactly to a standard gauge. Once fitted together, these surfaces would remain tight, as is found to be the case after two years or more trial under constant work. Any strain tending to loosen the joints, and whether arising from head weight, or the internal agitation of the water, is apparently compensated by the slightly yielding form of the spheres, in a line or row of which a considerable compression can, if desired, be effected by one or two forcible turns of the nuts of the holding bolts. There can be no question that the re-introduction of cast-iron boilers is due chiefly to the truth and certainty afforded by the novel system of machinery employed for making the joints, and so far as the result can be judged by a lengthy experience with the waters of different parts of the kingdom, complete and continued tightness has been fully secured, and without incurring any undue strain upon the parts of the boiler.

"The most useful peculiarity of the cast-iron spherical generator is, perhaps, its exemption from scale. So far as experience has gone it appears to be impossible to accumulate an adhesive scale within small cast-iron spheres employed for evaporative purposes. This cannot be said of any other form of generator of any other material. It does not appear to be the case (nor would there appear to be any reason for anticipating such a result) that the cast-iron repels the scale naturally tending to deposit from hard water, but as soon as a slight thickness of scale is formed it breaks off to make room for more, which is detached in its turn, and so on, apparently *ad infinitum.* It is not certain what would be the result if the water were left continually boiling, say for weeks together; nor is it, perhaps, worth while to inquire, since boilers are seldom, if ever, subjected to such trying treatment. It appears to be the fact that the scale is deposited while the spheres are heated, and, therefore, slightly expanded. On blowing off, however, the spheres, after having been emptied, acquire a further temperature from the surrounding brickwork. They expand somewhat further, therefore, and equally so at every conceivable diameter; but the scale, being non-elastic, can only follow by first cracking to pieces. On the re-admission of cold water this would tend to undermine the scale, while the consequent contraction of the spheres, at all parts alike, would complete the process of unscaling the inner surfaces. However this result goes on, it is certain that cast-iron spheres, employed as steam generators, do shed their internal coat of scale as often as they are blown out. Unexpectedly, no doubt, the cast-iron boiler has been found to be the only one which is free from the evil of scaling, and this and its other advantages are sufficient to account for the increasing favour with which it is now regarded."

10. Another of the vexed questions of modern engineering—although we have a difficulty to see why it should be one, as the evidence both of theory and practice is as decided in favour of the first system as it is against the other—is the comparative value of the methods of *drilling or punching holes in plates.* On this the "Engineer" has an able leading article, which we here partly give :—

"The process of punching is a rough, and we may say a barbarous mode of making a hole in an iron plate. A series of holes, too, in a row, can hardly be punched with that degree of accuracy which is necessary in modern boiler making and bridge building. We are here speaking only of accuracy of line and pitch, for no punched hole is in itself cylindrical or smooth. Besides, whatever want of truth and accuracy there may be in ordinary punching, it is believed that the action of the punch strains, and thus weakens the iron. Few, we think, employ punches which exactly fit their dies, and therefore the operation of punching does not give the clean shearing cut which is commonly counted upon. An examination of a plate which has been only half punched through will at once show how much the punch distorts, and therefore of necessity strains the iron upon which it acts. No iron can be once strained beyond its limit of elasticity without injury, or, in other words, without being made weaker ever afterwards. Yet an ordinary punch does strain the iron surrounding the punched hole, and to an extent which Mr. Fairbairn has estimated pretty closely from the results of experiments upon punched plates. Although with $\frac{11}{16}$in. rivet holes of $1\frac{3}{4}$in. pitch, less than 40 per cent. of the iron is removed by punching, the single-riveted joint loses at least 44 per cent. of the strength of the solid plate. This too, is the result, notwithstanding the friction at the lap of the plates, which thus gives each plate a certain hold upon the other. We believe Mr. Fairbairn's experiments showed a loss of strength in the iron left between the holes punched in a row equal to about 15 per cent. of the strength of the same net section of iron before punching. With very thick plates the injury by punching is greater, we believe, than with thin plates. The French engineers prefer very thick iron for large locomotive boilers, and for those 5 ft. in diameter, of the largest Engerth engines, iron of 15 millimetres, or $\frac{6}{10}$in. thickness, is employed. Here we believe the loss of strength by punching amounts to something considerable, and we can say that, in some of the French bridge work, we have seen three consecutive rivet holes cracked out to the edge of the plate under the combined action of punching and riveting. A series of experiments, made by a committee of Lloyd's, with reference to the strength of the riveted plating of iron ships, went to show that a joint in $\frac{3}{8}$in. iron was absolutely as strong as one in $\frac{1}{2}$in. iron, the loss of the whole strength, due to riveting, being only 40 per cent. in the first case, and nearly 60 per cent. in the second. If, instead of trusting to general opinions, engineers chose to investigate by actual experiment the effect of punching upon the strength of iron plates, they would, we believe, have reason to abandon punching to a great extent, if not altogether. The drill makes a clean cut, without the chance of injury to the iron, and in this way its employment must add greatly to the strength of riveted structures, and this extra strength is quite irrespective of the additional strength obtained, by the certainty that the rivets exactly fit the rivet holes, and that the holes are exactly coincident in opposite plates without the use of the drifting tool. Rivet holes are now drilled with nearly the rapidity with which they can be punched.

"There were those, however, at the Glasgow meeting,* who contended stoutly that drilled rivet holes were in no respect superior to those punched in the ordinary manner. We are unwilling to refer personally to the speakers who supported this view, but they had no facts whatever in support of their assertions upon this point beyond the negative proof that boilers made with punched holes had not yet blown up, nor bridges, with holes

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* Allusion is here made to a discussion of this subject at a meeting of the Institution of Mechanical Engineers in Glasgow.—ED.

thus punched, yet broken down. This argument, however it may commend itself to a certain class of practical men, is not that upon which the question is to be discussed. No one pretends that bridges are in danger of breaking down merely because their rivet holes are punched, and therefore no question of this kind is at issue. The only question is, do punched holes leave as much strength, and are they as consistent with tightness and general excellence of workmanship, as those drilled with the improved machinery? It is no proof because a bridge has not broken that it is as strong as it might be made with the same materials. The necessity for the utmost strength, both of the materials and of their combination in bridges, boilers, and ships, is now more widely recognised and insisted upon than heretofore. Not only are we building numerous bridges of great span, but the weight of railway trains is increasing, not merely when taken collectively, but when weighed over each foot of line covered. So with boilers; while the old sizes are still retained, there is a tendency to increased pressures; and in the case of iron ships, no amount of strength consistent with lightness is too great. We shall have an additional guarantee of safety when all riveted work, to which the security of human life is confided, is carefully drilled instead of being punched, and yet we have to confess to a wonder that the representatives of great houses should, both at Glasgow and at the late meeting of the South Wales Engineers, contend that punched plates were as strong as, if not stronger, than those drilled by special machinery."

11. On the same subject the "Engineer" has another article, from which we take the following as usefully supplementary to that given above.

"Let us at once confess that we have no real experimental basis for the highly probable assertion that plate is injured by the passage of a punch. Pulling a riveted joint asunder by a gradually applied load does not really determine whether the two punched plates have been affected by the punching alone. We think that Mr. Fairbairn's experiments made in 1838, and Lloyd's surveyors' experiments, made by a ridiculous machine of which it was impossible to really measure the stress exerted, by no means settle the question. Other influences on the iron come into play in the case of a complete joint; there is the hammering down of the rivet heads, the caulking of the seams, the more or less complicated conditions produced by the arrangement of the rivets. The questions are:—Given a plate of a certain thickness, and of a known breaking strength, with a certain per-centage of elongation within the limit of elasticity, and of a certain per-centage of elongation preceding rupture; how are:—1st, The breaking strength, 2d, the limit of elasticity, 3d, the ultimate elongation, affected by punching holes of a given diameter and of a given pitch?

"We do not even know the laws of the resistance of plates to punching, as is indeed confessed by General Morin in the last edition of his 'Résistance des Matèriaux.' It is true that General Morin gives the results of five experiments made by Messrs. Hick of Bolton, with a four-cylinder hydraulic press. From these experiments he deduces the law that the value of the effort required for punching increases directly with the thickness of the plates. But he remarks that the accuracy of these experiments was vitiated from the pressure employed being measured by the loads on the safety-valve of the press—a most inaccurate way of measuring the effort exerted by the plunger. These experiments are, however, interesting from the large sizes of the holes, and the great thickness of the plates. The first experiment was made with a punch m. 0·200, or 7⅞in. diameter, the four others with a punch nearly 8⅜in., or 0·210 diameter. The thicknesses of the plates were respectively:—m. 0·042, 0·050, 0·065, 0·075, 0·085; or, in round numbers, 1⅝in., 2in., 2⅝in. 3in. and 3⅛in. The approximate force exerted by the hydraulic press was in the first case 711,000 kilogrammes, and rose successively with the 8⅜in. plates, and with the increase of the diameter of the holes, to 965,200 kilogrammes, 1,270,000 kilogrammes, 1,625,600 kilogrammes, and lastly, to 2,082,800 kilogrammes, or the enormous force of nearly 2,042 tons.

"Examining, however, a very complete series of experiments in punching (which have been unaccountably disregarded by Morin), made by Mr. John Jones, at the Great Western Steamship Works, Bristol, and published in 1853 in the 'Practical Mechanics' Journal,' we are inclined to deduce the sufficiently simple law as to the resistance afforded by plates to punching:—That this increases *directly as the* diameter of the hole, and also directly as the thickness of the plate. We may, therefore, fairly expect that the thicker the plate, the more will it be strained by the punch in excess of its limit of elasticity. According to this, thicker plates will be more affected by punching than thinner plates, and the expectation appears to agree with general experience.

"Then comes the question as to the effect of the quality of the iron on its ultimate state after leaving the punching machine. We may well assume that the iron left round the hole has been strained in excess of its elastic limit. The work of the punch is, in fact, done some time before it has pierced right through the plate, and the sharp snap caused when the plug leaves the hole is indeed heard before the tool is half through. We may thus fairly assume that an amount of the plate, within a concentric circle of a certain radius from the centre of the hole, is strained in excess of the elastic limit. This is also proved by the more or less amount of distortion. The effect of the punch will, therefore, also vary with the quality of the plate—with its more or less elasticity and ductility. A hard, harsh iron would be greatly injured, and probably, even cracked; a very ductile, elastic kind of iron might be but slightly, if at all, injured. According to Mr. Paget's explanation of the deterioration of wrought iron to which we recently adverted, the ultimate breaking strength under a static load of the iron in the neighbourhood of the hole will be increased. This view is borne out by some experiments of Mr. Maynard of the South Wales Institute, who found that 'the drilled riveting did not bear as great a tensile strain as the punched.' The difference against the rolled plates 'was in the proportion of twenty-six to twenty-seven tons strain as compared with the punched.' We should therefore say that the effect of the punching on the plates will, *cæteris paribus*, vary :—1. with the thickness of the plates; 2. with the elastic limit and latent work before rupture of the material.

"The way to very simply set the question at rest would be to test, by comparison, the elastic limit, breaking strength, and elongation before rupture of a narrow strip of plate cut out of the punching machine. If of good material, its breaking strength would probably be found to have been increased by the punching, while its elastic limit will have been proportionately diminished. Another rather broader strip might be tested after being punched, and after the plugs of metal which had been driven out had been replaced and hammered out as tightly in as was possible without causing much strain. A very harsh iron would be found to have been, perhaps, cracked by the punching; iron of rather superior quality will have been scarcely injured; while Bowling iron, for instance, will have had its elastic limit considerably lessened.

"In the work, or the *force vive de resistance*, taken out of the metal by the punch, will be found the general inferiority of the material at a riveted joint to the plate in its entirety. When, in addition to the effect produced by punching, we also take into account, in the case of a boiler, the effect on the iron of the bending when cold, the drifting of the rivet-holes, the hammering at the rivets, and the caulking, we must see that that punching is only one of a series of operations that tend to take the resistance out of the iron at a riveted joint. And it is just at the joints where elasticity and ductility are required. It is thereabouts that the action of the confined fluid in striving to produce a perfectly cylindrical vessel is most felt. The deduction, therefore, is that mere ultimate breaking strength is not sufficient in boiler plate. Although a boiler has not to resist shocks like a chain, and although it has not to absorb work by its elastic or permanent deformation, it nevertheless requires good iron with a high elastic limit, and more especially at the joints."

11. In pp. 6—12 of the volume of Engineering Facts and Figures for 1863, the reader will find some remarks upon the subject of *Tubes* for Boilers, on the use of iron, copper, and brass as a material of which to make them, their relative value, and a description of the mode of forming tubes cold drawn from the solid. In connection with this interesting subject, the following, from the Mechanics' Magazine, on the use of *steel for tubes*, will be read with interest:—"The manufacture of tubes is one of the most important, though least obtrusive, conducted within our shores. Turn where we will we meet with them, they are absolute necessaries to the Engineer, and the people at large would get on badly without them; our water, our gas, even to the remotest corner of London, find their way from the sources of supply to the region of demand, through the ubiquitous, all-pervading tube. Hundreds, if not thousands, of miles of piping, of almost every conceivable material, are turned out yearly in England alone. Cop-

per, cast-iron, wrought-iron, clay—nay, even paper—are all converted to the same purpose, and since ordnance has attracted and received so much attention, the whole process of manufacture becomes invested with a novel and overwhelming importance. After all, the relative merits of guns really depend mainly on their qualities—good or bad—as tubes, and the different systems of construction adopted have furnished matter for anxious thought and close calculation to many a toiling brain. The difficulty of getting good tubes for boiler flues is well known. Wrought-iron is but too often uncertain in its quality, and tubes made from it are easily rendered worthless by bad or careless welding. In retubing boilers especially, flues are exposed to an amount of hard usage, which tries them severely. The plates destined to receive them are seldom bored out afresh, and much driving of the old ferrules previously is pretty certain to distort and enlarge the holes. The new flues must nevertheless accommodate themselves to this state of affairs, and if they are not really good they are sure to split, either at once or by the subsequent action of the heat. Copper is free from this objection, and so is brass, in a minor degree. But copper is too soft for coal, the particles of which, flying under the action of the blast, soon cut them up, and the advantages possessed by brass over iron are rarely, if ever, worth the difference in price, all things considered. Nothing seems likely to answer so good a purpose as steel—a pure soft steel, be it understood, which will work like copper and wear better than iron. Steel ferrules have long been used with success; they dilate permanently within the tube when heated. Flues of the same material should possess the same qualification, a rather important one to the boiler-maker.

"Steel tubes are not easy to get by the mile, however, and their supply by the yard, or even furlong, would not suffice to meet a fair demand, or enable them, even partially, to supersede iron. The fact is simply that hitherto almost insuperable objections stood in the way of their manufacture on a large scale. It is almost needless to state what those objections are; the practical steel worker will comprehend them at a glance, and it would be a tedious task to explain them to the rest of the world. The hardness, toughness, and indomitable qualities of the metal stand in the way of every attempt to make them by ordinary means, and it is only within the last year and a half or so that a novel process, inaugurated at Paris by a firm, half French, half English, affords a promise that they can be supplied in quantity at a moderate price.

"The formation of tubes by the aid of the drawing bench and the die is nothing very novel. Copper and lead pipes have been so made for years, if not for centuries. Wrought-iron boiler flues, although lap-welded by the hammer, are passed through dies to give them a fair surface, and render them truly cylindrical. It is something strange to find that precisely the same principle as that employed in the manufacture of lead piping is now used with the greatest success in the formation of seamless steel tubes. Lead pipes are made by casting hollow ingots, short and very thick, which are subsequently drawn through dies, their diameter becoming less and their length increasing at each passage until the desired dimensions are reached. If we substitute the word steel for lead, we have the new process described; but it must be remembered that the intractable nature of the material requires corresponding power to force it into shape, and thus, although the mere principle may not be new, the means by which it is carried out are; and the whole system, both in its application and working, is beyond doubt a new and complete invention, well worthy of the serious attention both of the engineer and the artillerist.

"Messrs. Cristoph, Hawksworth, & Harding, secured a patent in December 1862, for 'Improvements in drilling, drawing, and rolling metals,' and it is from the success with which the invention thus named has been carried out, that we foresee the application of steel on an extended scale to the manufacture of tubes. Mr. Hawksworth is an eminent steel maker, carrying on business at Linlithgow, North Britain. Years of experience have conferred on him the ability of making steel of almost any quality with absolute certainty. Casting about for new applications of mild steel, the manufacture of tubes suggested itself to this gentleman and his partners in the patent to which we have just referred. The first experiments were conducted at Paris, and so the thing has grown until the commercial as well as the mechanical success of the invention is almost beyond doubt, one of the machines being already at work *in Bermondsey*.

"The details of the process are extremely simple. Two hydraulic presses, with rams $16\frac{3}{4}$ inches in diameter, having a stroke of about 12 feet, are erected, facing each other, in a horizontal position, on a massive bed-plate of cast-iron; each press has a very heavy flange some 4 feet square at each end. The rams, hollow to save weight, carry similar flanges cast in one piece with them. These last are bolted together so as to form a whole. The recession of one ram from its cylinder is consequent upon the entrance of the other into the opposite cylinder. Stout cast-iron girders brace the presses apart. In the flanges, on the stuffing-box ends of cylinders, are countersunk holes, six or eight in each flange, in which can be placed and secured die-plates of different sizes. In the flanges at the opposite ends are holes disposed in the same axial line, of much smaller diameter. The upper surface of the main bed-plate is fitted with planed tables, on which the central plunger-flange traverses, the bed-plate supporting its weight; this central flange is fitted with a peculiar arrangement of screw 'grippers,' to which the tubes to be drawn are affixed. These tubes are made, when the diameter is small, by drilling a hole right down an ingot or bar of cast-steel. The cavity is drilled from both ends at once by very ingenious machinery. One end is then tapped to Whitworth's standard, and the outside of the ingot turned down to a rather blunt point, sufficient to permit it to enter the die for an inch or two.

"The method of working the apparatus is extremely simple. The plunger-flange is brought into close proximity with one cylinder-flange. The ingot to be drawn is threaded, as a lady threads a bead, on to a mandril rod, on one end of which is an egg-shaped enlargement of tempered steel, and on the other a nut and screw. The mandril-rod is passed through one of the smaller holes in the back flange of the cylinder, and its length is so adjusted by the nut and screw that the egg-shaped projection is located exactly within the centre of the die in the forward flange. The nose, as we may term it, of the ingot, is then passed through the die and secured to the plunger-flange by screwing the gripper, corresponding to the particular hole in the cylinder-flange in which the die is placed, into the end of the internal cavity. Two or more ingots are put in place at the same time to equalize the strain on the flange. The pumps are then put in motion by a steam engine. The plunger-flange then proceeds leisurely from one end of its stroke to the other, drawing the ingots literally by the nose through the die, and off the mandril, the egg-shaped head of which maintains the diameter of the bore in its integrity, while it imparts a beautifully burnished surface to its interior superficies; the die doing the same kind office for the exterior. A repetition of the process, changing the dies at each draw for others a little smaller, quickly produces the finished tube, a reduction in external diameter of about 1-16th of an inch being effected by each die.

"After the ingots have been passed three times through the dies they become very hard from compression; they are then removed to a reverberatory furnace, and heated to a bright red heat to anneal them. It is a singular fact that their temperature is scarcely sensibly raised by their passage through the dies, provided these last are in good order. A slight abrasion of the wearing surface, however, of either die or mandril, although so slight that the longitudinal furrows produced thereby on the tube are so small as to be scarcely visible, will raise the temperature 80° or 90° at one passage. This is a strange phenomenon, which we have practically verified. The molecular disturbances, and the work done, cannot be materially effected by such trifling imperfections; indeed, a glance at the pressure gauge on the press shows that there is no sensible increase in friction. To what, then, are we to attribute this remarkable effect, produced by so insignificant a cause? Such things apparently introduce a new element into the dynamic theory of heat.

"When two highly polished surfaces are forced in close contact by heavy pressure, they adhere and become one. The old system of plating was based on this fact, thin sheet silver adhering to burnished copper with the utmost tenacity when passed together through the rolls of a flatting mill. Precisely the same thing takes place with steel, and we have seen an iron tube drawn over a steel one by Messrs. Hawksworth & Harding's apparatus adhere so firmly that they virtually lost identity, and it was impossible to discover where steel left off and iron began, save by the action of an acid. The two metals had been 'cold-welded' to each other. Sir William Armstrong's system of constructing ordnance is rude and clumsy in comparison with that placed at our command by this fact. It is easy to draw tubes 10 inches in diameter, if necessary, or even larger. Such tubes, being made from an ingot cast hollow, are thoroughly homogeneous. By drawing a succession of them one over the other, all the surfaces being bright and burnished, the whole mass becomes 'cold-welded' into one whole, supplying us at once with a gun, stronger possibly than any yet produced. The advantages of this method of constructing ordnance do not cease here, however. If the inner tube is left unannealed, it may be made, by the simple act of drawing, to possess that quality of hardness essential in the chase of any gun intended to stand heavy charges. In addition, by an ingenious arrangement, Messrs. Hawksworth & Harding are enabled to rifle the tube in the act of drawing. Not, be it observed, by cutting away metal to form the grooves, but by pressing them, as a seal does wax. It is a sufficiently suggestive fact that the French Government have ordered, and are now being supplied with, 50,000 rifle barrels constructed in this way, furnished by Messrs. Cristoph & Harding of Paris.

"Quitting the subject of ordnance, we find that steel tubes can be produced of almost any length, diameter, and shape. Square with a circular bore, or circular with a square bore, octagonal, square, round, or flat, be the section what it may, it is almost equally easy to manufacture. There are a thousand and one uses to which these tubes can be applied with advantage. Not the least, perhaps, is the hooping of journals. The steel being perfectly homogeneous, and utterly devoid of fibre, such journals, when in use in a good brass bearing, acquire a skin of surpassing smoothness, revolving with so little friction as to be practically indestructible.

"Although good iron, Bessemer metal, and even ordinary soft steels, can be thus drawn into tubes, the work is not easily accomplished; and there can be no doubt whatever that the success of the whole thing depends on the admirable qualities of the Hawksworth steel. Some of the details of its manufacture, then, cannot fail to prove interesting. 'The calico printers,' says Mr. Hawksworth, 'taught me how to make steel.' In the search for a peculiarly fine steel for cotton printing rolls, he made one or two apparently trifling discoveries, which for obvious reasons he retains in his own possession. These placed at his command the ver of making the best steel for 'print use' which has, perhaps, ever been produced, and which is in extensive use both here and abroad. The process of manufacture is simply this:—About 40 lb. weight of the very best soft Swedish bars which can be produced are placed in a fire-clay crucible, and melted in an air furnace—two pots at a time, just as steel is melted. The temperature required to effect the fusion of so infusible a material as soft iron is perhaps one of the highest met with in the range of the arts. The crucibles are composed of an ordinary fire-clay, prepared with extraordinary care. The Sheffield steel maker kneads his clay for three hours. Mr. Hawksworth kneads his for days, finding his infusibility is to be thereby materially increased; in addition certain foreign matters are added and thoroughly incorporated. The result is a clay which is practically infusible, and capable of affecting the quality of the iron melted in contact with it.

"The iron is not only melted; it is retained at the highest attainable temperature, out of contact with oxygen, for a period of about six hours; and during this stage of the process Mr. Hawksworth carbonises it to any extent he thinks proper, and with the utmost certainty, by means which for the present remain secret. It will be seen, however, that this is the Bessemer process inverted, the iron being carbonised while in the fluid state instead of being decarbonised. This duration of fluidity is an essential condition to the absence of fibre, and we thus find that the Hawksworth steel has every possible degree of hardness which can be required, from that of lead to that of a file; but in no case can the slightest approach to fibre be detected in any of the samples with which we are acquainted. Large masses of the metal have never been produced, simply because the aim of the manufacturer has always been quality, not quantity. Were this steel a new thing, we would not have said so much in its favour, but it is a marketable commodity sold by hundreds of tons in the year, and we cannot, therefore, be accused of partiality if we say that it is one of the most perfect materials produced, and the sooner it is applied to ordnance purposes the better. The introduction of a new mechanical process is always a matter worthy of note, and it is certainly many months since anything so remarkable as Hawksworth and Harding's method of making tubes has come under our notice."

12. In connection with the *use of steel for boilers*—on which a fuller note will be met with in p. 73 of the volume of "Facts and Figures for 1863"—the following brief extract from the same Magazine from which par. 11 is taken, will be useful:—

"Some interesting experiments have been made in Prussia with steel steam boilers, an account of which has been published in *Dingler's Polytechnic Journal.* A steel boiler of the egg-end shape, 4 ft. in diameter and 30 feet in length, without flues, was tried. It had a steam drum 2 ft. in diameter and 2 ft. in height, and the plates were one-fourth of an inch in thickness. Beside it there was placed another boiler, similar in every respect, excepting that the plates were of iron 0·414 of an inch in thickness. The steel boiler was tested by hydraulic pressure up to 195 pounds on the inch, without showing leakage, and both the iron and steel boilers were worked under a pressure of 65 pounds on the inch for about one year and a half. During this period the steel boiler generated 25 per cent. more steam than the iron one, and when they were thoroughly examined after eighteen months' practical working, there was less scale in the steel than in the iron boiler. The former evaporates 11·66 cubic feet of water per hour; the iron boiler 9·37 cubic feet. The quantity of coal consumed was on an average 2,706 pounds for the steel one in twelve hours, and 2,972 pounds for the iron boiler. The plates of the steel boiler over the fire were found to be uninjured, while those of the iron one were about worn out. In Prussia several worn-out plates of iron boilers have lately been replaced with steel, which, it is stated, lasts four times as long. As steel is twice as strong as iron, thinner plates of the former may be employed for boilers, and more perfect riveting can be secured. A greater quantity of steam can also be generated in the steel boiler on account of its thin plates, and thus much fuel may be economized. Such steam boilers should engage the attention of all who make and use steam boilers for engineering and manufacturing purposes."

13. *c. Working and Testing of Boilers,* (See conclusion of par. 1.).—From p. 17 to 68, in the first volume of 'Facts and igures' the reader will find numerous details bearing upon this hly important department of Engineering; which it is unneces- ere to repeat, and he is therefore referred to them as com-

prising nearly all that can be said upon it. During the year which we are now recording, some valuable papers have appeared on this department which we now give. The first of which, from the "Mechanics' Magazine," takes up the subject of the supply of water to, or the "feeding of boilers," a neglect of which leads to many sad catastrophes.

"The supply of water," says the author, "to a steam-boiler is by no means a simple matter. Although a force-pump is easily constructed and easily worked, it does not follow that it can always be persuaded to perform its duties with the unvarying certainty and regularity so essential in mechanism intended to supply a generator with water. A particle of dust, half the size of a pea, located beneath one of the valves, may suffice to render a very powerful pump wholly inoperative, and in addition, very great inconvenience and expense is often occasioned by the necessity for adapting the pump to some situation, either far removed from the boiler or the engine, in order that it may be got to work at all. Engines are frequently separated by a distance of as much as 100 ft. from the boilers. The well or tank from which the water has to be drawn may be an equal distance from both; long mains and suction pipes are then indispensable, and the disadvantages entailed by their use is well known. Long suction pipes are so objectionable, whether vertical or horizontal, that they are seldom or never used in direct connection with a feed-pump; it being preferable to incur the expense and trouble of a subsidiary pump and tank, rather than encounter the risk and danger of filling the boiler at one operation directly from the well; and it is frequently found far from an easy task to get the power to the right place. Boiler and engine are very rarely near together in our factories or ironworks; and as it is usually found more convenient to drive the feed-pump directly from the main shaft or working beam of the engine, than by means of separate gearing. The pump is found in one part of the premises and the boiler in another. The engineer in whose charge the engine is, leaves the question of water-supply to stokers, who work altogether by gauges; and as there is little communication between these men, both pump and gauges may become out of order, and shortness of water result, in the absence of that check on their *efficiency* which a simultaneous observation of all the apparatus connected with the supply of the boiler affords. Feed-pumps should always be under the direct control and inspection of the stoker or other individual, whose duty it is to see that the boilers are fed properly; and it follows, as a matter of course, that the feeding apparatus should be placed in the boiler-house, and not in the engine-room.

"The question of boiler supply is so complex, and really entails so many practical difficulties, that it has always proved a tempting subject for inventors. It will not suffice that a pump or other appliance should work well for years; if it give out unexpectedly, all its past services are regarded as nothing. It may be impossible to construct any piece of mechanism thoroughly reliable; but the attempt to get as near perfection as we can reach, is commendable; and the feeding of a steam-boiler now is far better managed than it was half a century since. Even yet, however, it is not too much to say that feed-pumps cause more trouble and annoyance than anything else connected with steam-machinery. They are so whimsical and uncertain, so tenacious of their rights, and prone to resent the smallest infringement of the laws by which they are governed, that, without constant supervision or adjustment, no reliance whatever can be placed on them. Engineers are well aware of the fact; and the duplication of alimentary apparatus in every class of engine of any considerable size, shows how little confidence pumps have earned for themselves.

"In locomotive, portable, and marine engines, no difficulty is experienced in combining pump, boiler, and engine in one whole best adapted to the transmission of power from one section to another. Little space is lost; and the necessity for long suction and forcing pipes, as in stationary engines, never occurs. The force-pump, if driven by the main engine, now fails, however, in one important particular. In order that a few cubic feet of water may be pumped into the boiler, the entire engine must be put in motion. The inconvenience connected with this cannot be overrated. Locomotives so constructed frequently run their water down to the lowest limit, from the absolute impracticabi-
of moving them in crowded stations. We know of one lo-
e superintendent, who, some years ago, before the advent
ector, actually removed the lead plugs from the furnace

crowns of certain engines working particular sections of the line under his control, substituting iron rivets in their place, simply because—with the utmost care on the part of his drivers—the boilers frequently got short of water, and the replacement of lead plugs became an intolerable nuisance. Such a state of affairs could only arise from mismanagement; but no amount of mismanagement could lead to similar results, in these latter days of injectors and donkey pumps. The injector, as at present constructed, does not possess a single advantage over the pump, save those which lie in the facility with which it can be used while the engine is standing, and the fact that water does not lie in the suction pipes to burst them in frost. We are not disposed to undervalue Mr. Giffard's invention. Every engineer, who has had experience in its use, will agree with us in bearing testimony to its efficiency; but they must also admit that it is crochetty and variable in its action. So long as a locomotive is standing, it performs its duty pretty well, although prone to throw itself out of action now and then, without any ostensible cause. When running at a high speed, it is sometimes simply impossible to get it to work: a few drops of water passing through it with the steam stop its action at once. The agitation of the water in the tender produces the same effect. Over and over again have we seen a vain attempt made to get a drop of water into a locomotive boiler fitted with *two* injectors, while the train continued to travel at speed. It is to be remembered, too, that locomotives use purer water, as a rule, than any other kind of engine; and, therefore, we hear nothing of the evil effects likely to be produced by incrustation about the nozzles, in situations where dirty water is employed. Notwithstanding these things, the injector is so convenient in its application, so durable, and so independent of the engines proper, that its introduction was a great step in advance. But we would commit an error did we pronounce the problem of boiler alimentation solved either by Mr. Giffard or any one else. We want something still, as cheap, as simple, and as independent in its action as the injector, and far more certain in its action.

"Many schemes for automatic boiler-feeding have been propounded on the continent; more than one enjoys some favour. They all depend on the same principle. By the descent of a float, valves or cocks are opened, by which steam from the boiler is allowed to press on the surface of a body of water previously raised to a vessel placed above the boiler. The equilibrium thus established, the fluid descends by its own gravity to the generator; the float rises; the valves are shut; the steam is suffered to escape or is condensed; the receptacle is filled again, in readiness for the next descent of the float. It is evident enough that, however applicable such expedients may be to stationary boilers, they are quite unsuitable to locomotive and probably to marine engines. They have found little favour here; nor is this remarkable. Any automatic appliance of the kind is certain to render stokers and engine-men careless. The better the scheme answers its purpose, the more likely is it to produce this effect. It is not to be expected that a boiler which has taken care of itself for a thousand days will fail in its duty the thousand and first. Such things do happen, nevertheless, and fearful mischief follows as a result. The best means of making a careful stoker is to let him feel his responsibility, and pay him accordingly.

"Any future progress in feeding apparatus must, we think, rest on the further development of the donkey pump. The principles involved in its use are correct; and it only requires such a modification of form as will render it cheap, simple, and compact, to at once entitle it to well-deserved popularity. Hitherto, in its simplest form, the donkey has been neither more nor less than a complete steam-engine in miniature, with all the complications of fly-wheel, eccentric, bearings, stuffing-boxes, &c. No wonder that the injector superseded it, as it were, in a moment. What engineers want is a small steam-pump, which will work whether the engine is going or not—which will draw from a fair depth, and deliver with certainty against any pressure; and this must be done, so to speak, by a steam piston and a water piston, and very little else. Fly-wheels, crank-shafts, and a multiplicity of parts, moving or at rest, must be eschewed. The smaller it is made the better. There is no good reason why such a pump should not be capable of feeding a 20-horse boiler, and yet small enough and light enough to be carried under the arm. The force-pump still possesses many advantages not found in the injector; while this last confers powers on its user not bestowed by an ordinary pump. In the combination of the best features of both, will be found the surest way of producing that grand desideratum—a thoroughly good boiler-feeding apparatus."

14. In close connexion with the feeding of boilers, are the appliances in ordinary use, by which the condition of the boiler as regards its supply is ascertained. Of these appliances the "*water gauges*" are perhaps the most important. The consideration connected with and affecting the practical use of these are well discussed in the following article from the "Practical Mechanics' Journal."

"The importance of a correct and safe means of indicating the actual water level in steam-boilers, is too well appreciated by engineers of the present day to need any further urging as to its value. It is proposed, in the present paper, to set forth the most serious and alarming defects of the existing systems of indicating the true water level in these "*magazins de violence.*" The defects of the old float system are so well known that any comment upon them would amount to superfluity, and yet, if we choose to use our powers of observation, we can every day discover several of these dangerous instruments in constant, and as unfortunately too often happens, "*quasi*"-reliable use by their ignorant proprietors. The number of explosions which have occurred, and are likely yet to occur, from the reckless persistency in the use of these reprehensive boiler appendages, are more than enough to justify the utmost censure that can be raised against them.

"It is, however, to the more modern forms of water gauge that we wish to have attention more particularly directed, and it is presumed that its general form and principles of construction, namely, (the glass tube mounted with cocks at both ends in direct communication with the water and steam spaces of a boiler,) are thoroughly understood. The writer has had ample opportunity of testing the results obtained, and the consequences which follow from the employment of the glass tube water gauge, having himself taken off several of them at various times from different boilers (chiefly locomotive) on an important line of railway in the south of England, noting at the time the amount of corrosion or deposit that had formed on the interior of the channels connecting the glass tube to the boiler. These passages or channels have, on several occasions, been found nearly closed or choked by corrosive or deposited matter.

"Having measured the diameters of the connecting channels of a large number of gauges when perfectly free from corrosion, they have only in one or two instances, being found to exceed ·375 inch diameter, frequently they are not more than ·25 inch diameter, the more usual size being a mean between the two, or about ·3125 inch diameter, and it is believed that there is a very urgent affinity existing between the material of which the gauge mountings are made (which is always brass or gun metal), and the deposit produced from the water. The reasons for believing this to be the case, are inferred from the fact that the amount of deposit found in these channels is greater than that generally found in any other part of the boiler. It may perhaps be suggested that the locality and position of the channels of water-gauges would favour the excess of deposit in a superior degree to any affinity that may exist, but in the writer's opinion, if position influenced the extent at all, it would cause a thick layer on the lower side, and little or perhaps none at all on the upper side of the channel, whereas in every case the amount has been found equal on all sides.

"Two gauges were taken off locomotive boilers in which the deposit had taken place to such an extent as to leave a passage for the water of little more than ·0625 inch diameter, and one in which the lower channel was entirely closed, the result of which was, as might naturally be expected, a burnt boiler.

"But it may be contended, and no doubt will, as against these statements, that such a state of things cannot really exist; for how, it may be said, can such an amount of corrosion occur, provided, as most gauges are, with screw plugs which can be withdrawn, and an instrument inserted for the removal of all corrosive matter from the interior of these channels? The answer is, that the substance which adheres to the sides of these channels is so excessively obdurate, that any instrument which can be inserted through the plug holes fails in the attempt to remove it.

"The writer remembers having tried to remove the corrosive substance from the interior of several gauges by the use of a hammer and chisel, when the substance proved to be so hard a incapable of being operated upon, that the chisel was instant blunted, and but a trifling portion of the corrosive matter unseated; and besides all this, if even the substance could be removed by the use of an instrument such as could be inserted through the small plug holes, it is asked, how often would an engineman take such precaution? It is perfectly true that some of our locomotive superintendents are very fond of putting fines on their men for non-fulfilment of duty; but how often do they trouble themselves to inquire into what are considered generally minor details, such as have been above enumerated? In the present instance, there is much difficulty in ascertaining the actual state of things, as this can only be done when the boiler is cold. On some of our lines of railway it has frequently happened that a gauge glass has either burst or in some other way become broken at the time an engine was proceeding with its train; the engineman at once attempts to prevent the steam and water from gushing out, by endeavouring to shut off the communication with the boiler; still, it frequently is only an attempt, for he finds that the cocks have become so firmly fixed from want of use and occasional turning, that he cannot stop the exit of steam and water from the fractured orifice. He has but one remedy, and this must be resorted to instantaneously or dire consequences would inevitably follow; he stops the engine, drops the fire as speedily as possible, to prevent at least the burning if not the explosion of the boiler. Many readers of the *Practical Mechanics' Journal* are doubtless aware of the utter misery of being detained on a long journey by some such catastrophe.

"Still another proof of the insufficiency and inaccuracy of the tubular water gauge may be adduced, which also arises from an excess of corrosive deposit in the channels, viz., on ascending an incline the gauge will probably indicate full or nearly so, and on arriving at the summit, and then either taking a level or descent the water should instantly fall in the gauge in a proportion corresponding to the new position of the boiler; such, however, is not always the case, the channels or passages having become so nearly closed, the water cannot find a level in the gauge to correspond with that in the interior of the boiler for some little time. A more extended list of defects could be adduced, to bear out the justice of the foregoing censorious remarks, but it is considered that enough has *been said to* discover (though only to a small extent) the utter impropriety of looking for accurate indications by these boiler appendages which are known to be so fallacious.

"After saying so much that is unfavourable to the most common forms of the instrument in question, it will no doubt be expected that some suggestions will be thrown out for its improvement, and it is asked, why, what is the reason that a gauge or indicator constructed on principles similar to that brought out in the year 1848 by Mr. Robinson, and described in the first volume of the *Practical Mechanics' Journal*, page 43, has not been adopted? It is believed that absurd prejudice is the only barrier.

"By this instrument we always have the means at hand of ascertaining the true water level without the slightest possibility of error, consisting, as it simply does, of a piece or strip of plate-glass fitted with a proper casing and joint to the side or front of a boiler, and forming itself a portion of the boiler's side, a narrow slot being cut in the plate to give the water direct access to it. The weakness that would be produced in the plate by the cutting out of the slot may easily be counteracted by riveting a joint ring on to it in a manner similar to that which is used for strengthening boilers at the man hole joint.

"Mr. Fairbairn, some years since, demonstrated, by a series of most elaborate experiments, the severe strains that glass was capable of enduring, which will be found fully detailed in the second series of that gentleman's 'Useful Information for Engineers,' and on perusal will convince any attentive reader that there is no difficulty in obtaining a strip of glass equivalent in tensile strength to any part of the boiler itself; this, therefore, cannot be raised as a practical objection to its introduction. It may also be contended that the difference due to the expansion between the glass and iron would prevent a tight joint from being effected; theoretically this objection may be raised, but it is not of practical importance, if so, how could 'flat glass gauges' be in use? It certainly is thought that no solid objection can be raised against the introduction of such a gauge as that last-mentioned; at all events, it is high time some remedy should be adopted to improve the existing forms and construction of t instrument, and so prevent many persons from further grouping the dark as they have hitherto done, and are still doing. There is ample proof to justify the statement, 'that the existing means of indicating the true water level in steam boilers cannot be depended upon.'"

15. The *testing of boilers by means of "hydraulic pressure"* is another of the "vexed questions" with which practical engineering abounds, and about which there has been probably more dispute than in connection with any other. In the multiplicity of opinions which have been promulgated on the point, the tyro, or he who doubts his own ability, and is anxious for a wise counsellor to guide him, is perfectly bewildered. Some, he finds, maintain that this mode of testing is of imperative necessity, as being the only way in which its ultimate safety, when in practical use, can be secured; others take the opposite view, that the very testing brings about that unsafe condition which it is its object to obviate. Then, again, those who agree as to the value of the principle of the test, hold very diverse opinions as to the extent to which it should be applied, or the amount of pressure which, by its means, is put upon the boilers. Still further, some hold that it is useful to ascertain the condition in which old boilers are which have been long in use, but insist upon its inapplicability, or, at all events, its inutility, in the case of those which are new, and have not been in use at all. Then, again, the condition of the water is another disputed point, some insisting upon cold—which is the rule—others upon hot water, which is the exception in practice. On this point we may say it appears to us that if the water is hot—and the higher the temperature the better—the condition of the boiler in the trial is brought nearer to what is undoubtedly its condition than in practical use. The expansion of the boiler under the action of hot water is a condition which should not be ignored in the testing of a boiler. It is right, however, here to note the fact, which cannot, we think, well be disputed, that by far the greater majority of practical authorities are in favour of the hydraulic test for boilers. The subject, in its practical bearings, is well discussed in the following article from the "Engineer," which, although confined specially to the *testing of locomotive boilers*, obviously conveys much that is applicable to other forms:—"Within the last few years a considerable number of locomotive boiler explosions have taken place,

and in every case upon one or other of the great lines upon which locomotive boilers are never tested by the force pump. On the other hand, we believe that there is no account of the explosion of any boiler regularly tested by the pump upon either of the lines where that test is adopted. The engineers of the Manchester Boiler Association, and the Midland Boiler Association, each having many hundreds of boilers under their care, insist upon the hydraulic test as the only searching inquiry which can be made into the internal character of a boiler; in France the law requires all steam boilers to be tested by the force pump, and in those parts of the United States where a police inspection of boilers has been adopted (and this is the case in the adjacent cities of New York and Brooklyn) the hydraulic test is always required. Now none of the great numbers of boilers under the care of the Manchester and the Midland Boiler Associations have exploded for years; explosions are especially rare in France, and even in New York, and notwithstanding the terrific explosion the other day on the Chenango steam vessel, the occurrence of this class of disasters is now unusual. We believe that experience is altogether in favour of a regular test of boilers by water pressure, up to nearly, or quite, twice their working pressure. Yet there can be no doubt that the opinion of many well-known and long-experienced engineers is decidedly opposed to this, or, indeed, any kind of testing, and we have heard it said that the locomotive superintendent of one of the principal lines in the kingdom has declared that, if he were called upon by his directors to apply the hydraulic test to the boilers of his engines, he would resign his position. This is the feeling, we believe, on the London and North-Western, London and South-Western, Great Western, Great Northern, Midland and North-Eastern lines, and with, perhaps, one exception, locomotive boiler explosions have become comparatively common upon all these lines. It is feared, and we will not say without reason, that a temporary pressure, much beyond that at which the boiler is intended regularly to work, may permanently injure the boiler, and thus cause it to fail at a lower pressure than would otherwise have been the case, or, to put it more strongly, lead to failure, where, otherwise, no failure would have happened. Now, it is quite certain that good boiler iron may always be tested up to a strain of 10 tons per square inch without injury, remaining every way as strong as before the test. This, we repeat, is true with respect to the best boiler iron, and even to the average of Yorkshire plates. It is only iron that breaks at 20 tons strain, or less, that is injured by a strain to half that amount, or rather more than one-half, for a single strain up to one-half the breaking strength of iron does not, on the general experience in such matters, produce injury. The bursting pressure of a strong locomotive boiler, 4 feet in diameter, and made of the best ½-inch plates, with double riveted joints, should not be less than 850 lbs. to 900 lbs. per square inch, corresponding to a strain of, say, 27½ tons per square inch of the strained section of the iron. Upon the ordinary experience with iron under all other circumstances, it should be prudent to test such a boiler to even 350 lbs. per square inch, and at least to 300 lbs. It is to be remembered that there are 51-inch boilers made of 7-16ths of an inch, and, in some cases, of no more than ⅜-inch iron, and which, single riveted as they are, would, when new, burst at 500 lbs. pressure; but this style of boiler-making is not now continued in locomotive practice in this country. Even here, however, the boiler should bear a test-pressure of from 200 lbs. to 225 lbs. without injury. Nevertheless,. in boiler-making, the strength of the structure is sometimes unequal, and in parts less, perhaps, than that of the cylindrical barrel, the bursting pressure of which has been taken in the estimates just given, and to which bursting pressure all other parts of the boiler should be equal. It is, perhaps, the fear that they are not that causes many locomotive superintendents to hesitate before loading their boilers, even for a temporary trial, to more than their ordinary working strain. If, however, we assume the existence of weakness, whether original or produced, in any part of the boiler, it may, of course, happen that, without disclosing the defect, a hydraulic test would aggravate it. Here is the real ground of objection to the hydraulic test carried, say, to twice the working pressure, or to even one-half more than the usual load. And as the fear is grounded within the range of probability, engineers will never, perhaps, fully divest themselves of it. Dr. Joule has proposed to infer the strength of boilers by filling them quite full with cold water and then closing the safety-valves, and lighting *a fire in the* fire-box or other fireplace.

The strain here applied would be that produced by the expansion of water by heat. The density of water being greatest at 39°, it is the same at 46° as at the freezing point, and from 46° to the boiling point the expansion in volume amounts to about one twenty-third of the original bulk, the rate of expansion being very rapid after a temperature of about 150° has been reached. Dr. Joule's plan is to watch the increase of pressure upon a pressure-gauge, and if it be regular, to infer the soundness of the boiler; a jerk or succession of starts of the pointer of the gauge denoting weakness. We have no means of knowing how far this mode of testing has the advantage over that by the pump, but we fear that, even if some portion of the boiler was overstrained in the process, the rise of pressure would not be so irregular as to attract attention; nor, allowing for the almost inevitable want of exact truth of form in the boiler, should we expect the gauge to rise quite steadily, however sound the boiler might afterwards be proved to be.

"The real defects to be anticipated in a boiler are not uniform weakness, affecting all parts alike, but local unsoundness, often where the cause can hardly be detected, even when the iron has yielded under strain. If the iron, being weak, were uniformly so, nothing would be easier than to place a steel tape around the boiler and to note whether, after the pressure was let down, the barrel assumed its normal circumference. But a flaw at a single part, as long as the remaining strength there was just above the test pressure, could not, of course, tell sensibly upon the dimensions of the whole boiler. But the real value of the hydraulic test is not injured by this reasoning, nor, if properly considered, need any danger be apprehended as the result of its application. If a boiler is really as strong as, with what are believed to be the best materials and workmanship, it may be calculated to be, no test up to one-third, nor, indeed, one-half this strength, should injure it. We would not, at the same time, recommend much, if any, more than one-third the calculated bursting strength. Let us suppose that the test pressure is twice the working pressure, and that, in reality, the ultimate strength of the boiler was, in consequence of some local weakness, but twice and a-half the working pressure. Here the boiler is already unsound, and although it is possible that the test may aggravate the unsoundness, it is certain both that the weakness will, after a time, show itself in any case, and that, practically, the danger is not greater than before, so long as the working pressure is kept at one-half of that at which the boiler is tested. In other words, 300 lbs. having been borne without visible failure, 125 lbs. to 150 lbs. should be within the limits of safety for a moderate period of time. If, at the end of this, the boiler has grown worse, a subsequent test with the pump may be expected to show it at once. In any case, a boiler which is injured, however unsuspectedly, by the force-pump test, must have been already much less strong than was to have been fairly calculated upon, unless, indeed, there were reasons for suspecting weakness, in which case the boiler should be examined in the most thorough manner, and, unless quite satisfactory, condemned at once. The danger, we believe, from a boiler overstrained by a force-pump, is not, practically, greater than from the same boiler, supposing it not to have been tested. If locomotive superintendents everywhere should adopt this view, and act upon it, we are confident that locomotive boiler explosions would become of very rare occurrence."

16. With reference to the practical points involved in the working of boilers, however unanimous may be the opinion as to the value of the principles upon which they are founded and the appliances which are the practical outcome or result of these principles, it is obvious enough that much will depend upon the way in which these principles are carried out, and on the manner in which these appliances are attended to. For in this, as in other things, there are two ways of attending to a duty or duties, the *careless* and the *careful*. The *wear and tear of a boiler*, or to put it in other words, the rapidity with which it is brought from a condition of efficiency and safety to one of inefficiency and danger, although doubtless dependent in some, possibly in great, measure upon a variety of causes occult and otherwise, over which little direct control is obtained; is nevertheless in other measure also dependent upon the way in which it is worked and the care to which it is subjected. On this same subject of *wear and tear of boilers*, the *Mechanics' Magazine* has such excellent remarks that we here extract the article in which they appear. Many of these remarks, *we are glad* to see, are corroborative of

what we have ourselves said in the introduction to the present Division, and to which some by the way may have taken exception as giving a perhaps too low an estimate of the position which 'boiler engineering' occupies as compared to other departments of the art or science.

"The wear and tear of a steam boiler, properly made, and properly worked, should be, and often is, almost infinitesimal. Instances are not wanting, where plain cylindrical boilers have been in use for more than thirty years, and yet remain in a state fit for service. The nature of the strain to which the plates of a generator are exposed from the pressure within, in no way resemble those which produce crystallization and fatigue in iron. They are scarcely dissimilar from those due to simple gravity without motion; and it is not more likely that the molecular relations should be disturbed in a boiler plate, than in a girder or breastsummer supporting the front of a house. Pressure, or any variation in pressure, so long as it does not approach the limit at which iron loses its elasticity and suffers permanent deflection or elongation, cannot inflict injury of any kind; and we may, therefore, consider it under such limitation, as absolutely innocuous in its relation to the material of which boilers are ordinarily composed.

"Were no other agency called into play by the operation of making steam, the duration of boilers would be measured by centuries rather than years. Unfortunately, chemical action, more or less resulting from unavoidable ignorance, or downright neglect, acts destructively from the moment the plates leave the rolling mill until they are deemed no longer worthy of confidence in the shape of a vessel for generating steam. The plates of locomotive and portable boilers, having other duties to perform, as well as sustaining pressure and transmitting heat, following on the attachment to them of machinery, are exposed to additional agents of destruction—such as vibration, percussion, and various cross strains and twists—the effects of which are manifest enough, though the actual manner of bringing about these effects is still almost wholly a matter of conjecture; while the marine boiler is shortest-lived of all, for reasons lost for the present in total obscurity.

"The wear and tear of boiler plates is a subject worthy of the most serious consideration. It is not, perhaps, too much to say that nine out of every ten explosions are directly the result of corrosion. Setting aside the value of human life and limb, we find that the mere pecuniary interests involved in either the gradual or sudden destruction of a boiler are very considerable. Repairs are at all times expensive; and the time lost in making them is often a serious source of pecuniary loss, worry, and trouble. Hence the replacement of a plate or the alteration of a defective flue, is often staved off from day to day until irreparable mischief is done. Reflecting on these things, it seems strange that boilers should be built, and fired, and worked with a negligence which apparently regards iron plates as indestructible, and the results of an explosion as trifling to a degree. We cannot set such a system—or rather such a want of system—down wholly to the score of stupidity or neglect. We know that boilers, in the best hands, under the most careful management, often become worthless with a startling rapidity which no amount of theoretical reasoning can account for, nor practical skill can arrest or delay. The utter uncertainty in which the engineer is doomed to live as to what really does or does not promote durability, leads naturally to recklessness, neither the result of want of thought nor of indolence. Corrosion is too often regarded in the light of a fate—a destroyer, merciless, and indiscriminate, before which, as before a kind of fetish, the manufacturer and the shipowner bow down and submit.

"Through all this darkness, however, a certain light gleams out, which, if it fails to clear up every mystery, at least enables us to avoid many errors and mistakes. The teachings of experience inform us that the wear of stationary boiler plates is almost uniformly the result of leakage, over-firing, or, what is nearly the same thing, shortness of water. As these boilers are usually set, water in small quantity insinuates itself between the plates and the seating walls. Oxidation quickly ensues, with all its destructive results. Boilers so set cannot receive too carefully or oftenly repeated examination. The deposit of water between the plates and the brickwork is not, invariably, a result of leakage. Every time that steam is raised from cold water, a copious deposit of moisture, produced either by the direct formation of steam from damp fuel, or by the combustion of escaping hydrogen, settles on the cold plates, running down them in drops, and insinuating itself by capillary attraction into the minutest cracks and crannies, from which it is afterwards expelled with difficulty. This aqueous fluid is invariably charged, more or less, with some one or other of the acids arising from the burning fuel, and its powers of attack on the plates with which it comes in contact are proportionally energetic. We invariably find that those boilers which are most steadily worked, and are least seldom allowed to cool down, last longest in proportion to the whole quantity of work which they perform. Other agencies, no doubt, aid in producing this result—such as the suppression of the strains due to alternate contraction and expansion, which always have a powerful tendency to cause leakage; but these simply co-operate with the action which we have just referred to. It is very desirable that the system of using bottom seating walls should be completely abandoned in favour of some other less objectionable method of supporting boilers in brickwork.

"The duration of a boiler depends more on the quality of the water used within it than on perhaps anything else. In the peculiar effects produced by different waters lies nearly all that is mysterious in the wear and tear of boiler plates. Water perfectly harmless in one boiler, is powerfully destructive, now and then, in another placed beside it. One plate will be attacked, pitted, furrowed, or eaten away in great patches, while the rest will be found, after years of use, to retain the hammer marks of the boiler-maker, as fresh as when they came from his hands. All attempts at accounting for this action have been all but futile hitherto. Possibly, it may depend on the presence or absence of some peculiar ingredient in the plates. Absolutely pure iron is unknown outside the chemist's laboratory; and the analysis of plates displays a total absence of accurate uniformity in the results obtained from different samples. Some irons oxidate very readily, and others crystallize or exfoliate under the action of heat. We know these things certainly; and all the rest is, to a great degree, mere guesswork. Recent experience clearly demonstrates that the purest and softest water is usually far more injurious to iron plates than the hardest water ever met with. It is true that, without extraordinary care, deposit from this last omes so thick and impervious that the furnace plates become overheated and are burned out in consequence; but this can only be regarded as an induced effect; directly, the water does not come in contact with the plates at all, and cannot therefore do them any injury. Perhaps the purest water used for raising steam, is that flowing from a surface condenser; yet the corrosion which frequently follows on its use is so rapid and destructive, that surface condensation still makes but slow progress to general adoption as a consequence. All things considered, the wisest policy appears to lie in keeping the water out of contact with the plates, by the interposition of some insoluble medium. Nothing answers better than a moderate amount of deposit. Careful blowing out from time to time, and, when the water is very hard, the use of some solvent, will easily keep this within reasonable limits, so that very little heat indeed need be wasted. Varnishes of various kinds have been proposed and used from time to time to fulfil the same purpose; but the success they have met with is doubtful. The causes which lead to the injury of a plate when in contact with water, cease to demand much investigation at the hands of the engineer, when we can avoid the injury simply by preventing the contact.

"Steam frequently produces corrosion to a remarkable extent. The plates far above the water level, in marine boilers, are often eaten away after a fashion almost impossible to account for. One side will be found untouched, the other reduced in places to the thickness of a sheet of paper, in the course of a few months. Those boilers most constantly under steam are least subject to this peculiar action. It is not easy to find a remedy. Constant painting with strong red-lead paint is useful. Were it possible to enamel the interior of that portion of the boiler devoted to steam, we would hear no more of this kind of corrosion; and this will probably be accomplished some day soon. Meanwhile, hundreds of plates are destroyed annually, and no perfect panacea has yet been found.

"The destruction of furnace plates is usually caused by mismanagement, or defective design. Scant water-spaces as surely lead to over-heating, as shortness of water. A great deal has been written to show that, within moderate limits, the transmission of heat is not affected by the thickness of the plates. Such statements involve *a great fallacy*. Heavy fire-boxes actually burn out quicker than light ones; and besides the difficulty of getting good plates half-an-inch or so thick, which will not exfoliate, many disadvantages incidental to the process of constructing a boiler are encountered in the attempt to use them. In American locomotives, it has been found that copper fire-box plates 7-16ths of an inch thick, rapidly burn away to 1-4th of an inch, where the process seems to be arrested; the fire-boxes lasting a long time subsequently. Very intense combustion, and the direct impact of highly-heated flame, are of all things to be avoided; and therefore, a large grate is usually found conducive to the duration of furnace plates, by permitting the necessary quantity of coal to be burned per hour, without an excessive draught.

"Locomotive boilers are exposed to a source of wear and tear from which other generators are exempt; the strains produced by the attached machinery, and the shocks and vibrations resulting from inequalities in the road, inducing crystallization in the plates, and in all probability leading indirectly to that peculiar furrowing to which this class of boiler is so notoriously subject. It is by no means easy to give a reason for the existence of a furrow 1-4th of an inch wide, grooved half through a 7-16ths plate for a distance of eight or ten inches, almost as accurately as though it had been done with a special tool. No hypothesis yet advanced affords any solution of the problem; nor is it likely that our curiosity will soon be satisfied. Possibly, these furrows may occur at a "node" in the circumference of the boiler. When a bell is struck, certain portions of its periphery remain at rest, the remaining portions vibrating. Much the same phenomena may occur in a boiler vibrating under the shocks and jars incidental to high speed, and a certain internal change may possibly take place in the iron. What this change is, no one can say, and so the matter rests for the present. A more tangible source of injury is found in the faulty system of construction, which attaches the waist of the boiler to the frame, by a deep 'motion plate' carrying the ends of the guide bars in inside cylinder engines. The expansion and contraction due to changes of temperature keep the bottom plates attached to this cross-girder—for so we may term it—under a perpetual strain, which starts off rivet-heads, and leads in time to the total destruction of the plates so confined. Bottom plates require frequent renewal from this cause; and thus a motion plate attached to a boiler is always evidence of careless or ignorant design.

"With care, moderate firing, and good water, the duration of any boiler may generally be calculated on pretty closely; but any variation on the system of management pursued from the first, and found to answer, generally produces bad results. Many a boiler is destroyed by an alteration in the furnace, or the mode of firing, or a change in the quality of coal or water. With all possible care, it is impossible to provide for those mysterious agencies with whose existence we are acquainted, but of the exact operation of which we know little or nothing. Constant inspection at short intervals, can alone obviate fatal catastrophes; and we would again and again impress on our readers that all experience goes to show that durability, safety, and exemption from explosion, are ensured by well-organized inspection, more effectually than by any other means ever devised by man."

17. In connection with the economical working of boilers, the *kind of coal employed in firing* exercises a most important influence, hence the value of those experiments which have been from time to time inaugurated, in order to ascertain the relative heating value of different varieties of fuel. The effect, however, of using a mixture of different kinds has not received the attention it deserves; we, therefore, here give an article from the *Engineer* entitled "*On the Economic value of mixing different kinds of Coal.*

"It may be taken as pretty certain that the next great naval war will bring, for one indirect result, a great accession to our means of economising fuel in steam boilers. In spite of Sir W. Armstrong's warnings, we do not much care, in these piping times of peace, about the amount of fuel we waste in our steam furnaces. But the case will be far different with our war steamers when engaged in actual operations, and they might just as well be without powder in their magazines as without coal in their bunkers. Every means will then be tried to diminish the consumption of fuel, and we shall then see in use a number of expedients of all kinds, beginning at the furnace and ending with the condensed water that has passed in the form of steam through the engine. The most natural and obvious beginning is to attempt to econ*omise by improving* the fuel. It is often forgotten in speaking of coal what an almost innumerable variety of fossil fuel is burnt under the generic name of coal. The principal ingredients of different coals—fixed carbon appearing in the form of cake, when the volatile hydrocarbons, such as olefiant gas, tar, naphtha, &c., are driven off, and leaving different ingredients behind in the form of ash, when both the free carbon and the hydrocarbon have been consumed—vary to a great extent. The relative amount of fixed carbon in different coals varies from 30 to about 90 per cent.; the different hydrocarbons from 5 to 58; and the proportion of water from a very small amount to 27 per cent.; while the proportion of ash is, in some specimens, only about 2 per cent.; and in others as much as 26 per cent. Remembering what an essentially complicated phenomenon combustion is, we should not be far wrong in expecting that each different gradation in the kind of coal would require a different kind of apparatus for evolving its maximum thermal effect. Different treatment of one and the same coal must produce different values of useful heat. It is one and the same thing to say that a given form of furnace—the term being used in its widest sense—requires one certain kind of coal, stoked in a certain way. In the endlessly varying kinds of coal, in the multitudinous forms of existing coal-burning apparatus, and in the varying methods of burning coal—dependent on the skill and will of the stoker—do we see the reasons for the many anomalous statements and existing beliefs as to the qualities of different kinds of coal, as to the values of different forms of furnaces, and of different methods of stoking. A goodly proportion of the thousand and one patents that have been taken out for economising fuel are mere one-sided expedients, often good enough in their way under certain conditions, and more especially when in action under the fond parental eye of the inventor. But cast forth into the world, and tested under different circumstances, the results are far different.

"The most practical question in the very wide inquiry as to economy of fuel is:—Given a certain form of furnace, what is the most suitable fuel? Or could not the best fuel, for a given purpose, be obtained from a combination of different coals? Now a combination of different kinds of coal has long been used with good effect for domestic purposes. Mr. Wicksteed's experiments, made many years ago, gave 8·045 lb. of water evaporated per. lb. of average Welsh coal; 8·524 lb. for the best small Newcastle coal, and 7·865 lb. for Welsh and Newcastle mixed half and half. It seems a wonder that more attention has not been given to these experiments of Mr. Wicksteed. There has been a long and very warm contestation between the rival North-country and South Wales Coal Associations, as to the relative values, for steaming purposes, of North-country and Welsh coal. No small stake is involved in the contest, as the fat government contracts for provisioning the British navy are the great prize. Some years ago, the government caused an investigation of the matter to be made by De la Beche and Playfair, and the result was a lengthy Blue Book, the conclusions contained in which, however, have been much disputed. There can be no doubt that Welsh coal does possess higher evaporative power than Newcastle coal, but from the results of some experiments instituted by the Admiralty, and recently published in a Blue Book on the motion, made during last session, by Mr. Lindsay, M.P., it appears that very great practical advantages are obtained by using a combination of Welsh and Newcastle coals for marine purposes.

"The practical problem set by the Admiralty consisted in ascertaining whether North-country coal, in combination with Welsh coal, might not be used with advantage in firing marine boilers. The three proportions tried were:—One-third North-country to two-thirds Welsh; one-half North-country to one-half Welsh; and two-thirds North-country to one-third Welsh. The engineer in charge of H.M.S. Supply, Woolwich, reports that he found the best proportion to be one-third North-country to two-thirds Welsh, as the North-country coal kept the Welsh more open, the fire required less pricking, while the total consumption was the same as when Welsh coal alone was used. A similar result was obtained on H.M.S. Wye, at Ascension. Two-thirds Welsh to one-third North-country were found to burn less than either of the other proportions for the same amount of work—'producing considerably less smoke, ashes, and soot, with an increase in the per-centage of clinker.' Similar experiments on H.M.S. Fearless, Sheerness, produced the same result, and the trials appear to have been conducted with much greater facilities for accuracy than on the two previous ships. The two different coals were also tested separately, 'in order to ascertain their respective merits,' and the Welsh coal (Russell's Block Vein) required 5·4 lb. per indicated horse-power per hour, North-country, (Duddle's West Hartley) required 7·6 lb. per indicated horse-power per hour. Combined together, in equal proportions, 5·9 lb. were consumed, but only 5·6 lb. per indicated horse-power were burnt when two-thirds of Welsh and one-third of West Hartley were employed. On the other hand, similar trials, conducted at Portsmouth, on H.M.S. Lucifer, would appear to give better results with Aberdare Welsh coal alone (Trial, No. 4) than with thin Ferndale Welsh alone, or half Ferndale Welsh and half Londonderry Hartley, or with one-third Ferndale and two-thirds Hartley.

"The most complete trials, however, were made at the steam factory, Keyham, Devonport, by the chief engineer there. In the first place, five experiments were made on board the Confiance steam-tug, 3 tons of coal being burnt in each experiment. The exact rate of evaporation could not be ascertained, as the boiler was not provided with an apparatus for measuring the water, but the table shows that the mean pressure on the piston, the mean number of revolutions of the engines per minute, the indicated horse-power, and the speed of ship, are pretty equal, so that the duration of the experiments and the total number of revolutions can be taken as the measure of the relative value of the fuels. Welsh Resolven thus gave a duration of 5 hours 5 min., and Hartley Main of 4 hours. When combined in equal proportions, the two coals together lasted 4 hours 48 min. Fifteen experiments were next made in the coal-testing boiler of Keyham Factory. This boiler is an ordinary marine boiler, but fitted with an apparatus for measuring the water fed in, and evaporating directly into the air. Four different kinds of Welsh coal evaporated, on an average, 9·34 lb. of water per 1 lb. of coal; Hartley Main evaporated 8·26 lb.; equal proportions of Welsh and North-country coal evaporated 8·79 lb., while the highest result through mixing was obtained from two-thirds of Welsh to one of North-country, as the mixture evaporated 9·07 lb. of water per 1 lb. of coal. But while these experiments were going on, the Association of the South Wales Coalowners objected to the description of coal being tried, and obtained leave from the Admiralty to send a cargo composed of a combination, in equal quantities, of

Powell's Duffryn, Nixon's Navigation, and Davis's upper 4ft. Merthyr. The North-country Coal Association, seeing this, also asked and obtained permission to send a chosen cargo—Davidson's Hartley. The Government contractor for North-country coal also sent some Harding's Hartley; and the Welsh coals, together with these North-country coals, were next submitted to a further series of twenty-eight experiments. Single samples were taken for each description and combination, and were burnt in the coal-testing boiler in average quantities of about 12 cwt. Some of the experiments were made with the furnaces fitted with common doors, and others with furnaces fitted with perforated doors. In the first case the experiments were made with ½in. spaces between the bars, and in the second with ⅝in., ¾in., and ⅞in. spaces, the representatives of the North-country Association also requested that trials should be made on a smaller area of grate—the original area being 14 ft., which was then reduced to 10½ ft.

"The first fifteen experiments, made on the steam-tug Confiance, showed that equal quantities combined of Welsh and North-country coals could be burnt with perforated doors almost without smoke, and with an evaporative power nearly equal to that of ordinary Welsh coal. The experiments in the Keyham coal-testing boiler with the very superior Welsh coals furnished by the two Associations and by the store-keeper General, gave as the average evaporative power of Welsh coal, 9·90 lb. of water per 1 lb. of coal, and 165·34 lb. per hour per foot of fire-grate; for North-country coal, 8·41 lb. of water per 1 lb. of coal, and 153·87 lb. per hour per foot of fire-grate; and for the combination of the two descriptions in equal proportions, 9·42 lb. of water per 1 lb. of coal, and 153·16 lb. per hour per foot of fire-grate. These results were produced with common doors, and when perforated doors were used the evaporative powers of the Welsh coals were slightly diminished, while those of the North-country coals alone, and those of the combination of both in equal proportions, were slightly increased. After the furnaces were shortened the evaporative powers of the Welsh coals rose to 10⅓ lb. of water per 1 lb. of coal, and 229·60 lb. per hour per foot of fire-grate. The experiments with the short fire-grate also show that it is possible to burn Welsh coal dust (which is now often thrown away) when it is mixed with North-country coal.

"Doing away with smoke as much as possible on board a war steamer, is not merely economically, but is also strategically, important, as the smoke from the funnel would serve as a mark to the enemy's guns, or as an index to the enemy's signalmen. The amount of the smoke formed was determined at Keyham Factory by setting down a certain number of marks for certain degrees of density and colours. Thus, very light smoke had one mark, light smoke two marks, light brown, brown, black, very black smoke, three, four, five, and six marks respectively; and these marks were recorded for every minute the smoke was seen after stoking when the smoke lasted more than one minute. Briefly stated, the whole experiments show that the economic value for Welsh coal obtained from store was 9·34 lb., with an average equivalent of smoke of 90; for best coal received from South Wales Association, 9·90 lb., with an average smoke equivalent of 30; for the same coal, when burnt on the short furnace, 10·13 lb., with average smoke equivalent of 12; while the evaporative value of the North-country coal obtained from store was 8·26 lb., with an average smoke equivalent of not less than 278; and with the coal received from the North-country Association, it was 8·41 lb., with a smoke equivalent of 292. 2. The economic value of the coal received from the South Wales Coal Association was 9·73 lb., with an average smoke equivalent of 1½; and with the same coal burnt in the short furnaces, 10·44 lb., with an average equivalent for smoke of 13; while it was for the North-country coal from the North-country Coal Association, 8·61 lb., with the average equivalent for smoke of 34; and for the same coal when burnt in the short furnaces, 10·23 lb., with the average equivalent for smoke of 25. 3. When common doors were used, the combinations in equal quantities of Welsh and North-country coal from store evaporated 8·79 lb., with an average equivalent for smoke of 47; for the half-and-half combination of the coals received from the two Associations it was 9·42 lb., with the equivalent of smoke of 23; and for the half-and-half combination of the Welsh small and the ordinary North-country coal burnt in the short furnaces it was 9·91 lb. and 9·54 lb. 4. When perforated doors were used, the combination of the Welsh and North-country coals in equal proportions gave 9·45 lb., with an average smoke equivalent of 14½.

"The important deductions from these experiments are, that a mixture of Welsh and North-country coal burns in the furnaces of a marine boiler with an economy almost equal to Welsh alone, while the combination also gets up steam at a quicker rate, and with a lower average of smoke. The combination renders practicable a consumption of small Welsh coal, while less smoke is produced, and the steam boiler is rendered more powerful through its increased powers of evaporation. Mr. Miller remarks that 'there would be no difficulty in coaling a ship with the two descriptions of coal, as the bunkers on the one side of her might be filled with North-country coal, and those on the other with Welsh coal.' Half the number of coal sacks in the store coal hulks might contain one kind of coal, and the other half the other kind. There can be little doubt that the example of the naval administration might be followed with advantage in many parts of the country, and that a superior fuel could oftener be obtained by a judicious mixture of inferior qualities."

18. *d. The Explosion of Boilers* (see end of par. 1).—Although there is no doubt that in the practical working of a boiler the causes which are likely to bring about, or, as we may with safety say, do, in truth, bring about the explosion of boilers, arise, not from a single source as a mechanical one, but from possibly a rather wide variety of sources, partly mechanical, partly chemical, and therefore, by consequence, it is difficult in some cases to decide from which of these sources, or if not from all of them in combination, any boiler explosion takes place, and that, reasonably enough, causes which are in every sense obscure may be presumed to exist, still it is, as the writer of the following article in the "*Scientific American*" clearly puts it, rather unsafe, or at least unwise, to give practical men the impression that the causes of explosion *are* so obscure or 'mysterious' as some express it; and that it is, on the contrary, wise to consider the probability that causes, *coming within the reach of their practical ability to prevent*, are also likely to operate. The remarks, to which we direct special attention, are at the end of the article we now quote, which is entitled, "*Will sudden relief from Pressure cause Boiler Explosions?*" "Many instances," says the author, "are on record where boilers have been suddenly punched by the bow-sprits of vessels, and thus relieved of great quantities of steam and water *in a very* short space of time. The

Mound City, a gunboat on the Mississippi, had a shot through her boilers, which caused large volumes of steam to escape, scalding numbers of the crew, yet no explosion followed; the water was not 'flashed into steam,' neither did it, as theorizers say it should have done, become converted into a huge projectile, and dash away the surrounding walls of the boiler like so much paper. Every day a most mischievous practice may be observed in commercial cities; the safety-valves of steamers arriving from sea, or from inland waters, are suddenly lifted, and the mighty force pent up in the boiler shoots out into the air with a deafening roar. Is not this a sudden relief of pressure? It is so sudden that the index hand of the steam-gauge goes back almost as fast as the pulse beats, and ten minutes are enough to blow the steam from the largest boiler. The practice is, as we remarked, a mischievous one, not upon the theory that sudden release of pressure is attended with danger, but because the boiler is unduly strained. The whole force within is directed upon one part, and that suddenly, and it is wonderful that so few accidents occur from this practice.

"The occasions have been neither few nor far between, during the war and previous to it, where the boilers on gunboats have been pierced with heavy shot. The *Sassacus*, one of the new double-enders, having a large Martin boiler of the same kind as the one which exploded on the *Chenango*, was recently struck with a 100 pound rifled shot, which passed entirely through the boiler. The sudden escape of steam scalded many of the crew, but beyond the perforation there was no casualty to the boiler itself. From this, and the other cases we cited, it may be seen that the particular theory queried in the caption of this article must be at fault. Why is it not better, in striving to account for boiler explosions, to look first at purely mechanical causes? When the piston-rod of a steam engine breaks, men say it was too weak, or from such and such a specific cause (as water getting in the cylinder, or a follower bolt coming out and getting jammed between the head and piston), a violent strain was put upon it which it was not capable of withstanding. No one thinks of examining the chemistry of heat, or the oil which lubricated it, or of the packing which surrounded it, to account for the rupture; and any one who should propose such a course would be looked on as an idiot by his professional brethren. Because the disengagement of steam from water is both mechanical and chemical, when a boiler bursts some men seem to have passion for diving into the most profound and absurd theories, and descant about matters they know nothing of, when a defective brace or a rotten sheet was most probably the source of all the trouble.

"*There is great mischief in attributing boiler explosions to obscure causes*, for by so doing we make practical engineers, who are not versed in the "mysteries" of their art, believe that all their care is of no avail, and that precaution or no precaution, an explosion is sure to occur, provided a certain chain of circumstances is produced in the boiler. Let us look first, and earnestly, at the mechanical construction of steam boilers, and if it is settled that no improvement can be made in this respect, turn our attention to theories and the tedious discussion of them."

19. In this paragraph we put together a few short papers bearing upon causes, or assumed causes, of explosion, which will be read with interest:—

a. The theory of Boiler Explosions from the Decomposition of Water.—"Among those who are wedded to the opinion that the explosions of steam boilers are generally produced by some mysterious force, a very favourite theory is that of the decomposition of water. It is well known that when steam is brought in contact with red-hot iron, it is decomposed, the oxygen entering the iron to form oxide of iron, and the hydrogen being set free as a gas. It is also well known that when hydrogen and oxygen gases are mixed together in the proportion of 8 lbs. of oxygen to one of hydrogen, and set on fire, an explosion results. It has been argued by some very intelligent writers that these operations take place in steam boilers, and are the most common cause of explosions.

"There is no doubt that if a portion of a steam boiler becomes red-hot, and steam is then brought in contact with it, the steam will be decomposed; the oxygen of the steam combining with the iron, and the hydrogen being set free. But the quantity of water thus decomposed in a steam boiler must be very limited. The oxide of iron which is formed in this case is the magnetic oxide, in which 3 atoms of iron combine with 4 of oxygen, $Fe_5 O_4$. As the atom of iron weighs 28, and the atom of oxygen 8, the proportions are 84 *lbs.* of iron to 32 of oxygen, or

21 of iron to 8 of oxygen. As 8 lbs. of oxygen combine with 1 of hydrogen to form water, it follows that 21 lbs. of iron will be oxidized to produce 1 lb. of hydrogen gas. This whole 21 lbs. must be upon the surface, for as soon as a thin scale of oxide is formed, it becomes a protecting coating to the metal beneath, and prevents further action.

"If the 1 lb. of hydrogen is mixed with 8 lbs. of oxygen, and set on fire, the two elements will immediately combine to form 9 lbs. of water, and the amount of heat generated by the combustion will be sufficient to raise the temperature of 1 lb. of water 42,480°, or to raise the temperature of the 9 lbs. 4,720°. Consequently, the water would be in the condition of very highly superheated steam. Though it is uncertain whether, at this high temperate, steam expands in the same ratio that it does at the lower temperatures and pressures, which are more easily measured, there can be little doubt that the pressure would be sufficient to burst any ordinary boiler, provided the whole steam space of the boiler could be filled with the two gases in the proper proportion, and the gases could then be set on fire. But in practice this could never occur, nor, indeed, could any mixture and burning take place sufficient to produce an explosion.

"In the first place, all of the oxygen taken from the water would be combined with the iron, where it would remain permanently fixed. It is true that oxygen is absorbed by water in small quantities from the atmosphere, and is forced into the boiler with the water. The first action of the heat upon the water is to expel this oxygen, together with the nitrogen, carbonic acid, and other gases which the water holds in solution, and if the oxygen remained in the steam space it might be mixed with any hydrogen set free by the decomposition of the water. But the oxygen does not remain in the steam space; it is constantly being drawn off with the steam, and worked through the cylinder. The hydrogen, too, as it is set free, being the lightest of all gases, must rise instantly to the highest portion of the boiler, and pass at once into the cylinder.

"Even should the engine be at rest, the two gases would be so mingled with the steam and with carbonic acid gas expelled from the water, that they would not burn if fire was applied to them. This objection is fatal to the theory. In consequence of the large proportion of steam in the mixture, no explosive compound of gases can ever be found in the interior of a steam boiler."—*Scientific American.*

b. The theory of Boiler Explosions from Superheated Steam.—"On the inquest into the cause of the *Chenango* disaster, one of the witnesses stated that the generally-received theory of boiler explosions is that they result from a mixture of superheated with saturated steam—that the steam, by becoming superheated, forms a reservoir of heat, which evaporates the minute particles of water carried along by the saturated steam, and thus produces an exploding pressure.

"It is probable that a dozen other theories might with as much truth be said to be generally received. At all events, several others have been advanced which cannot be so easily and clearly shown to be unsound.

"It is fully proved that the pressure in the boilers of the *Chenango*, just before the explosion, was 33 to 34 lbs. to the square inch. Now, if we suppose a portion of that steam to have been superheated to a temperature equal to red heat, how much heat would that steam have contained, and what would that heat do in evaporating water and producing pressure?

"According to the determinations of Fairbairn and Tate, saturated steam formed under a pressure of 33·1 lbs. per square inch has a volume 758 times greater than the water from which it was formed. Consequently, a pound of such steam occupies in round numbers 12 cubic feet. Its temperature is 255°, and if we superheat it to 968°, its volume will be doubled; supposing it to expand in the same proportion as air, though Fairbairn found the co-efficient of the expansion of steam to be a trifle greater than that of air. We now have a pound of steam occupying a space in the boiler of 24 cubic feet. and if we introduce a pound of water at a temperature of 255° into this space, what will be the effect? Plainly, the temperature of the steam and water will be equalized; and if there is just enough surplus heat, and no more, in the steam to evaporate the water, we shall have the space filled with saturated steam at the old pressure of 33·1 lbs. per inch.

"But there is not enough surplus heat in the steam to evaporate the water. The specific heat of steam is 0·475, consequently it would take only 339 units to raise the temperature of 1 lb. 713°—from 255° to 968°. The latent heat of steam at a temperature of 255° is 930°, in other words, 930 units of heat are required to evaporate 1 lb. of water at a temperature of 255°.

"The 'great reservoir' of heat in superheated steam, so far from being sufficient to evaporate enough water to produce an explosive pressure, is not sufficient to evaporate enough water to fill its own volume with saturated steam. The introduction of water into superheated steam under the conditions which obtained in the *Chenango* boilers would not have increased the pressure in the least."—*Ibid.*

The same journal has further remarks on this subject under the head

c. *The Superheated Theory tested by Experiment.* — "The theory that boiler explosions are caused by the introduction of water into superheated steam has formerly been discussed, and we showed that the surplus heat in the steam would not be sufficient to evaporate enough water to fill its own volume with saturated steam, and thus to keep up the pressure—much less to increase it so greatly as to produce an explosion.

"We are informed by Mr. Albert Hussey, the engineer at Hecker's mills, in this city, that two years ago he tried the experiment of injecting water into highly superheated steam, and that the effect was to reduce the pressure.

"Meeting in some work the theory of boiler explosions discussed in our article (see par. *b*, above given) he saw that if it was sound he could arrange to inject water into superheated steam, and thus obtain a high pressure with a small consumption of fuel. He was running an engine that was supplied by three boilers, and he prepared for his experiment a small boiler, 1 foot in diameter and 2 feet long, having it well jacketed with felt. He then led a small pipe from the steam space of one of his large boilers, and passed it several times back and forth through his furnace, so that it was bathed in the flame, and then conducted it to his small boiler. The pipe became red hot, and the steam passed through more than 50 feet of this red-hot pipe before it entered the small boiler. Mr. Hussey connected a pressure gauge with the small boiler, and formed a pressure of 60 pounds to the inch —of course, the same as the large boiler. He also attempted to measure the temperature, but the mercury in his thermometer was evaporated the instant he brought it in contact with the hot steam.

"He now, by means of a small force pump, injected a minute quantity of cold water, through a pipe arranged for the purpose, into the small boiler, and the gauge immediately fell about five pounds. He then arranged his connection with the pump so as to inject hot water from the large boiler into his experimental boiler, and the result was the same—the gauge went down five pounds.

"All sound theory must be founded on facts, and must, of course, agree with all other facts. Before we published our calculation of the effect which would be produced by injecting hot water into superheated steam, we were satisfied of its correctness, but it is gratifying to find it confirmed by an experiment so direct and conclusive as that of Mr. Hussey's. The theory of boiler explosions from the mixing of water with superheated steam may be regarded as settled."

d. The Corrosion of Boilers.—"Nearly all of the large number of boiler explosions, the causes of which are annually investigated by the engineers of the Manchester and Midland Boiler Associations, are clearly found to have occurred in consequence of either internal or external corrosion. In the case of locomotive boilers—and they are now exploding sufficiently often to cause considerable anxiety—'furrowing,' along a seam of rivets, or rather under the line of an overlap, is found to be the usual malady. In many boilers, especially on those lines where the hydraulic test is regularly applied, 'furrows' are discovered in time to prevent explosion. In other instances the plates become 'pitted' on their inner surfaces as with small pox. We have a photograph, kindly sent us by Mr. Longridge, of a small portion of the inner surface of one of the plates of a boiler which exploded, with great loss of life, some time ago, at Aberaman, South Wales. To compare the pits therein shown with the lunar seas disclosed in Mr. De la Rue's photographs of the moon would not do justice to the former. The iron is eaten away almost everywhere, not uniformly over the whole surface, but in numberless holes. Wherever very pure water is used, or peat water, or water containing sulphur, there is *the same* corrosion always going on, while, as for furrowing, there appears to be no effective precaution against it.

"So far as furrowing and other forms of corrosion are concerned, there can be no doubt that wrought-iron is the worst material that can be employed for a boiler. Whether steel better resists corrosion under the same circumstances has not been conclusively ascertained, but in other respects the attempts to employ steel as a material for boilers cannot be said to have satisfied the hopes with which it was originally introduced for this purpose. Copper is now wholly out of the question, nor were it abundant and cheap would its strength be reckoned sufficient. No material applicable to boilers is less liable to corrosion than cast-iron. Wherever great heat has to be borne, its resisting powers make it second only to platinum among the metals. For heating stoves for blast furnaces, and, indeed, for domestic stoves, wrought-iron is entirely unfit. For gas retorts it is, of course, worthless, while cast-iron, until the introduction of the most refractory clay retorts, was considered to serve a very good purpose. For superheaters it is quite superior to wrought-iron in any form. The Peninsular and Oriental Company have, indeed, long since abandoned wrought-iron for copper superheaters, but equally good, if not better, results are obtained by Messrs. Richardson & Sons from Mr. Jaffrey's cast-iron superheaters. The motive for the use of cast-iron in heating stoves, gas retorts, and superheaters, is economy; but in the case of steam boilers, where the principal source of danger has been found to be in corrosion, the use of cast-iron (with a large margin of strength to resist bursting) appears to be essential to safety. The highest required tensile strength is now given to cast-iron boilers—their bursting pressure being from 1,500 lbs. to 2,000 lbs. per square inch, while it appears reasonable to consider them as entirely secure from the common danger of corrosion."—*Engineer.*

20. The various points connected with what may be called *the chemistry of boiling water* possess doubtless much interest to the practical man desirous of viewing the subject from all possible points; to such, the following paper "*On Boiling Water,*" by W. R. Grove, Esq., Q.C., F.R.S., M.R.I., read before the Royal Institution, will be valuable and suggestive.

"A paper by M. Donny ('Mémoires de l'Académie Royale de

Bruxelles,' 1843) makes known the fact that in proportion as water is deprived of air, the character of its ebullition changes, becoming more and more abrupt, and boiling like sulphuric acid with *soubresauts*, and that between each burst of vapour the water reaches a temperature above its boiling point. To effect this it is necessary that the water be boiled in a tube with a narrow orifice, through which the vapour issues; if it be boiled in an open vessel it continually re-absorbs air, and boils in the ordinary way.

"In my experiments on the decomposition of water by heat, I found that with the oxy-hydrogen gas given off from ignited platinum plunged into water, there was always a greater or less quantity of nitrogen mixed. This I could never entirely get rid of, and I was thus led into a more careful examination of the phenomenon of boiling water, and set before myself this problem, What will be the effect of heat on water perfectly deprived of air or gas?

"Two copper wires were placed parallel to each other through the neck of a Florence flask, so as nearly to touch the bottom; joining the lower ends of these was a fine platinum wire, about 1½ in. long, and bent horizontally into a curve. Distilled water, which had been well boiled and cooled under the receiver of an air pump, was poured into this flask so as to fill about one-fourth of its capacity. It was then placed under the receiver of an air pump, and one of the copper wires brought in contact with metallic plate covering the receiver, the other bent backwards over the neck of the flask, and its end made to rest on the pump plate. By this means, when the terminal wires from a voltaic battery were made to touch, the one the upper and the other the lower plate, the platinum wire would be heated, and the boiling continued indefinitely in the vacuum of a very excellent air pump. The effect was very curious; the water did not boil in the ordinary manner, but at intervals a burst of vapour took place, dashing the water against the sides of the flask, some escaping into the receiver. (There was a projection at the central orifice of the pump-plate to prevent this overflow getting into the exhausting tube).

"After each sudden burst of vapour the water became perfectly ranquil, without a symptom of ebullition until the next burst took place. These sudden bursts occurred at measured intervals, so nearly equal in time, that, had it not been for the escape from the flask, at each burst, of a certain portion of water, the apparatus might have served as a timepiece.

"This experiment, though instructive, did not definitely answer the question I had proposed, as I could not of course ascertain whether there was some minute residuum of gas which would form the nucleus for each ebullition; and I proceeded with others. A tube of glass, 5 feet long and $\frac{4}{10}$ths of an inch internal diameter, was bent into a V-shape; into one end a loop of platinum wire was hermetically sealed with great care, and the portion of it in the interior of the tube was platinised. When the tube had been well washed, distilled water, which had been purged of air as before, was poured into it to the depth of 8 in., and the rest of the tube filled with olive oil; when the V was inverted the open end of the tube was placed in a vessel of olive oil, so that there would be 8 in. of water resting on the platinum wire, separated from the external air by a column of 4 ft. 4 in. of oil. The projecting extremities of the platinum wire were now connected with the terminals of a voltaic battery and the water heated; some air was freed and ascended to the level of the tube. This was made to escape by carefully inverting the tube so as not to let the oil mix with the water, and the experiment continued. After a certain time the boiling assumed a uniform character, not by such sudden bursts as in the Florence flask experiment, but with larger and more distinct bursts of ebullition than in its first boiling.

"The object of platinising the wire was to present more points for the ebullition, and to prevent *soubresauts* as much as possible.

"The experiment was continued for many hours, and in some repetitions of it for days. After the boiling had assumed a uniform character, the progress of the vapour was carefully watched, and as each burst of vapour condensed in the oil, which was kept cool, it left a minute bead of gas, which ascended through the oil to the bend of the tube; a bubble was formed here which did not seem at all absorbed by the oil. This was analysed by a eudiometer, which I will presently describe, and proved to be nitrogen. The beads of gas, when viewed through a lens and micrometer scale at the same height as the tube, appeared as nearly as may be of the same size. No bubble of vapour was condensed completely, or without leaving this residual bubble. The experiment was frequently repeated, and continued until the water was so nearly boiled away, that the oil, when disturbed by the boiling, nearly touched the platinum wire: here it was necessarily stopped.

"To avoid any question about the boiling being by electrical means similar experiments were made with a tube, without a platinum wire, closed at its extremity, and the boiling was produced by a spirit-lamp. The effects were the same, but the experiment was more difficult and imperfect, as the bursts of vapour were more sudden, and the duration of the intervals more irregular.

"The beads of gas were extremely minute, just visible to the naked eye, but were made visible to the audience by means of the electric lamp.

"In these experiments there was no pure boiling of water, *i.e.*, no rupture of cohesion of the molecules of water itself, but the water was boiled, to use M. Donny's expression, by evaporation against a surface of gas.

"It is hardly conceivable that air could penetrate through such a column of oil, the more so as the oil did not perceptibly absorb the nitrogen freed by the boiling water and resting in the bend of the tube; but to meet this conjectural difficulty the following experiment was made. A tube 1 ft. long and $\frac{2}{10}$ in. internal diameter, bent into a slight angle, had a bulb of $\frac{3}{4}$ in. diameter blown on it at the angle. This angle was about 3 in. from one end and 9 in. from the other; a loop of platinum wire was sealed into the shorter leg, and the whole tube and bulb filled with and immersed into mercury; water, distilled and purged of air as before, was allowed to fill the short leg, and, by carefully adjusting the inclination, the water could be boiled so as to allow bubbles to ascend into the bulb and displace the mercury. The effect was the same as with the oil experiment, no ebullition without leaving a bead of gas; the gas collected in the bulb, and was cut off by what may be termed a valve of mercury, from the boiling water, then allowed to escape, and so on; the experiment was continued for many days, and the bubbles analyzed from time to time; they proved, as before, to be nitrogen; and, as before, continued indefinitely.

"A similar experiment was made without the platinum wire, and though, from the greater difficulties, the experiment was not so satisfactory, the result was the same.

"As the mercury of the common barometer will keep air out of its vacuum for years, if not for centuries, there could be no absorption here from the external atmosphere, and I think I am fairly entitled to conclude from the above experiments—which I believe went far beyond any that have been recorded—that no one has yet seen the phenomenon of pure water boiling—*i.e.*, of the disruption of the liquid particles of the oxy-hydrogen compound, so as to produce vapour which will, when condensed, become water, leaving no permanent gas. Possibly, in my experiment of the decomposition of water by ignited platinum, it may be that the sudden application of intense heat, and in some quantity, so forces asunder the molecules that, not having sufficient nitrogen dissolved to supply them with a nucleus for evaporation, the integral molecules are severed, and decomposition takes place. If this be so, and it seems to me by no means a far-fetched theory, there is probably no such thing as boiling, properly so-called, and the effect of heat on liquids in which there is no dissolved gas may be to decompose them.

"Considerations such as these led me to try the effect of boiling on an elementary liquid, and bromine occurred as the most promising one to work upon; as bromine could not be boiled in contact with water, oil, or mercury, the following plan was ultimately devised:—A tube, 4 feet long and $\frac{4}{10}$ths of an inch in diameter, had a platinum loop sealed into one closed extremity; bromine was poured into the tube to the height of 4 inches; the open end of the tube was then drawn out to a fine point by the blow-pipe, leaving a small orifice; the bromine was then heated by a spirit lamp; and when all the air was expelled, and a jet of bromine vapour issued from the point of the tube, it was sealed by the blow-pipe. There was then, when the bromine vapour had condensed, a vacuum in the tube above the bromine. The platinum loop was now heated by a voltaic battery, and the bromine boiled; this was continued for some time, care being taken that the boiling should not be too violent. At the end of a certain period—from half an hour to an hour—the platinum loop gave way, being corroded by the bromine; the quantity of this had slightly decreased. On breaking off under water the point of the tube, the water mounted and showed a notable quantity of permanent gas, which, on analysis, proved to be pure oxygen. As much as a quarter of a cubic inch was collected at one experiment. The platinum wire, which had severed at the middle, was covered with a slight black crust, which, suspecting to be carbon, I ignited by a voltaic spark in oxygen in a small tube over lime water; it seemed to give a slight opalescence to the liquid, but the quantity was so small that the experiment was not to be relied on. No definite change was perceptible in the bromine; it seemed to be a little darker in colour, and had a few black specks floating in it, which I judged to be minute portions of the same crust which had formed on the platinum wire, and which had become detached.

"The experiment was repeated with chloride of iodine and with the same result, except that the quantity of oxygen was greater. I collected as much as half a cubic inch in some experiments from an equal quantity of chloride of iodine; the platinum wire, however, was more quickly acted on than with the bromine and the glass of the tube around it to some extent.

"Melted phosphorus was exposed to the heat of the voltaic disruptive discharge by placing this between platinum points in a tube of phosphorus, similarly to an experiment of Davy's, but with better means of experimenting; a considerable quantity of phosphuretted hydrogen was given off, amounting in several experiments to more than a cubic inch.

"A singular experiment was made with melted sulphur, and sulphuretted hydrogen was given off, but not in such quantities as the phosphuretted hydrogen. I tried in vain to carry on these experiments beyond a certain point; the substance became pasty, mixed with platinum from the arc, and from the difficulty of working with the same freedom as when they were fresh, the glass tubes were always broken after a certain time. Had I time for working on the subject now, I should use the discharge from the Ruhmkorf coil, which had not been invented at the period of these experiments. At a subsequent period, when this discharge was taken in the vacuous receiver of an air-pump from a metallic point to a metallic capsule containing phosphorus, a considerable yellow deposit lined the receiver, which, on testing, turned out to be allotropic phosphorus. No gas is, however, given off. I had an air-pump (described, 'Phil. Trans.,' 1852, p. 101) which enabled me to detect very small quantities of gas, but I could get none. It was in making these experiments that I first detected the striæ in the electric discharge, which have since become a subject of such interesting observations, which are seen, perhaps, more beautifully in this phosphorus vapour than in any other medium, and which cease, or become very feeble, when the allotropic phosphorus is not produced.

"I tried also phosphorus highly heated by a burning-glass in an atmosphere of nitrogen, but could eliminate no perceptible quantity of gas, though the phosphorus was changed into the allotropic form.

"It is not difficult to understand why gas is not perceptibly eliminated in the last two experiments; the effect is probably similar to that described in my paper on the 'Decomposition of Water by Heat,' where, when the arc or electric spark is taken in aqueous vapour, a minute bubble of oxy-hydrogen gas is freed and disseminated through the vapour, recombination being probably prevented by this dilution; but however long the experiment may be continued, no increased quantity of the gas is obtained, all beyond this minute quantity being recombined. If, however, the bubble of gas be collected, by allowing the vapour to cool, and then expelled, a fresh portion is decomposed, and so on.

"So with the phosphorus in the experiments in the air-pump and with the burning-glass; if any gas is liberated it is probably immediately recombined with the phosphorus; possibly a minute residuum might escape recombination, but the circumstances of the experiment did not admit of this being collected, as the gas was with the aqueous vapour.

"When, on the other hand, the gas freed is immediately cut off from the source of heat—as when the spark is taken in liquids—an indefinite quantity can be obtained.

"Decomposition and the elimination of gas may thus take place by the application of intense heat to a point in a liquid, or also in gas or vapours; but, in the latter case, it is more likely to be masked by the quantity of gas or vapour through which it is disseminated.

"I believe there are very few cases in which some alteration does not take place by the application of the intense heat of the voltaic arc of electric spark. If the arc be taken between platinum points in dry oxygen gas over mercury, the gas diminishes indefinitely, until the mercury rises, and by reaching the point where the arc takes place puts an end to the experiment. I have caused as much as a cubic inch of oxygen to disappear by this means.—I at one time thought this was due to the oxidation of the platinum; but the high heat renders this improbable, and the deposit formed on the interior of the glass tube in which the experiment is made has all the properties of platinum-black; so, if the spark from a Ruhmkorf coil be taken in the vapour of water for several days, a portion of gas is freed which is pure hydrogen, the oxygen freed being probably changed into ozone, and dissolved by the water in this case, while in the former it combined with the mercury.

"I have alluded to the eudiometer, by which I analyzed the gases obtained in these experiments; it was formed simply of a tube of glass, frequently not above 2½ millimetres in diameter, with a loop of wire hermetically sealed into one end, the other having an open bell-mouth. By a platinum wire a small bubble of the gas to be examined could be got up through water or mercury into the closed end of the tube, and by the addition of a bubble of oxygen or hydrogen gas a very accurate analysis of very minute quantities of gas could be made. I have analyzed by this means quantities no larger than a partridge-shot.

"I need hardly allude to results on the compound liquids, such as oils and hydrocarbons, as the fact that permanent gas is given off in boiling such liquids would not be unexpected; but the above experiments seem to show that boiling is by no means necessarily the phenomenon that has generally been supposed, viz., a separation of cohesion in the molecules of a liquid from distension by heat. I believe, from the close investigation I made into the subject, that (except with the metals, on which there is no evidence) no one has seen the phenomenon of pure boiling without permanent gas being freed, and that what is ordinarily termed boiling arises from the extrication of a bubble of permanent gas either by chemical decomposition of a liquid, or by the separation of some gas associated in minute quantity with the liquid, and from which human means had hitherto failed to purge it; this bubble once extricated, the vapour of the liquid expands it, or, to use the appropriate phrase of M. Donny, the liquid evaporates against the surface of the gas.

"My experiments are, in a certain sense, the complement of his. He showed that the temperature of the boiling point was raised in some proportion as water was deprived of air, and that under such circumstances the boiling took place by *soubresauts.* I have, I trust, shown that when the vapour liberated by boiling is allowed to condense, it does not altogether collapse into a liquid, but leaves a residual bubble of permanent gas, and that at a certain point this evolution becomes uniform.

"*Boiling, then, is not the result of merely raising a liquid to a given temperature; it is something much more complex.*

"One might suppose that with a compound liquid the initial bubble, by which evaporation is enabled to take place, might, if all foreign gas were or could be extracted, be formed by decomposition of the liquid; but this could not be the case with an elementary liquid; whence the oxygen from bromine or the hydrogen from phosphorus and sulphur? As with the nitrogen in water, it may be that a minute portion of oxygen, hydrogen, or of water, is inseparable from these substances, and that, if boiled away to absolute dryness, a minute portion of gas would be left for each ebullition.

"With water there seems a point at which the temperature of ebullition and the quantity of nitrogen yielded become uniform, though the latter is excessively minute.

"The circumstances of the experiments with bromine, phosphorus, and sulphur, did not permit me to push the experiment so far as was done with water, but as far as it went the result was similar.

"When an intense heat, such as that from the electric spark or voltaic arc, is applied to permanent gas, there are, in the greater number of cases, signs either of chemical decomposition, or of molecular change; thus compound gases, such as hydrocarbons, ammonia, the oxides of nitrogen, and many others, are decomposed. Phosphorus in vapour is changed to allotropic phosphorus, oxygen to ozone, which, according to present experience, may be viewed as allotropic oxygen. There may be many cases where, as with aqueous vapour, a small portion only is decomposed, and this may be so masked by the volume of undecomposed gas as to escape detection; if, for instance, the vapour of water were incondensable, the fact that a portion of it is decomposed by the electric spark or ignited platinum would not have been observed.

"All these facts show that the effect of intense heat applied to liquids and gases is much less simple, and presents greater interest to the chemist than has generally been supposed. In far the greater number of cases, possibly in all, it is not merely expansion into vapour which is produced by intense heat, but there is a chemical or molecular change. Had circumstances permitted I should have carried these experiments further, and endeavoured to find an *experimentum crucis* on the subject. There are difficulties with such substances as bromine, phosphorus, &c., arising from their action on the substances used to contain and heat them, which are not easy to vanquish, and those who may feel inclined to repeat my experiments will find these difficulties greater than they appear in narration; but I do not think they are insuperable, and hope that, in the hands of those who are fortunate enough to have time at their disposal, they may be overcome.

"To completely isolate a substance from the surrounding air and yet be able to experiment on it, is far more difficult than is generally supposed. The air-pump is but a rude mode for such experiments as are here detailed.

"Caoutchouc joints are out of the question; even platinum wires carefully sealed into glass, though, as far as I have been able to observe, forming a joint which will not allow gas to pass, yet it is one through which liquids will effect a passage, at all events when the wires are repeatedly heated.

"In some experiments with the ignited platinum wire hermetically sealed into a tube of glass, the end of the tube containing the platinum wire was placed in a larger tube of oil, to lessen the risk of cracking the glass. After some days' experimenting, though the sealing remained perfect, a slight portion of carbon was found in the interior liquid. This does not affect the results of my experiments, as I repeated them with glass tubes closed at the end and without platinum wires, and also without the oil-bath; but it shows how difficult it is to exclude sources of error.

When water has been deprived of air to the greatest practicable extent it becomes very avid for air. The following experiment is an instance of this:—A single pair of the gas-battery, the liquid in which was cut off from the external air by a greased glass stopper, having one tube filled with water, the other with hydrogen, the platinised platinum plates in each of these tubes were connected with a galvanometer, and a deflection took place from the reaction of the hydrogen on the air dissolved in the water. After a time the deflection abated, and the needle returned to zero, all the oxygen of the air having become combined with the hydrogen. If now the stopper were taken out, a deflection of the galvanometric needle immediately took place, showing that the air rapidly enters the water as water does a sponge. Absolute chemical purity in the ingredients is a matter, for refined experiments, almost unattainable; the more delicate the test, the more some minute residual product is detected; it would seem (to put the proposition in a somewhat exaggerated form) that in nature everything is to be found in anything if we carefully look for it.

"I have indicated the above sources of error to show the close pursuit that is necessary when looking for these minute residual phenomena. Enough has, I trust, been shown in the above experiments to lead to the conclusion that, hitherto, simple boiling, in the sense of a liquid being expanded by heat into its vapour without being decomposed or having permanent gas eliminated from it, is a thing unknown. Whether such boiling can take place may be regarded as an open question, though I incline to think it cannot; that if water, for instance, could be absolutely deprived of nitrogen, it would not boil until some portion of it was decomposed; that the physical severance of the molecules by heat is also a chemical severance. If there be anything in this theoretic view, there is great promise of important results on elementary liquids, if the difficulties to which I have alluded can be got over.

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strength each year. To ascertain what the strength is, we must test it, and this can be done in a simple, cheap, and expeditious manner by water and heat. If a boiler be filled *full* of water up to the very safety valves and all apertures closed, when a fire is built in the furnace the water will be expanded and raise the valve, if the boiler is strong enough to withstand the strain, but if it is not the weakest part will be shown, and sometimes sheets are torn out by this method. Steam is not generated from the water during this test, and if a rupture does take place in the boiler no one will be injured by it. The safety-valve must be loaded to the utmost limit of strain that it is supposed the boiler will bear; and if the test is favourable, only three-fourths of the load on the safety-valve must be employed for the working pressure.

"It has never been proved beyond question that a steam boiler exploded from any of the theories put forth in each disaster. Some persons have a passion for 'explaining' matters that they do not understand by something else they are ignorant of; and we have had hydrogen gas brought forward as an agent in causing explosions; water suddenly flashed into steam as another; electricity for another; and so on, through the category. These are simply excuses on the part of some one at fault for the disaster. *After* a boiler has exploded, it seems almost supererogatory to go and look at it, and say what caused the disaster. We have heaps of smoking ruins, iron bent and blackened, and in most cases each part is a fac-simile of every other explosion; the torn sheets are gravely examined, and the conclusion arrived at is that 'somebody was to blame.'

"We have no desire to treat the matter with levity, but is it not time that we had more careful superintendence of steam boilers and fewer inquests? In some cases the cause of accident may be pointed out after the explosion, but in such it might have been done equally well before. As we have before remarked, it is to be expected that some boilers will explode in spite of all inspection, just as cannon do with the most careful gunners, but it is a part, and a most important part, of an engineer's duty to be thoroughly convinced of the soundness and strength of his boiler. When we see how seldom accidents of this kind occur to marine boilers, we have positive proof of the value of thorough oversight and watchfulness; and we feel that we cannot speak too

strongly or too often in the SCIENTIFIC AMERICAN, upon the necessity which exists for prompt, thorough, and frequent inspection of steam boilers.

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"No stronger proof can be adduced of the empirical state of existing knowledge of the management of boilers than that afforded by a consideration of their average duration. While some marine boilers last only about three years, there are carefully-worked land boilers which have lasted as long as thirty. Captain Tyler, R.E., estimates the average duration of a locomotive boiler at from five to twenty years. Perhaps the average duration of a marine boiler may be reckoned at from five to seven years; that of a locomotive boiler at from eight to nine years; that of a stationary boiler at from eighteen to twenty years—all being supposed to be fairly worked under ordinary conditions.

"It is clear that, subjected as a steam boiler is to so many destructive influences, the precise effects of which can scarcely be yet very accurately known, the working tension should be only one-eighth of the ultimate bursting strength. But when boilers, as is too often the case in England, are bought by the weight; when cheaply paid labour is employed in their management; when inspection of the progress of the wear and tear necessarily happening even with good boilers and good attendance, is procrastinated for the sake of gain, there is then a suit of expense versus risk, in which parsimony too often gains the day. At any rate, a number of painful accidents in all parts of the world have, at different times, pointed to the fact, that every man picked at hap-hazard cannot be safely trusted with steam-power. In fact, there is probably no civilized country in which the legislature has not more or less interfered in the management of steam boilers. In the states of America, the frequency of boiler explosions has in some localities produced a more despotic interference than perhaps anywhere else. In the city of New York, boilers are under the supervision of the municipal police; they are tested *periodically*; and, as a result, many are condemned every year. By an enactment of Congress, applicable to all the states, steam passenger vessels are subjected to Government inspection. The 13th section of this Act shows a very acute perception of the real cause of a boiler explosion, 'which,' it states, 'shall be taken as full *primâ facie* evidence' of negligence on the part of the owner, upon whom is thus put the onus of disproof. The law of Louisiana is particularly severe, requiring the application of a hydraulic test threefold that of the working pressure. Of course, there is a great distinction between enacting a law and putting it into practical execution, and it is probable that laws like these could only be carried out by organised bodies of police, like those on the continent. In France, in 1810, 1825, 1828, 1829, 1830, 1843, and lastly on the 25th of January, 1865, as many different regulations have been issued with respect to steam boilers of all kinds. Beginning by requiring that every boiler, even of wrought iron, should be submitted to a hydraulic test of five times the working pressure, this has been successively lowered down to a threefold pressure in 1843, and lastly to a twofold pressure, by the Imperial decree of this year. The previous law fixed the minimum thickness of the plates—a regulation which undoubtedly did much injury to boiler making in France. The old Prussian regulation of the 6th of May, 1838, also fixed the thicknesses of the plates, but did not require any hydraulic test. By the *Regulativ* of the 31st of August, 1861, this was completely altered. The construction of the boiler was left entirely in the hands of the maker; but stationary boilers had to withstand a threefold, and locomotive boilers a twofold, hydraulic pressure. In the same way as with the present French law, the test had to be repeated after any considerable repairs. On the 5th of March, 1863, a ministerial decree reduced the testing pressure for old locomotive boilers down to 1½ of the working pressure; and another *Circular Erlass*, published on the 1st of December, 1864, reduced the test for all kinds of boilers down to twice the working load. There is now no material difference between the French and the Prussian regulations respecting boilers; and it may be expected that those continental states, such as Russia, Switzerland, and Spain, which have more or less copied the old French law of *1843, will* also adopt the present alterations. There is also some talk about altering the present Austrian law, which determines the thickness of the plates, but only demands a double pressure test. The Belgian *réglement* also requires double the working pressure for common boilers, but only 1½ for tubular boilers. According to Article 31, the test must be annually applied to locomotive, portable, and marine boilers, as also after all considerable repairs. There does not seem to be any general law in Italy, but in the special acts authorizing railway companies, similar requirements to the French regulations are laid down, and government commissioners see that they are carried out. Each of the smaller German states also has its law, more or less like that of France and Prussia. Mecklenburg-Strelitz requires that common boilers be proved to three, and tubular boilers to twice the working pressure; to be renewed every fourth year, and every time that the boiler is repaired or altered; Saxony, that cylindrical boilers be tried to twice the working pressure, and tubular boilers to a pressure three atmospheres above it. Bavaria now requires double the working power pressure for new, and one and a half for old boilers; while both Hanover and Brunswick each have a somewhat similar regulation. The French law, and indeed most of the others, require two safety valves; and many are extremely minute in their directions with respect to glass gauges, steam gauges and other fittings. In Great Britain there are no express legislative enactments with respect to boilers beyond those stated in two clauses of the Merchant Shipping Act, according to which (1) one safety-valve in every boiler of a vessel carrying passengers shall be placed beyond the control of the engine-driver; and (2) any overloading of this valve is made punishable by a fine of not more than £100, 'in addition to any other liabilities' which may be incurred by such an act. The boilers of all vessels carrying passengers, before clearing out of port, are subjected to a careful inspection by an engineer-surveyor of the Board of Trade, who can require the boiler to be tested in the usual way to twice the working pressure; and, if he think fit, he can, as the result of such an examination, place the option beore the shipowner of either lowering the working pressure or enewing the boiler. Armed with such powers, the government urveyor is also responsible for any explosion which may directly ccur through wear and tear. *When* an explosion takes place on a passenger railway, one of the Board of Trade inspectors of railways examines the fragments and reports upon the accident to the government board, who communicate it to the railway board. The reports are then printed, in order to be presented to Parliament, and this is the extent to which the British government can interfere in these cases. As with other railway accidents, however, the Board of Trade inspector is examined as a witness in any action for damages against the railway company. All other boilers in the United Kingdom are worked without any government or municipal interference whatsoever. Within late years, however, private companies (the first of which was organized by Mr. Fairbairn of Manchester) have been formed for the prevention of boiler explosions. In return for a small annual fee, or for a small annual insurance premium, the boilers of any subscriber or insurer are periodically inspected, and, if required, tested by skilled engineers. There can be no doubt that these companies have already prevented a great amount of loss and disaster.

"It may thus be said that there are three distinct plans for the general management of steam boilers :—1. There is the continental plan ; 2. the free English and American mode ; 3. what may be termed the Manchester system. The continental mode consists in a strict supervision, sometimes ruled by formulæ, of the original construction, and there its action may be said, for the most part, to end. It does not, and cannot, without periodical inspections, take into account the effects of wear and tear. It may even be doubted whether the old French law, for instance, did not do more harm than good as regards construction. The official formula, according to which were calculated the thicknesses of the plates, founded as it was upon the assumptions that a cylindrical boiler formed an exact circle, and that a plate, however thick, conducted the same amount of heat to the water, was obviously incorrect. What may be termed the ordinary English and American plan throws the onus of proof of the negligence of the owner on those damaged by an explosion. This system is subject, besides other difficulties, to all the objections that exist against the trial of scientific questions by a jury, not composed of experts, and unaided by scientific witnesses. The continual occurrence of explosions in those cities and States in America in

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"It is clear that, subjected as a steam boiler is to so many destructive influences, the precise effects of which can scarcely be yet very accurately known, the working tension should be only one-eighth of the ultimate bursting strength. But when boilers, as is too often the case in England, are bought by the weight; when cheaply paid labour is employed in their management; when inspection of the progress of the wear and tear necessarily happening even with good boilers and good attendance, is procrastinated for the sake of gain, there is then a suit of expense versus risk, in which parsimony too often gains the day. At any rate, a number of painful accidents in all parts of the world have, at different times, pointed to the fact, that every man picked at hap-hazard cannot be safely trusted with steam-power. In fact, there is probably no civilized country in which the legislature has not more or less interfered in the management of steam boilers. In the states of America, the frequency of boiler explosions has in some localities produced a more despotic interference than perhaps anywhere else. In the city of New York, boilers are under the supervision of the municipal police; they are tested periodically; and, as a result, many are

strength each year. To ascertain what the strength is, we must test it, and this can be done in a simple, cheap, and expeditious manner by water and heat. If a boiler be filled *full* of water up to the very safety valves and all apertures closed, when a fire is built in the furnace the water will be expanded and raise the valve, if the boiler is strong enough to withstand the strain, but if it is not the weakest part will be shown, and sometimes sheets are torn out by this method. Steam is not generated from the water during this test, and if a rupture does take place in the boiler no one will be injured by it. The safety-valve must be loaded to the utmost limit of strain that it is supposed the boiler will bear; and if the test is favourable, only three-fourths of the load on the safety-valve must be employed for the working pressure.

"It has never been proved beyond question that a steam boiler exploded from any of the theories put forth in each disaster. Some persons have a passion for 'explaining' matters that they do not understand by something else they are ignorant of; and we have had hydrogen gas brought forward as an agent in causing explosions; water suddenly flashed into steam as another; electricity for another; and so on, through the category. These are simply excuses on the part of some one at fault for the disaster. *After* a boiler has exploded, it seems almost supererogatory to go and look at it, and say what caused the disaster. We have heaps of smoking ruins, iron bent and blackened, and in most cases each part is a fac-simile of every other explosion; the torn sheets are gravely examined, and the conclusion arrived at is that 'somebody was to blame.'

"We have no desire to treat the matter with levity, but is it not time that we had more careful superintendence of steam boilers and fewer inquests? In some cases the cause of accident may be pointed out after the explosion, but in such it might have been done equally well before. As we have before remarked, it is to be expected that some boilers will explode in spite of all inspection, just as cannon do with the most careful gunners, but it is a part, and a most important part, of an engineer's duty to be thoroughly convinced of the soundness and strength of his boiler. When we see how seldom accidents of this kind occur to marine boilers, we have positive proof of the value of thorough over- and watchfulness; and we feel that we cannot speak to

strongly or too often in the SCIENTIFIC AMERICAN, upon the necessity which exists for prompt, thorough, and frequent inspection of steam boilers.

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"Other examples, where, from the defective condition of the safety-valves, boilers were found in equal danger, might be given, but the above may suffice.

"The accidents resulting from deficiency of water have been numerous, not fewer than 71 having occurred in the course of the year to boilers insured, and although happily none of these have been attended with loss of life, the results might have been otherwise; since, in case of collapse, where fractures take place, the escaping water and steam frequently prove fatal to those who happen to be near.

"In illustration of the danger which is frequently incurred through the negligence of those to whose care boilers are intrusted, the circumstances connected with one of these accidents will be related. Several of the operatives having got wet in going to their work, had congregated before one of the boilers to dry their clothes. The fireman having neglected to try the water-gauge for some time, and presuming, from the presence of water in the glass, that there was a sufficient supply in the boiler, gave it no further attention, so long as the workpeople stood before it; but on their returning to work he observed leakage from the furnace crowns, and, on trying the gauges, found the water to be low. He immediately drew the fires, and thus, in all probability, prevented a serious accident. As it was, both flues were injured from overheating, and required repairs. Had the flues collapsed, as might have been the case if the workpeople had remained a short time longer, it is scarcely possible that one of them would have escaped without fatal injuries. Many have been the instances, where explosion or collapse of flues has occurred during meal hours, when the workmen were collected about the boiler and the loss of life has been most serious. It would be, therefore, well, if, as is the rule in some mills, all millowners strictly prohibited any one but those in charge of the boilers, entering the boiler-house or stoke-hole.

"The majority of accidents of this kind are solely attributable to the inattention of the fireman, and show that, however well a boiler may be provided with gauges or feed apparatus, something more is required to insure safety.

"A combination of float and safety valve, which is recommended by some engineers, is so far useful, that in case of deficiency of water the valve allows the escape of steam, and thus gives warning of danger; but many instances have come under notice where, under such circumstances, the flues of boilers, provided with mountings of this kind, have been seriously damaged, although no actual explosion took place. Others advocate the use of alarm whistles, but most of these are very liable to derangement, and I can say little in their favour. Others, again, advocate fusible plugs fixed on the furnace crowns, but with the exception of the fusible caps recommended by this Company, none have been found worthy of confidence. In confirmation of the favourable opinion I have so often expressed in regard to the latter, I may state that during the last twelve months 42 cases of deficiency of water have occurred to boilers provided with these mountings, where no damage was sustained, the steam escaping on the melting of the plugs, and extinguishing the fires. The only objection to their use, and one that has frequently been raised, viz., that if not kept clean these caps are of no service, is equally applicable to glass tube water gauges, safety-valves, and, in short, all boiler mountings.

"Before leaving this part of the subject, reference must be made to a somewhat remarkable accident which occurred to a boiler in Glasgow, but happily without serious results.

"This was a plain cylindrical boiler, 5 feet diameter, with hemispherical ends, used for supplying steam for the manufacture of starch, and usually worked at a pressure of 25 lbs. per square inch. One Saturday afternoon, in the absence of the regular attendant, the boiler had become short of water owing to derangement of the float-gauge, unknown to the man in charge, who, previous to leaving the premises, had thrown on fresh coals, and 'banked' the fires for the night. One of the members of the firm, finding a strong smell of burning, sought for the cause, and at length discovered that it proceeded from the boiler, the bottom of which was then red hot. Having closed the steam and water valves, he proceeded to draw the fire, and observed, while doing so, a bright flame issuing, as it were, from the circular seams of the boiler. This, however, soon disappeared, and, supposing it to have been caused by the combustion of some of the coal dust adhering to the edges of the plates, he took no further notice, and left the boiler to cool, opening the tap of a small pipe, with one end descending about a couple of feet into the interior of the boiler, the other communicating with the atmosphere; by which means the air would have free access to the interior of the boiler, and thus assist, as he thought, in cooling it. On the following morning, another member of the firm, being anxious to ascertain the extent of damage, took off the man-hole cover, and was on the point of introducing a lighted lamp, when a large volume of gas, issuing from the interior, ignited, and, extending to the roof above, set it on fire. This was, however, speedily extinguished, and the owner escaped uninjured. Having investigated the matter carefully, this conclusion was arrived at:—After the evaporation of the whole of the water—the steam having a free communication—by means of a small pipe, with an open vessel containing water for the manufacture of starch, had gradually condensed. This vessel was situated in another building, and at a lower level, the steam-pipe crossing an open yard, exposed to the atmosphere. As the steam condensed, the pressure within the boiler would, by degrees, become less than that of the atmosphere, and a partial vacuum would be formed unless filled up by air or gas of equal density. The damper being closed, and the seams on the underside sprung from overheating, some of the gas from the fuel, not finding egress by the chimney, appears to have thus entered the boiler. In no other manner can the presence of the gas be satisfactorily accounted for.

"A somewhat similar accident, by which the attendant lost his life, occurred in this district about the year 1837. The boiler, which was of similar construction, had been emptied by a plughole over the fire, and on the following morning the attendant was on the point of entering the boiler with a lighted lamp, for the purpose of cleaning it, when a violent explosion took place.

"A great diversity of opinion existed at the time as to the nature and origin of the gas; according to the most trustworthy evidence, it was proved that in consequence of the fire not having been entirely extinguished at the time of letting off the water, the gas generated from the fuel had entered at the plug-hole as the water escaped.

"The last of the defects to which reference will be made is the injury to plates from overheating, notwithstanding a sufficiency of water in the boiler. This is of more frequent occurrence than is generally supposed, though many deny its possibility altogether. Seventeen cases of this kind occurred during the year, one or two of which may be mentioned.

"At one mill, where six boilers are employed, five of these suffered successively from this cause at intervals of a few weeks. Four of these were of the ordinary construction, with two internal furnace flues; the fifth had also two internal furnaces, but these were connected with a combustion chamber, from which smaller flues or tubes conveyed the products of combustion to the end of the boiler, whence they took their course to the chimney in the usual manner. There was nothing peculiar in the construction or dimensions of these boilers, or in the mode of firing. Each was provided with a glass tube water-gauge, Hopkinson's patent safety-valve, and other mountings usually considered necessary. More than ordinary attention was paid to their condition, and none of them were ever known to have been deficient of water. Nevertheless, at short intervals, and without any apparent cause, the flues of these five boilers partially collapsed, where exposed to the direct action of the fire, causing considerable alarm, and necessitating the replacement of several of the plates. A careful examination showed that this, as in many similar cases which have come under notice, was solely attributable to the peculiar nature of the deposit and the imperfect circulation of the water. This deposit, after floating on the surface of the water, is ultimately precipitated in the form of a fine powder upon the plates, which, owing to the non-conducting property of the deposit, gradually become overheated, and then yield to the ordinary working pressure.

"Similar results were observed in two plain cylindrical boilers, which had only been at work a few months; and in another instance, where the same kind of deposit was present, one of the plates over the fire bulged outwards, forming a circular hole about 4 inches diameter, through which all the water and steam made their escape.

"The best remedy against these evils, if water cannot be obtained from another source, is the daily introduction of soda in the manner already described, together with frequent blowing off from the surface. This has been found effectual when all other means have failed. An analysis of some of these deposits showed them to be composed chiefly of carbonate of magnesia and carbonate of lime.

"Such deposit is chiefly to be met with in the limestone districts, or where water is drawn from wells in the red sandstone formation.

"In another instance, similar results were observed where this deposit was not present. It was quite evident, however, that the latter was solely attributable to excessive firing—the best Low Moor plates over the fires bulging outwards within a few days of being put in. The heat beneath these boilers was more like that of a mill furnace than that of a steam boiler, and no iron could be long subjected to it without serious deterioration. Some of these plates at the part bulged were reduced in thickness from $\frac{3}{8}$ths to little more than $\frac{1}{16}$th of an inch.

"The loss of life resulting from boiler explosions has been rather less than in the previous year."

DIVISION SECOND.

STEAM ENGINES, AND PRACTICAL POINTS CONNECTED WITH THEIR WORKING AND CONSTRUCTION.

25. If the reader will turn to the introductory part of the Second Division of *last* year's volume, he will find a brief classification of the varieties of steam engines in use, with some remarks on the peculiar features of each. This classification and those remarks it is unnecessary here to repeat, although necessary to be alluded to, and we proceed, therefore, to place before our readers such papers or abstracts of them as have been published during the year, bearing upon one or other of the various classes of steam engines.

26. Of stationary engines the *Cornish Pumping Engine* for a long period held the highest place as the most economical producer *of power*—through the agency of steam. At one period in the

history of steam engineering it was indeed held to be universally conceded that by it alone was the attainment of that great practical aim secured—the maximum of power with the minimum expenditure of fuel. So completely, indeed, had this opinion gained ground and taken hold of men's minds, that, in the words of an article from the Mechanics' Magazine, which we hereafter give *in extenso*, it was a "machine *per se*, to which none but itself could be its parallel." Of course it was as a pumping engine that the Cornish engine laid claim to such a high standard of perfection; but yet to it, even as such, were men directed as to a model combining in itself all that might be suggestive of a fine balance of mechanical arrangement and construction, applicable to any other of the many purposes for which steam power is used in our industrial and manufacturing economy. Men's minds are apt, so to speak, to run in certain grooves, careless to know whether others exist or may be brought into existence, which will lead to as good if not to better results in practice; until, by the introduction of some disturbing element, they are forced out of the old into and along the new. In this, as in other departments of practical science, this disturbing element has been at work, and now it has become a question amongst engineers as to whether the Cornish pumping engine deserves longer to maintain the long supremacy which it claimed and almost without question received. Before entering into the points in dispute involved in its consideration, it will be useful, as it assuredly will be interesting, to glance at the leading features in the history, as well as the mechanism of the Cornish engine. This will best be done by giving here a paper entitled "*On the use of the Cornish Pumping Engine*," read before the "Society of Engineers" by Mr. A. Fraser. "From the earliest period," says Mr. Fraser, "of the world's history the raising of water from a low to a higher level, by some mechanical contrivance for the saving of labour, has exercised the ingenuity of mankind; and the works of irrigation carried out from time immemorial in China and other parts of the East have brought into use many very ingenious machines. But the application of steam for this purpose, it need hardly be said, has thrown their performance into the shade, and they are now considered little better than toys. It is a remarkable fact that the men who were the first to perceive the *wonderful advantages* that would accrue from the use of steam appear to have first turned their attention to the raising of water by its means, and the earliest forms of steam engines were pumping engines, as early as the year 1663. The Marquis of Worcester, in his 'Century of Inventions,' describes what he calls a 'Fire Water Work,' which is evidently the most simple form of single-acting engine, in which the pressure of the steam was applied directly to the water, without the intervention of piston, cylinder, or pumpwork. The Marquis appears to have obtained an Act of Parliament, or patent, for the protection of his invention, under the name of a Water Commanding Engine; but as the duty performed by it was only the 200th part of that of a steam engine of the present day, it probably did not come into very general use. But to the Marquis of Worcester must be ascribed the first invention and trial of a practical mode of applying steam as a prime mover, and of applying it to one of those great purposes for which it has been so useful to society.

"Several other early inventors and improvers of the steam engine appear to have considered it exclusively as a means of raising water, as Sir Samuel Morland, in 1683, Dr. Papin, in 1695, Thomas Savery, in 1698—who published a description of his invention in a pamphlet called the 'Miners' Friend,' and exhibited a model of it before the Royal Society in 1699. Several engines for raising water appear to have been erected on Savery's plan, and to have succeeded tolerably well where the lift was not more than 40 ft., but as the principle consisted of a vessel alternately filled with steam and cooled by a jet of cold water, the effect produced was very small, compared with the fuel consumed.

"But the immense expense incurred in raising water from mines so embarrassed their proprietors, that most powerful incentives existed at that period to engage further researches on the subject, and to this stimulus we are indebted for another construction of the steam engine by Thomas Newcomen, a smith of Dartmouth, who took out a patent in 1705 for a form of engine, which was, in fact, the rudiment and first conception of the present single-acting engine. It consisted of a piston in a cylinder, the top of which was open to the atmosphere, steam being admitted under the piston to force it to the top of the cylinder. *Cold water* was next introduced, which cooled the cylinder and condensed the steam, causing a vacuum, the pressure of the atmosphere bringing the piston to the bottom of the cylinder.

"It was while attending one of Newcomen's engines, that the boy, Humphrey Potter, who preferred playing with his companions to the monotonous labour of opening and shutting the various cocks, contrived, by attaching strings and catches to the working beam, to make the engine self-acting, after which more permanent arrangements were made for this purpose.

"In 1775 John Smeaton designed a pumping engine, the cylinder of which was 72 in. in diameter, and the stroke 9 ft., and introduced several improvements, but so imperfect was the state of mechanical science in his day, that he actually designed an engine to be erected at Long Benton to raise water for turning a water-wheel to draw coals from a pit.

"Hitherto the only form in which the pumping engine had been employed was the atmospheric, with an open-topped cylinder, and it was not till 1780 that James Watt, by his striking improvements, brought the machine to something like perfection, and caused its introduction to any extent. He provided the cylinder with a cover, contrived the separate condenser and air-pump, and worked the steam expansively to a certain extent. This principle was adopted in an engine erected by Watt at the Shadwell Waterworks. In 1781 Jonathan Hornblower patented a double cylinder engine, in which the steam was used in a small cylinder at a high pressure, and expanded in a large cylinder. This is a form of engine in very extensive use at the present day; but the greater amount of surface, causing friction and condensation, diminished to a great extent the apparent advantages of this mode of working, and induced a preference for the single cylinder engine, with its greater simplicity and freedom from complication. It may be observed that the first form of double-beat valve was introduced by Hornblower.

"In 1802 Messrs. Trevithick and Vivian began to make use of steam at a high pressure; and in 1804, on the expiration of Hornblower's patent, Arthur Woolf improved upon his ideas, and produced the well-known Woolf's engine, with two cylinders for using high-pressure steam expansively. With these engines a duty of fifty million pounds raised 1 ft. high by the consumption of 1 cwt. of fuel was obtained. After this Samuel Grose, a pupil of Mr. Woolf, turned his attention to the improvement of the steam valves, and by a proper arrangement of their areas obtained a duty of eighty-four millions, with an engine erected at Wheal Towan mine, in Cornwall, as reported by Messrs. Lean. In this engine only one cylinder was employed.

"After this time Woolf's engines appear to have gone out of use; and the next alteration in the form of the engine was made by Mr. Sims, of Redruth, who patented a combined engine with the small cylinder placed over the large one; the steam being introduced over the small piston and expanded under the large one; but as the space between the two pistons was always exposed to the temperature of the condenser great loss of heat was the result, and, at the present time, most of these engines that were made have been abandoned.

"The constantly increasing demand for engine power for raising water renders the question of the description of engine to be employed, one of the greatest importance; and there are many circumstances to be taken into consideration in determining whether to make use of a rotary or reciprocating engine.

"In some cases it may be desirable to economise the first outlay rather than the future working expenses, and in others there may be sufficient capital available to warrant the employment of machinery which, though costly in the first instance, may enable the owners to carry out their operations at the lowest possible expense for years to come, without any material repairs or alterations.

"Double-acting rotating engines may be classed under the first head, and single-acting Cornish engines under the second. The advocates for double-acting engines, working a fly-wheel, are in the habit of ascribing to them, in addition to their original low cost in comparison with Cornish engines, several advantages—as economy in fuel, safety in working, and a freedom from breakage in the mains and pipes, in consequence of the flow of water being maintained in a constant stream, instead of being propelled by strokes or jerks; and asserting that the single-acting engine labours under the disadvantages of a fixed load to lift at all times, although the height to which the water is to be raised constantly varies; a propensity to burst the pipes connected with it from *the intermittent* nature of its action; a danger of breakage to its own parts, from the use of high-pressure steam on the one hand, and the heavy weight to be lifted on the other; and increased cost of attendance, from the extreme care and vigilance required for the avoidance of accidents. It remains to be seen how these assertions are borne out by facts.

"The introduction of the single-acting Cornish engine in its present form, for pumping purposes, to London, dates from the year 1837, when Mr. Wickstead purchased an 80-inch cylinder engine in Cornwall, made by Harvey & Co., and re-erected it at the East London Waterworks, where it is working at the present time; but it is well known to have been used for many years in the county of Cornwall for pumping water out of mines, the arrangement being as follows:—The engine was fixed so that the outer end of the beam hangs over the shaft of the mine, and is attached to the pump-rods. These pump-rods, being of enormous weight, are lifted by the engine, and the pumps being at various distances down the shaft, the weight of the rods descending forces the water up a rising pipe to the surface. The duty performed by these engines has been stated at from one hundred to one hundred and ten millions of pounds weight lifted 1 foot high with 1 cwt. of coal; but from the pump work being, in most cases, so far underground, there is no doubt that facilities were given in many instances for letting in air into the pumps, and so arriving at a fallacious result. This large duty has, however, of late years been much reduced, and various causes have been assigned for this apparent falling off—such as the greater depth now attained in mining operations, the modern practice of sinking shafts at an angle instead of perpendicular, so causing increased friction, the diminishing interest felt in the subject by the owners of mines, &c.; but the most probable cause for the seeming reduction in the rate of duty is the use of inferior coal, which is found to be more economical in proportion than fuel of the best quality, of course, where the boilers and grate surface are adapted for the purpose of slow combustion. This fact has been proved by experiment at the waterworks at Kew Bridge, where a 90-inch cylinder Cornish engine was lately worked for several days from five boilers, burning the best coal that could be procured, costing about 25s. per ton, when the duty performed was ascertained to be one hundred and *five millions, the* average duty with small coal, costing 10s. 9d. per ton (which is the fuel in ordinary use), being sixty-two to sixty-five millions.

"Setting aside the Cornish engine as employed in mining operations, and confining our remarks to the engine as used for the purpose of supplying water to towns and cities, it may be as well to limit our attention to the Cornish engine as we find it employed in the various establishments of the London water companies, where operations are conducted on the most extensive scale, and everything has been done to bring the pumping engine to perfection.

"The London water companies have a very large capital embarked, and having a constantly increasing quantity of water to raise, in some cases three or four times over, it has become with them a very serious consideration to secure a description of engine that will lift the greatest quantity of water with the smallest consumption of fuel and the smallest number of attendants, and, in addition to this, will meet the increasing demand for water without alterations or additions, or much increased working expenses. All these conditions are fulfilled in the Cornish engine to a greater extent than in the rotary engine.

"The thorough-bred Cornish engine comprises a cylinder very strongly bolted down to a massive stone or granite loading, the piston-rod being attached by the usual paneled motion to the inner end of the beam, to the outer end of which the pump-work is fixed in a similar manner. The cylinder is invariably surrounded by a cast-iron jacket, into which steam is introduced from the boilers at the top, a drain-pipe being provided at the bottom to take the condensed water into the boilers again. By this arrangement the temperature of the steam is kept up at the moment of its introduction into the cylinder to the same point as in the boilers, and this is so important as far to exceed the small loss of heat occasioned by the condensation of the steam in the jacket, which becomes, in fact, a superheater. The stuffing-box of the piston-rod contains a lantern-brass, a contrivance by which steam is introduced from the boilers by a pipe into the middle of the packing, so that it is impossible for air to be drawn into the cylinder in the event of the packing of the piston-rod leakin There are four valves in connection with the cylinder, all of whic are on the double-beat principle, and are made of gun meta

The first valve is on the steam-pipe, and is worked by hand. This is called the governor, and regulates the quantity of steam to be admitted to the cylinder. The second is the top steam-valve. This is worked by the engine, and is opened by the operation of a cataract, the adjustment of which is under the control of the engineer, and is shut by a slide fixed to the plug-rod, the slide, being movable, regulating the point of the stroke at which the steam is cut off. The third is the exhaust-valve, also worked by the engine, and also under the control of a cataract. The fourth is the equilibrium-valve, which is kept closed during the working stroke, and is opened by the engine during the up stroke. The air-pump, condensers, &c., are of the same description as those in use in ordinary engines, but care is taken to have all the pipes and valves in connection with them as large as practicable. The beam, which is generally of cast-iron, and of great strength and weight, is supported by a massive wall, and a great improvement has been lately introduced by forming the beam of wrought-iron plates; but a very strong beam is frequently made by trussing the cast-iron beams with strong iron tie-rods. The pump work usually consists of a plunger, which is loaded to a weight sufficient to counterbalance the height of the column of water to be raised. The pump-valves are usually on the double-beat principle, and as the plunger is raised very quickly, and the water should follow through the bottom valve with great speed, the bottom or suction valve is usually made of larger area in its apertures than the top or delivery valve, through which the water is propelled more slowly, and a very decided improvement has taken place in the working of several engines by the introduction of a four-beat valve, patented by Mr. Husband.

"But the most important point to be attended to is that the level of the water in the reservoir or pump-well should always be at least as high as the level of the top of the suction-valve, and in arranging the relative levels of the water to be pumped, and the valves of the pump, it will always be found more convenient to force the water from the lowest possible point, and not to have to draw it up to the plunger-case any higher than is positively necessary. It is usual to provide a perpendicular stand pipe, up which the water is forced to fall over into the main pipes at any point that may be determined. The great advantage of the stand pipe is its safety, as, in case of a breakage occurring in the main pipes, the column of water left in the stand pipe prevents the loaded plunger from falling with any very great force; but to provide against any such contingency, as well as to limit the length of the strokes, wrought-iron spring beams and catch pins on the engine beam are usually provided.

"Between the pump work and the stand-pipe a cast-iron air vessel is attached, placed in a vertical position on the outlet pipe; the air which collects in the upper part of the vessel, forming an elastic cushion, takes off a considerable portion of the shock at the commencement of the descent of the plunger. There is a small air-pump worked by the engine, which keeps up a supply of air to the air-vessel, as it is found that under great pressure the air becomes mixed with the water and carried away into the stand pipe. Some of the London pumping-engines have double-acting pipes, in which the outer stroke is performed by a loaded plunger, and the indoor stroke by a piston; the different areas being arranged to suit the height of the lift. With these pumps it is usual to work with an air-vessel of considerable size, and to dispense with the stand pipe altogether, substituting for it a balance safety-plunger, the invention of Mr. Husband of Hayle. The economy in working is less than the single-acting pump, in consequence of the steam being kept on the piston a longer time, and the difficulty of carrying out the principle of expansion so far as in the former case.

"The whole of the steam-pipes, and the cylinder, jacket, nozzles, &c., are carefully covered up with felt, and cased in wood.

"The boilers are usually on the single tube principle, and should have a capacious steam chest, from which the steam-pipe is taken to the cylinder, and the larger these pipes, and all the passages in connection with them are, the better.

"The boilers are carefully built in with fire-bricks, and covered with dry sand, and so small an amount of heat is allowed to escape, that during the recent frost ice might be seen on the stoke-hole floor of the boiler-house in one of the London establishments. It may be observed that experience in boilers shows that the greater the number of boilers in use, the greater the economy in fuel and in wear and tear; and it is advisable to have as many spare boilers as possible, in order that plenty of time may be allowed for them to cool down before cleansing. Nothing ruins boilers so much as the rapid change of temperature, and consequent contraction, through letting in cold water before they are quite cool.

"As every double stroke of the engine comprises in itself all the operations of the machine in a complete form, and no acquired momentum is carried on to the next stroke, a description of its action during one stroke is sufficient.

"The steam in the boilers being at a pressure of from 35 lbs. to 40 lbs. per square inch above the atmosphere, the stroke commences by the sudden opening of the exhaust-valve, which ensures a thorough clearance of the cylinder under the piston; the steam valve is then thrown open by a heavy weight suddenly disengaged by a catch connected with the cataract; the steam rushes from the boilers with its full pressure into the cylinder and forces down the piston; the steam-valve is then closed by a slide on the plug-rod, which is adjusted so as to close the valve when the piston arrives at one-third to one-fourth of the stroke. The remainder of the stroke is accomplished by the expansion of the steam left in the cylinders, which is reduced to a pressure below that of the atmosphere by the time the piston has reached the bottom of the cylinder; at this point the exhaust-valve is closed and the equilibrium-valve is opened, which establishes a connection between the top and bottom of the cylinder; the weight of the loaded plunger then raises the piston to the top of the cylinder, forcing the steam from the upper to the lower part of it; the equilibrium-valve is closed shortly before the finish of the stroke, so that a portion of steam remains above the piston and becomes compressed, keeping the space over the piston full of steam, and at a high temperature ready for the next admission of steam.

"In a pumping engine constructed on this principle, and of the best materials and workmanship, a greater amount of working effect is obtained from a given quantity of fuel than in any machine known at the present time; and this is, to a great extent, the result of the great attention paid to the prevention of loss of heat from radiation, and the plan of using the steam at a high pressure, and letting it into the cylinder in such exceedingly small paces of time. The steam is maintained at a high pressure without difficulty where a sufficient number of boilers is provided, and the loss of steam at each stroke is hardly perceptible; and in consequence of the slow rate of combustion maintained in the furnaces, an opportunity is afforded of burning the cheapest description of fuel. The coal in use at the pumping stations in London, where Cornish engines are employed, is so small as to be little better than dust, and costs from 10s. to 11s. per ton delivered. The number of boilers, and area of fire-grates, is arranged so that the consumption is at the rate of about 4 lbs. of coal for every square foot of fire-grate per hour; but in the recently-constructed works of the Grand Junction Company at Camden-hill, the rate of consumption is only 1½ lb. per square foot per hour.

"It may be observed that experience in the use of Cornish pumping engines during the last twenty years points to the conclusion that the larger the engine the greater the economy in working, the friction being less in proportion both in the working parts and in the steam passages, and the number of men required to attend to a large engine is no greater than for a smaller one. The engines that do the best duty have cylinders 80 in., 90 in., or 112 in. in diameter. The engine at Great Wheal Vor and that at Lea Bridge are 100 in. in diameter.

"The single-acting Cornish engine is peculiarly adapted for the purpose of a waterworks in which the quantity of water to be raised varies or increases from time to time. From the nature of its action, the piston travels at the same speed, whether working at the rate of one stroke per minute or twelve strokes, and consequently the proportion of steam used to water raised remains the same in both cases; whereas, while a crank engine is working slowly, and raising but a small quantity of water, a large quantity of steam is consumed in bringing the piston to the end of its stroke, and the objection often made to the principle of employing the engine to raise a weight which remains always the same, while the levels to be reached by the water vary from time to time during the day (as must be the case in the districts of all London water companies), does not in reality apply to Cornish engines in particular. It is a disadvantage under which every description of engine must labour, and it does not appear to have been overcome in those works using crank engines, viz., the Chelsea works, the New River, and the Lambeth works, in all o which high-level reservoirs are provided of sufficient altitude t supply the highest tenant in the district, and to this maximum height the whole of the water is raised, whereas the majority of the houses supplied from the same reservoir do not require perhaps half such a pressure.

"It has frequently been mentioned that the single-acting Cornish engine is dangerous, that it is liable to accidents in its own parts, and by the intermittent nature of its action bursts the pipes in connection with it more frequently than crank engines; in fact, that the only safety consists in the fly-wheel. But the fact is that each stroke of the Cornish engine being, as before stated, a perfect and complete operation, the pause which takes place at the end of it brings everything to a state of rest, and should any such accident occur, the engine simply stops; but in the rotary engine the heavy fly-wheel spinning round with an accumulated momentum drives the water with irresistible force along the mains, and should any of them be shut down it must inevitably burst the pipes or break the engine, and in case of accident is by no means easily stopped in its career; and in practice it is found that, if a proper stand pipe is provided, accidents of this nature are very rare with the Cornish engines.

"With respect to the cost of attendance on these engines, or, in other words, the wages of engine drivers, certainly the minimum of expense in this respect has been reached in those establishments where Cornish engines are employed. The machines are so self-acting, and it may almost be said intelligent, that one man only is required to attend to an engine of the largest size; and a Cornish engine, with a cylinder nearly 10 ft. in diameter, may be seen at work in one of the London waterworks under the control of one man, whose wages are probably not more than £2 per week. In another establishment, containing two engines of about 150-horse power each—one of which works night and day, and raises three thousand millions of gallons of water, equal to 1½ mile square, and 9 ft. deep, 60 ft. high in the course of the year—the cost of engine-drivers, stokers, coal wheeler and boiler cleaner, superintending engineman, &c., is only £550 per annum; and these men not only work the engines, but keep them packed and in repair, and clean the boilers and flues, being at the rate of 22,000 gallons for a penny.

"There is no question that the first cost of Cornish engines is considerably in excess of rotary engines, from the expensive description of foundations that is indispensable. Probably the cost of an engine of this description, with pump work, stand pipe, and air vessel, with boilers, houses, &c., would approach £100 per effective horse power; but the expense has been much reduced in some direct-acting engines lately introduced, in which the cylinder is placed vertically over the pump, and the beam is dispensed with. This arrangement reduces the cost of the building by one-half, and this engine is much lighter and more handy than the beam engines; and the absence of beam and parallel motion reduces the chance of accident very materially, and a greater speed in working is attained, consistently with safety, than with the beam engine.

"To show the durability of Cornish engines it may be stated that there are engines now working in London that have been at work for the last thirty years; and many of the engines at the London waterworks have worked night and day for twenty years, without any material repairs, further than the renewal of packing to piston, &c. But at the end of that time a thorough overhaul is required, and it will probably be found that the high-pressure steam has eaten the cylinder cover and nozzles, and other portions of cast-iron not subject to friction but exposed to the first rush of steam, into holes. These being renewed, and fresh brasses put in the bearings, the engine is as good as new.

"At the Ipswich waterworks a trial was recently made to ascertain the comparative duties performed by a Cornish engine and a crank engine, working under precisely similar conditions, and, in fact, from the same boilers. The Cornish engine has a cylinder 33 in. in diameter, and 8 ft. stroke, single-acting. The crank engine has two cylinders, one 17 in. diameter and 3 ft. 6½ in. stroke, and the other 29 in. diameter and 5 ft. stroke, working a double-acting pump.

"The result was a duty in the case of the Cornish engine of seventy-six millions, and the crank engine fifty-four millions; and it is the practice in these works to do all the work with the Cornish engine, and keep the crank engine in reserve.

"There are eight water companies supplying the metropolis with water, pumping daily at least 100 millions of gallons, and a considerable portion of the quantity is pumped two or three times over. This involves the daily labour of lifting the contents of a reservoir, a quarter of a mile square and 10 ft. deep, as high as the London monument; and for this purpose five of the most important companies use exclusively Cornish engines; so that, in round numbers, three-fourths of the water supply of this metropolis is carried out by the adoption of the Cornish principle—a convincing proof that, in the opinion of hydraulic engineers, there are advantages to be derived from its application to this purpose.

"The advocates for the adoption of the Cornish engine for pumping purposes maintain that the unquestionable advantages of high speed of piston, slow combustion of fuel, and great expansion of high-pressure steam, are to be found in this machine to a greater extent than in any other in existence; and they confidently hope, by increasing the size of cylinder and length of stroke, with a higher speed of piston and a greater expansion of steam in working, to obtain a still greater effect from a given quantity of fuel than has ever been arrived at hitherto.

"For drainage purposes engines in the Cornish principle have been extensively introduced in England, Holland, and elsewhere; and it is rather surprising that, in designing the various works for the drainage of London, the economy which experience shows is attendant on the pumping of water by these engines appears to have been overlooked.

"One of the most successful examples of the use of the single-acting Cornish engine for drainage purposes is the drainage of the Lake of Haarlem, in Holland, which covers a space equal to 45,230 acres to an average depth of 14 ft., the cubic contents being 800 millions of tons of water—a quantity sufficient for the supply of London for seven years. This has been pumped out into the sea by three engines, which will hereafter have to be worked occasionally, as the rainfall alone amounts to thirty-six millions of tons monthly, and must all be removed artificially. These engines are all of the largest description, and monstrate the advantage of employing machinery of this sort the largest possible scale. An account of one of them will, haps, be interesting.

"The engine house is circular, and stands in the centre of a ervoir containing eleven *pumps*; the suctions communicating with the lake; and the heads brought up through a flooring forming the bottom of a trough running into the sea, 13 ft. above the bottom of the lake.

"The engine has two cylinders, one within the other, fixed concentrically, united at the bottom, but with a clear space of 1½ in. between them at the top under the cover, which is common to both. The large cylinder is 12 ft., and the small one 7 ft. in diameter. The small cylinder is fitted with a piston, and the space between the cylinders with an annular piston. The pistons are connected, the inner by one piston rod, and the outer by four smaller rods, to a large cap or cross-head, having a circular body 9 ft. 6 in. in diameter, and formed to receive the ends of the balance beams of the pumps.

"The pumps are eleven in number, and each 63 in. diameter, with 10 ft. stroke, with a cast-iron balance beam turning upon a centre in the engine-house wall, and having one end connected with the cap of the engine, and the other with the pump rod. Each pump rod is of wrought iron, 3 in. diameter, and 16 ft. long, with an additional length of 14 ft. of chain attached to the pump piston. Each pump is calculated to lift six tons of water per stroke, and the total quantity actually delivered by the eleven pumps is sixty-three tons. The action of the engine is as follows:—Steam being admitted, the pistons and heavy cap are thereby raised, and the pump pistons make their down stroke; at the top of the steam stroke a slight pause is made to enable all the valves to fall out and be quite ready to take their load on the down stroke without shock. In order to sustain this great weight during the interval, an ingenious hydraulic apparatus is brought into use, in which the weight is supported by two plunger poles.

"The two cylinders were introduced with the idea of bringing the load under better command, and meeting the difficulty of the variation in the height of the lift; but the advantage of this plan is questionable. The duty performed by these engines is ninety millions of pounds, raised 1 foot high with 1 cwt. of coal, and the effective force 350-horse power. The stroke of the pum being 10 feet, and the lift 13 feet, 80 tons of water are lift per stroke, and only 63 tons discharged.

"When working for a trial, with a 10-feet lift, and all *pumps* in full action, 109 tons of water were raised per stroke.

"The consumption of fuel is 2½ lbs. per horse power per hour when working with a net effect of 350 horses.

"The cost of each of these engines was £21,000, and the buildings and machinery £15,000—a total of £36,000—or rather more than £100 per horse-power, with all the disadvantages of bad foundations, distance, &c., &c; and it is calculated that there will be a saving of £100,000 in the cost of the works over the ordinary system of steam engines and hydraulic machinery, and £170,000 over the system of windmills hitherto prevailing in Dutch drainage. The annual cost of the three methods is thus estimated:—By three of these engines, £4,500; by windmills, £6,100; and by ordinary steam engines, £10,000.

"For drainage purposes there is evidently a very large economy in the use of engines of this sort. The low rate of consumption of fuel in their case is certainly not likely to be arrived at with rotary engines employed for the same purpose."

27. The following paper on "*Pumping Engines*," from the "Mechanics' Magazine," takes up the consideration of the question already alluded to, as to whether the Cornish form of engine, or the rotative engine, with crank and fly-wheel, is the best for pumping purposes:—

"Ten or fifteen years—perhaps twenty—have rolled away since the Cornish engine arrived at the zenith of its fame. Then, tables, professedly accurate, were published monthly, giving the duty of nearly, if not quite, every engine used for pumping in Cornwall or South Devon. Then men considered that expansion had been carried to the last practical limit; that it was impossible to get a higher mechanical duty from a pound of coal than that realized by some of the best specimens of steam machinery used to drain the mines, for which the extreme south-western shire of England is so celebrated. Then engineers laid it down as a rule, without an exception, that the only economical pumping machinery which could be employed embodied all that constituted the Cornish engine a machine *per se*, 'to which none but itself could be its parallel.' Even ten or fifteen years, however short e time they mark is, suffice now and then to usher great changes to the world; and thus men first began to doubt, and then to sbelieve, the wondrous tales told of the doings of steam ma-inery in Cornwall. They perceived that nothing in the air of the mining districts could possibly affect the labour involved in the raising of a certain quantity of water from the depths of the earth, or the laws which regulated the expansion of steam, the combustion of fuel, or the friction of surfaces; yet experience proved that the Cornish engine resembled a rare plant, which could only flourish in the soil to which it was indigenous. In other words, engines constructed and worked in all respects as they were constructed and worked in Cornwall, failed to give such excellent results as men expected, in Lancashire or Yorkshire, or in Scotland, or anywhere else, indeed, out of the southern shire. Thus, the duty reports came gradually to be regarded with some doubt, and then, by an easy transition, the reports themselves showed a falling-off in the duty of the engines of whose working they professed to be the exponents. And, as a result, we are told that the Cornish engine does not do as much work per cwt. of fuel consumed now, as it did some years ago. This statement is only partially true, however, for other causes, independent of the influence of those in charge of the engines, have come into operation, and apparently reduce the duty to something much less than it was. For example: the coal now used in Cornwall is very far indeed from being as good as that formerly used. Time was when nothing but the best Welsh was ever employed to raise steam there; but now coal is brought from the midland counties by rail at a very cheap rate, and fuel, if not so good, is at least more plentiful in Cornwall than it was. One or two changes, too, have been made in the methods of draining the mines, which throw heavier work on the engines, which are thus slightly overtasked in not a few cases, with, of course, a corresponding loss of economical effect; and we thus find that there is more than one satisfactory reason for that falling-off of duty so remarkably evident in the more recent reports.

"The application of steam power is not confined to the pumping of mines, and it was soon found that expansion, steam-jacketing, &c., could be used with equal effect, whether the engine to which those expedients were applied, caused the rotation of a fly-wheel shaft or worked the bucket of a pump. These truths are so well known now, that it is not easy to meet with an engineer who will dispute them. Taking the work done in the raising of a given quantity of water through a given number of fee in a stated time at so much, it is easy to see that the mechanical effort required to drive a cotton or an iron mill, or to propel a train, may be just the same; and if the work done in each case is performed with like qualities of fuel, then the duty obtained must be the same in both cases. All the work done in ten hours by a Cornish engine is only equivalent to a certain number of millions of pounds raised a foot high. The work of any other class of engine may be calculated in the same terms, and thus there is no difficulty whatever in reducing the work done by all kinds of steam machinery to a common measure. Arguing thus, it was soon seen that the economy, if economy there were, which the Cornish engine possessed in comparison with the rotative engine, must depend on something with which the raising or using of steam had very little to do; and we find this borne out by modern practice. The best class of marine engine uses only the same quantity of coal, per indicated horse power, as the very best Cornish engines that ever existed. The locomotive, even without the aid of condensation, is very little behind. The fact is that steam does not know whether it is pumping or driving a steamship across the waste of waters, or enabling a locomotive to career across the country with some hundreds of tons behind it; and, therefore, provided it is raised and used under similar conditions of expansion, pressure, and warmth preserved, it will give similar economical results, no matter what the engine does with the power originally impressed on the piston. If that power is wasted subsequently, the steam must not be blamed for a loss altogether independent of its mode of action. The fault must be sought for elsewhere.

"Now, the laws which regulate the flow of water through pipes, or its elevation through pumps, are very few and all-powerful. Water being practically inelastic, must be treated very differently from elastic fluids, such as steam; and any attempt to impress on it a velocity, or a motion, which is contrary to the laws regulating its economical movement, must be attended with loss of useful effect. Unless, in fact, it is permitted to have its own way very much, the engineer must prepare to enter upon a contest, from which he can never escape victorious. 'Water,' the old millwrights used to say, 'will lead, but it won't drive.' And the principal source of the great useful effect developed by the

Cornish engine is to be found in the fact that all the arrangements connected with it are specially intended to humour the whims of the water to be raised. The principles of hydrostatics and hydraulics are carefully studied. The water is as nearly as possible treated according to fixed rules laid down by theories, of which experience has long since demonstrated the accuracy, and with the best results. But how are these results obtained? Strictly speaking, in the old Cornish engine, without suction-lifts for the indoor stroke, the steam never pumps a single drop of water. Such an engine is not a steam-pumping engine. The steam has nothing whatever to say directly to the raising of water; nor is it employed to pump water. We have no doubt that these statements may seem a little startling to the superficial observer, but it scarcely requires a moment's thought to see that the whole useful effect of the *steam* is expended in raising the balance-bob and the pump spears, weighing together many tons, to a certain height, three or four times in a minute. And regarding the matter in this, the correct light, the duty obtained, or the work done by the steam, is much greater really than appears from any calculations, into which the weight of water raised enters as an element. Indeed, the latter ought to be excluded if we want the gross work done by the fuel, and should only be retained when we want to calculate the gross effect produced by the *engine*, because all that the steam does is involved in the elevation of a given weight of timber and iron. Once brought up to the required height, the steam has no more to say to the use made of the descent of this weight afterwards, than the dock labourer who carries a sack of wheat up a flight of stairs, has to say to its subsequent grinding between the mill-stones to which it descends. It is the descent of this weight which really pumps the water; and the action of the whole apparatus, cylinder, piston, spears, and pumps, is, in every respect, analogous to that which it was proposed should take place when Smeaton put up engines to pump water, which fell into the buckets of an over shot wheel, in order that a motion of rotation might be imparted to machinery. It would be just as erroneous to calculate the effect produced by the steam in thi case, as though it were accurately represented by the work do in the mill, as it is to calculate the work done by the stea in the Cornish engine, as being represented by the water raised.

"The true comparison to be drawn between the Cornish and the rotatory engine when employed for pumping; the real questions to be asked are—Which is it better: to apply steam power directly to the raising of a given quantity of water? or, to the elevation of a certain weight, whose fall will raise the water? Now, put in this way, there can be no doubt whatever that steam must be employed most economically when merely raising a weight, whose velocity is trammelled by no considerations of inconvenience, and whose gravity is sufficient to absorb plenty of momentum to complete the work commenced by high-pressure steam subsequently expanded. We do know, however, that some loss of effect, be it ever so small, must take place in the execution of this task; and it is well to bear the fact in mind. When we come to consider the next problem, we find it far more complicated. Which is it better: to raise water by the direct action of steam on a piston? or, by the descent of a weight? The question might probably be answered in favour of the latter expedient, were it not that the loss suffered in raising that weight must be reckoned up in the account; and thus we find that, although steam in the Cornish engine is applied to the production of a certain amount of power, in a way possessing nearly theoretical perfection, the power so obtained is practically useless in itself, in that it is separate and distinct from the real object in view; and that, therefore, the whole train of cause and effect must pass through another stage before the water is raised to the surface, or the mine drained; with a falling-off from theoretical perfection so great that it is highly probable that the rotative engine, working at a moderate speed, and driving pumps of the proper construction, may, in every respect, be made to equal the Cornish engine as far as economy of fuel is concerned, while its first cost should not amount to more than one-half that of its magnificent rival."

28. It is unnecessary to remind our readers of what has been done of late years in the *working of steam expansively.* In addition to a vast deal done through the agency of private enterprise, and, as we may say, urged by professional enthusiasm, the subject has been greatly aided by what has been done by scientific

associations.—Under the head of "*New experiments in working steam expansively*," the "Scientific American" has the following:

"We made a brief announcement, some months since, that our government was about to initiate a series of experiments for the purpose of fully and fairly testing the value of working steam expansively. So much has been said for and against this theory, and the practical adaptation of it, that anything tending to increase the common stock of knowledge in this branch of engineering, will no doubt be gladly welcomed by the intelligent and unprejudiced reader.

"The engine chosen is a simple vertical cylinder working upward with a connecting rod, cross-head and slide valve; and the cylinders (for there are several of various diameters) are, respectively, one of 12 inches by 24 inches stroke, one of 14 inches adapted to the same frame, &c., one of 26 inches, and one of 30 inches. These are capable of being worked at either high or low pressure by a simple arrangement. The duty done by the engine must, in order to measure the relative economy at different grades of expansion, be constant, and therefore the following plan has, after due deliberation, been determined on:—

"This plan depends on the use of fans, having vanes of same area, run at same velocity and under the same circumstances, to furnish the required resistance. A single line of shafting, of adequate length and suitably supported, is to carry all the fans, to be run together, if need be twenty in number. This shaft is to pass through an enclosure twelve by forty-eight, formed by sides and ends fifteen feet high, and this enclosure is divided by partitions fifteen feet high, into compartments three feet wide. In each of these compartments, thus 3 × 12 × 15, open at the top, the shaft is prepared to receive four arms on each of which is a vane, the centres of the vanes being two to three feet from the centre of fan shaft. The structure and dimensions of the arms and vanes of the fans to be in every particular the same in all the fans. The inclosure of the fans (12 × 48) is to be within a building 30 × 90, so that all outside currents of air are shut out. At each end of each compartment a door gives access to the fan in that compartment. The shaft carrying the fans will receive its motion by a pinion on it, from a mortise wheel on engine shaft, of such proportions that 50 revolutions of engine produce two hundred revolutions of fan shaft. For the resistance required for a full stroke cylinder, it is proposed to use ten fans, placed in alternate compartments. The vanes on these ten fans to be, at the commencement of larger area than necessary, and then cut down on trial until that area of vane (all the vanes being reduced to precisely the same area) is obtained, which at two hundred revolutions will furnish the resistance, which will require all the power developed by the full stroke cylinder at fifty revolutions, and full pressure of steam throughout the stroke. As each of these fans will be of precisely same dimensions, will of necessity be run at same velocity, and will in every respect be under the same circumstances, any one of the ten will require one-tenth of the power required to revolve the ten. On removing the full stroke cylinder, and substituting an expansion cylinder, having a capacity of one cubic foot at the point of cut-off, such additional number of fans of exactly the same dimensions and structure will be attached to the shaft, in compartments adjacent to those already occupied by the ten, as the power furnished by the expansion cylinder may prove able to drive. The dimensions, revolutions, and circumstances of the additional fans being the same in every particular with those of the standard ten, the total number driven by the full stroke cylinder will embrace the facts by which to compare the two developments of power. In both cases the power required to drive the shafting, without the fans, will be common to both performances. It will therefore be necessary to determine what that power is. An additional fan driven, with the allowance referred to for friction of apparatus, will show ten per cent. more power developed; two additional fans twenty per cent., and so on.

"For cases where the increase of development of power is more than one more fan will measure and less than two more fans can measure, resort must be had to vanes of less area on one fan, and to deduction, based on the area for the relative power. The use of fans for the source of resistance, presents the advanage of the easy and favourable introduction of some form of dynamometer between the engine shaft and fan or resistance shaft. The Commission are under the belief that they will be able to determine, with sufficient accuracy, the actual power to drive the fan shaft, without any fans on it, and the power to drive one or more fans, up to twenty, and that they will therefore be able, not only to determine the relative economy of using steam with different measures of expansion, but the actual power developed, expressed in pounds, raised at an ascertained velocity, and therefore expressible in horse-power—the conventional unit of power.

"The commissioners are Horatio Allen and B. F. Isherwood. The engine is now well under way at the Novelty Works in this city. The experiments will be conducted in a building on Fourteenth street, New York. When they take place we hope to be present."

The following is also from the same paper, as descriptive of some of the results of experiments made upon the mode just explained.

"In our last number we published an account of four series of experiments of thirty hours each, the steam being cut off at different points in the stroke. In that account we gave the most important elements in the experiments, but as intelligent engineers may like to know some of the other conditions, we complete this week the history of the experiments by a statement of all the observations which were not given in our last issue, together with the calculations of the fuel and water consumed, and work done per hour and per minute.

The mean revolutions of the fan per minute during each thirty hours run, were with—$\frac{7}{8}$ths cut off 68·45, $\frac{2}{3}$rds cut off 68·4, $\frac{1}{2}$ cut off 68·34, $\frac{1}{4}$th cut off 68·41.

The consumption of fuel per square foot of grate surface per hour was with—$\frac{7}{8}$ths cut off 9·000, $\frac{2}{3}$rds cut off 7·780, $\frac{1}{2}$ cut off 7·380, $\frac{1}{4}$th cut off 6·710.

The pressure of steam in cylinder at point of cut off was given last week; the mean pressure in the cylinder at end of stroke was with—$\frac{7}{8}$ths cut off 24·042, $\frac{2}{3}$rds cut off 19·184, $\frac{1}{2}$ cut off, 18·170, $\frac{1}{4}$th cut off 14·846.

The total horse-power developed by the engine per indicator, including overcoming back pressure against piston, was with—$\frac{7}{8}$ths cut off 11·752, $\frac{2}{3}$rds cut off 11·639, $\frac{1}{2}$ cut off 12·121, $\frac{1}{4}$th cut off 11·682.

The mean back pressure against the piston during its stroke in pounds, was with—$\frac{7}{8}$ths cut off 4·05, $\frac{2}{3}$rds cut off 4·87, $\frac{1}{2}$ cut off 3·83, $\frac{1}{4}$th cut off 3·37.

The gross effective horse-power per indicator, was with—$\frac{7}{8}$ths cut off 10·079, $\frac{2}{3}$rds cut off 9·631, $\frac{1}{2}$ cut off 10·509, $\frac{1}{4}$th cut off 10·288.

The net horse-power applied to fan was with—$\frac{7}{8}$ths cut off 8·839, $\frac{2}{3}$rds cut off 8·392, $\frac{1}{2}$ cut off 8·889, $\frac{1}{4}$th cut off 9·049.

The pounds of feed water consumed per hour, per total indicated horse-power, were with—$\frac{7}{8}$ths cut off 47·140, $\frac{2}{3}$rds cut off 42·904, $\frac{1}{2}$ cut off 40·063, $\frac{1}{4}$th cut off 36·691

The pounds of combustible consumed per hour, per total indicated horse-power, were with—$\frac{7}{8}$ths cut off 5·525, $\frac{2}{3}$rds cut off 4·822, $\frac{1}{2}$ cut off 4·309, $\frac{1}{4}$th cut off 4·143.

Temperature of feed water with—$\frac{7}{8}$ths cut off 108·22, $\frac{2}{3}$rds cut off 107·15, $\frac{1}{2}$ cut off 107·15, $\frac{1}{4}$th cut off 104·42.

Temperature of water discharged by the air-pump, with—$\frac{7}{8}$ths cut off 111·26, $\frac{2}{3}$rds cut off 110·03, $\frac{1}{2}$ cut off 110·07, $\frac{1}{4}$th cut off 107·56.

Vacuum in condenser in inches of mercury, per open gauge, with—$\frac{7}{8}$ths cut off 26·25, $\frac{2}{3}$rds cut of 26·27, $\frac{1}{2}$ cut off 26·53, $\frac{1}{4}$th cut off 26·01."

In the *Scientific American* also, for July 30th, are given the following further particulars :—

"We give this week an account of four experiments tried between the 12th of May and the 4th of June, the space around the thin walls of the cylinder being heated with steam from the boiler, the exhaust steam being condensed. The four points of cut off were the same in all the experiments. The following are the figures :—

Total number of revolutions of the engine during each thirty hours run—$\frac{7}{8}$ths cut off 77·726, $\frac{2}{3}$rds cut off 77·762, $\frac{1}{2}$ cut off 77·763, $\frac{1}{4}$th cut off 77·624.

Total number of the revolutions of the fan—$\frac{7}{8}$ths cut off 123·289, $\frac{2}{3}$rds cut off 123·188, $\frac{1}{2}$ cut off 123·348, $\frac{1}{4}$th cut off 123·134.

Total number of pounds of water evaporated—$\frac{7}{8}$ths cut off 12·901, $\frac{2}{3}$rds cut off 11·267, $\frac{1}{2}$ cut off 11·188, $\frac{1}{4}$th cut off 9·632.

Total number of pounds of steam condensed in the steam jacket—$\frac{7}{8}$ths cut off 463, $\frac{2}{3}$rds cut off 450, $\frac{1}{2}$ cut off 498, $\frac{1}{4}$th cut off 532.

Total number of pounds of combustible consumed, adding coal and wood together and deducting the ashes—⅞ths cut off 1·212, ⅔rds cut off 1·069, ½ cut off 1·086, ¼th cut off 959·5.

Number of revolutions of engine per minute—⅞ths cut off 43·181, ⅔rds cut off 43·146, ½ cut off 43·209, ¼th cut off 43·124.

Vacuum in condenser in inches per open gauge—mean—⅞ths cut off 27·29, ⅔rds cut off 27·25, ½ cut off 27·70, ¼th cut off 27·19.

Mean height of barometer during each run—⅞ths cut off 29·80, ⅔rds cut off 29·89, ½ cut off 29·82, ¼th cut off 29·97.

Mean temperature of water discharged by air-pump during each thirty hours run—⅞ths cut off 98·88, ⅔rds cut off 98·32, ½ cut off 93·16, ¼th cut off 104·38.

Mean temperature of feed water—⅞ths cut off 95·92, ⅔rds cut off 95·53, ½ cut off 90·36, ¼th cut off 101·54.

Mean temperature of engine room—⅞ths cut off 72·32, ⅔rds cut off 76·58, ½ cut of 77·09, ¼th cut off 77·12.

Mean steam pressure in boiler per gauge—⅞ths cut off 25·93, ⅔rds cut off 25·41, ½ cut off 34·64, ¼th cut off 47·51.

Mean pressure in cylinder above full vacuum at beginning of stroke—⅞ths cut off 28·714, ⅔rds cut off 30·976, ½ cut off 36·181, ¼th cut off 47·02.

Mean pressure at point of cut off—⅞ths cut off 26·022, ⅔rds cut off 27·015, ½ cut off 31·448, ¼th cut off 41·52.

Mean pressure at end of stroke—⅞ths cut off 23·506, ⅔rds cut off 18·698, ½ cut off 16·772 ¼th, cut off 14·088.

Mean back pressure on piston—⅞ths cut off 3·540, ⅔rds cut off 3·390, ½ cut off 2·500, ¼ cut off 2·45.

Mean gross effective pressure—⅞ths cut off 23·413, ⅔rds cut off 23·761, ½ cut off 25·909, ¼th cut off 24·116.

Gross effective horse-power per indicator—⅞ths cut off 9·813, ⅔rds cut off 9·816, ½ cut off 10·760, ¼th cut off 9·958.

Total horse-power, including overcoming back pressure—⅞ths cut off 11·277, ⅔rds cut off 11·217, ½ cut off 11·754, ¼th cut off 10·970.

Net horse-power applied to fan, deducting back pressure and friction of engine—⅞ths cut off 8·572, ⅔rds cut off 8·577, ½ cut off 9·327, ¼th cut off 8·719.

Pounds of feed water per hour per total horse-power per ind cator—$\frac{7}{8}$ths cut off 38·130, $\frac{2}{3}$rds cut off 33·481, $\frac{1}{2}$ cut off 31·691, $\frac{1}{4}$th cut off 29·261.

Pounds of combustible per total indicated horse-power per hour—$\frac{7}{8}$ths cut off 3·582, $\frac{2}{3}$rds cut off 3·179, $\frac{1}{2}$ cut off 3·164, $\frac{1}{4}$th cut off 2·906.

It will be observed that an economy of nearly 25 per cent. in fuel was effected by cutting off at $\frac{1}{4}$th instead of $\frac{7}{8}$ths, the same work being done in both cases in the same time. But in cutting off at $\frac{2}{3}$rds and at $\frac{1}{2}$ of the stroke there was no material difference in the quantity of fuel."

29. The following paragraph will be useful here. "*An Experiment with a Steam Engine.*—Messrs. Editors.—I was called upon a few days since by Mr. G. B. M'Donald, constructing engineer of the Louisville rolling mill, to witness an experiment on one of its principal engines—an account of which may prove both useful and instructive to many of your readers.

"In this trial the throttle valve alone was used (the governor valve was thrown full open). After setting the throttle so as to give about the ordinary piston travel per minute it so remained through the experiment. The engine when cutting off at half-stroke made 28 revolutions per minute; the change was then made to full stroke by simply changing the cam hooks, when the running speed fell off until only 17 revolutions per minute were obtained in the same time. These tests were repeated three several times during half an hour, with precisely the same results. The boiler pressure by the gauge was 125 lbs. The engine was merely driving the unloaded machinery—shafting, gearing, &c.—which equals about fifty tons.

"Mr. M'Donald stated that the engine in question was in first-rate order, as it had been running but a few days since it was thoroughly overhauled by the maker. It has a 26-inch cylinder by 5$\frac{1}{2}$ feet stroke, with puppet valves, levers and lifters worked by eccentrics. The fly-wheel, 18 feet in diameter, is on the counter-shaft, driven by a 16-feet spur wheel on the engine shaft, and made about 2$\frac{1}{2}$ revolutions to 1 of the engine.

"Does not the above test show the practical difference between wire-drawing, as it is termed, and expanding steam?

"In my practical tests of stationary engines, using slide valves and steam chests, I *long since* discovered there was a proper or proportional size for the capacity of the steam chest relative to the size of the steam cylinder and point of cutting off. My experiments showed that a point could be reached where the supply preserved with the chest would approximate very closely to that of the boiler, while using the common governor and valve. It is easy to perceive, if the chest was too small, that the quantity would fall short; if too large, the amount of pressure would not be reached. Besides, large chests or castings, to fill between the governor valve and piston (when under the control of a governor), cause more fluctuation of speed than small ones, and especially so where the amount of fly-wheel is insufficient, which is too generally the case in the West. "N. Cope.

"Louisville, Ky., April 23, 1864.

"[We should like to see cards from the engine in question—they would tell the whole story. As our correspondent adds—in another portion of his acceptable letter—the principle, or rather the reason, for the defect is not new, and has been suggested many times before. Engines in general—ordinary stationary engines—follow a great deal further than they should; more steam enters the cylinder than is required to do the work, and the result is not only a waste of fuel but a loss of useful effect in the engine itself. Such engines labour heavily and act as if afflicted with the asthma. Five-eighths of the stroke is far enough for any engine to follow. Very many engines whose ports remain open to the end of the stroke, would be greatly benefited by adding lap, if the valve is a slide, and shifting the eccentric to cut off sooner, or altering the toes and eccentric to make the valves drop sooner if they are poppets.]—Eds." of *Scientific American.*

30. "*Valuable Experiments in Working Steam.*—Mr. George Hecker, of this city, has already expended some 6,000 dollars of his private funds in experiments designed to ascertain the practical value of working steam expansively. Those experiments were made about four years ago, and an account of them was published in the *Scientific American* at the time. An engine for the purpose was designed and constructed by Henry Waterman, 239 Cherry Street, and the experiments were made at his pla Though the engine was immersed in steam of the boiler tempe ture only about one-sixth portion of the theoretical value expansion was realized, a result very surprising to the exp

menters, and which led to much reflection in regard to the cause. Mr. Waterman came to the conclusion that if the condensation and re-evaporation of steam within the cylinder could be prevented, a larger portion of the value of expansion would be obtained, and he designed an engine to settle the point. Mr. Hecker, on considering the matter, determined to defray also the expense of this second series of experiments.

"Mr. Waterman's plan was to make the cylinder with very thin walls, so that the heat would be quickly transmitted from the outside to the interior. He accordingly made his cylinder of steel plate, $\frac{1}{10}$th of an inch in thickness, and surrounded this with a similar plate; the space between being $\frac{3}{8}$ths of an inch thick, and the two cylinders being stayed together by numerous screws passing through the walls of both. This double cylinder is then enclosed in an ordinary cast-iron cylinder where it is secured by red-lead cement.

"An experimental engine was constructed on this plan with a cylinder 10 inches in diameter and 2 feet stroke. The resistance is furnished by a large fan with 4 radial arms 6 feet long, each carrying a sail 3 feet $1\frac{1}{2}$ inch by 11 feet $1\frac{5}{8}$ inch; revolving about 68 revolutions per minute.

"The experiments are now being conducted at Mr. Waterman's shop. They are made in series of thirty hours each; competent men being constantly employed to watch the engine, and to make a record each hour of the following facts:—

Whole number of strokes of the engine,
Pressure of steam in boiler,
Temperature in the room,
Temperature in the feed tank,
Temperature in the hot well,
Temperature of injection water,
Vacuum in condenser,
Height of barometer.

"The time required to evaporate each tank-full of water, ghing 450 lbs., the time required to consume 350 lbs. of coal, l all other material facts are also recorded.

'We shall watch these experiments with great interest, and l publish a full account of them with the results."—*Scientific rican.*

31. *Beams of Steam Engines.*—In last volume we described pretty fully the best form and the best materials in which to carry out that form, of the beams of engines, and gave abstracts of an exceedingly valuable character from papers on the subject, called forth by the lamentable accident which happened at the Hartley Colliery, (see last year's volume). On the *construction of beams of wrought-iron* Mr. Fairbairn, in a valuable paper (on 'Iron and its Application to the Manufacture of Steam Engines, Mill-work and Machinery,') read before the members of the Literary and Philosophical Society, Newcastle-on-Tyne, has the following :—

"The lamentable and disastrous occurrence which took place at Hartley Colliery by the breaking of a cast-iron engine beam a few years since, must be fresh in the recollection of the public and those now present. This unfortunate catastrophe, by which upwards of two hundred valuable lives were lost, was chiefly due to the uncertainty of cast-iron when cast in large masses, subject, as is generally the case, to unequal contraction in the process of cooling. Altogether cast-iron is never a perfectly secure material when subjected to severe strains or force of impact ; it is nevertheless of great value in most constructions. On almost every occasion, when the casting is large, there is a degree of uncertainty arising from the want of proportion of the parts, secret flaws, and want of attention to uniformity in the process of cooling, and the danger of having some parts of the casting in a state of unequal tension—technically called hide bound—which ultimately leads to fracture. The greatest possible care is, therefore, necessary in every description of beam or girder to select, in the first instance, the proper mixture of metal ; to study the art of proportion in order to attain perfect uniformity in the cooling, and to relieve the article, whatever it may be, from unequal strain in the contraction of its parts. This is an art surrounded with many difficulties, as every casting calculated to sustain severe strains is subject to unequal contraction unless it is carefully prepared and duly proportioned to admit of uniform tension in th combination of its parts.

"I have been the more particular on these points, as I h witnessed, in my own experience, so many failures from want *knowledge* and neglect of these important considerations, th have ventured to direct your attention to them, and to show how essential it is to security and ultimate success to watch carefully the laws by which we are to arrive at sound castings, and how nature works in the process of passing from the fluid to the solid state, in different materials.

"On the question of engine beams we are, however, relieved from all doubts on the score of security by the employment of wrought instead of cast-iron. It has often occurred to me, in the exercise of my profession, that in engine beams, as in bridges, a judicious combination of that material would relieve us from all anxiety on the score of security; and moreover, it would establish a new and important era in the application of wrought-iron in place of cast-iron for the main beams of engines.

"This idea is not new, as it occurred to Mr. Murray, of Chester-le-street, and Mr. John Taylor, as well as myself, and the firm at Manchester has constructed for these gentlemen three large beams of this class. The first was at work shortly before the Hartley accident, and, having been constructed under my own immediate superintendence, I have considered that a description of its strength and other properties may not be unacceptable to the miners of this and other districts.

"The beam, of which the annexed figure is a drawing, (Fig. 1.) is of the tubular form, composed entirely of plate-iron, with cast-iron centre sockets to receive the axis, and crosshead of the pump rods, and parallel motion.

"The dimensions of the beam are as follow:—Length, 28 ft. 8 in.; depth, 5 ft. 6 in.; and 2 ft. wide. The sides are of $\frac{3}{8}$ in. iron, supported between the flanges with T-iron over the joints, and corresponding strips outside. The upper and lower flanges are composed of the best double-worked plates and covering plates, chain riveted, each 2 ft. wide, and $\frac{3}{4}$ in. thick, and these are rivetted to the sides by double-angle irons, as shown at *a a a a*, &c., in the drawing. For the reception of the main centre at A, are two cast-iron plates firmly riveted to the sides and gle irons of the flanges, as also to two T-iron ribs inside, which ffen the side at B, B. At the extreme ends C and D, are similar tings, to receive the pump rods, parallel motion, air pump ls, &c. These constitute the more important features of the ucture, as may be seen from the drawings.

Fig. 1.

Wrought-Iron Engine Beam.

'The calculation of its strength according to the formula $= \frac{a\,d\,c}{l}$ is as follows:—

Let the length of the beam . . . . = 28 ft. 8 in.
" depth " . . . . $d =$ 5 ft. 6 in.
" area of flange . . . . $a =$ 56 sq. in.
" constant derived from experiment $c =$ 80.

Hence $W = \frac{56 \times 5{\cdot}5 \times 80}{28{\cdot}66} = 870$ tons as the breaking ght of the beam in the middle.

'Now as the beam in its reciprocating action is subjected to rnate strains of tension and compression, and as the load to lifted will never exceed from 85 to 90 tons, we may safely sider the ratio of strength as 870 : 90, or nearly as 10 : 1—a safe margin of strength; and this will amply provide for the force of impact to which every description of engine beam is subjected in case of any accident to the buckets or pump rods in the pit. Besides, there is this additional security, that wrought-iron is three times the tensile strength of cast-iron; and, being a fibrous and ductile material, there is less chance of its snapping asunder without notice, and subjecting the helpless miners, as in the case of the Hartley pit, to an irremedial and lingering death. With these facts before and the means of rendering our engines free from danger, I e to urge upon the coal owners and engineers of this and er districts, and in all cases where there are doubts of security, l in all future engines, that the main beams be made of wrought-n.

Fig. 2.

Section.

"Having thus pointed out what is necessary to be observed in application of iron to the steam engine (I speak of it in its neral sense, without entering into the classification of iron and el to the principal parts of the steam engine), I may, in consion of this division of my subject, notice the cylinder, conting rod and crank, as requiring careful attention on the part the constructor and engineer. The forces applied to the cylin-, which is always made *of sound* cast-iron, are upon its circumference, bottom, and cover—the same as those applied the boiler; and the same formula may be used in the calculat in regard to strength, but with this difference, that seven t per square inch must be taken as the ultimate tensile strength the material. The same may be said of the connecting rod a crank, excepting only the transverse section of the former, wh shall be in the middle (if made in the form of ribs or webs) th times the diameter of the solid part of the rod at the beam a crank.

"As respects the crank, the same formula—

$$W = \frac{a\,d\,c}{l}$$

used for calculating the strength of beams may be applied, w this difference only, that the constant c, for wrought-iron, is while that for cast-iron is only 26. For ordinary purposes th calculations will be found practically safe, but, in all these c structions, I must confess, that much depends upon the exp ence and practical knowledge of the engineer, and that a k eye to proportion, and a sound judgment, is frequently of m greater value than a whole volume of algebraic formulæ.

"I much fear that in these investigations I have enlarged to extent sufficient to try your patience in my examination of important subject; but as steam, the steam engine, and the terial of which the latter is composed, enter largely, in these d of iron, into our daily occupations, I trust I may be excused have been a little prolix, and trenched to some extent upon y valuable time."

32. *The construction of Fly wheels.*—On this very import subject the Mechanics' Magazine has the following paper.

"Now and then, albeit rarely, fearful accidents occur from breakage of fly wheels, and it is worth while to consider fo moment to what proximate or ultimate causes such untow event should properly be attributed. The wheel, revolving speed, flies to pieces, and these pieces, under the influence of c trifugal force, depart from the path of previous rotation at t gents which carry them through roofs, walls, and buildings l cannon shot. A few hundred weights of iron, starting with t initial velocity of the rim of a wheel 20 feet in diameter, maki *100* revolutions per minute—by no means an exceptional sp

—represents a very considerable amount of concentrated power; quite sufficient, indeed, to perform a vast deal of mischief in an incredibly short space of time. Thus we find that an iron works at Deep-fields, near Wolverhampton, was partially destroyed by the breakage of a fly-wheel, in November, 1859. The damage done was estimated at £3,000. Accidents of the kind occur more frequently in rolling mills, perhaps, than anywhere else. The great size and weight of wheel, and the speed of rim necessary to drive a heavy train of rolls, puts a strain on the material of which it is composed—invariably cast-iron and not often of good quality—which must reduce the factor of safety to a very low limit. The sudden shock caused by the passage of a rather cold bar, or a hard bit, such as a morsel of steel, in a pile, through the rolls, may occasion a catastrophe at any moment. Sometimes the coupling boxes give way; sometimes the rolls; more frequently the gearing, and all too often the fly-wheel. But the breakage of fly-wheels is not confined to rolling, or, indeed any mills; every form of machinery using the device is liable to the same accident, and though the consequences are seldom very serious, they are none the less annoying.

"Very commonly it is asserted that centrifugal force is the principal agent of destruction. No statement, as a rule, can be more incorrect. When a wheel is of the proper weight, and of the proper diameter, the rim must, if made of cast-iron of fair quality, possess such a sectional area that the influence of centrifugal force at any ordinary or legitimate speed must be powerless to overcome the tensile strength of the material. Of course, instances may occur where, from the failure of some portion of the machinery in motion, or from some other cause, the load on the engine is so suddenly reduced that it will race before any measures can be taken to check the flow of steam to the cylinder. Under such conditions, a fly-wheel is very likely to give way. Even then, however, it does not follow that centrifugal force is the principal cause of the rupture. We have seen the arms completely broken out of moderately-sized fly-wheel in this way, while the rim remained act. The moment the spur or belt wheel on a crank-shaft— first driver, in fact, in the system—is suddenly relieved of a nsiderable amount of resistance, the tendency of the shaft to re-lve at a higher speed will be communicated to the fly-wheel rim through its centre boss and spokes; the great weight, the *vis inertia*, in fact, of the rim, will prevent it from assuming this increased speed with corresponding promptitude, and the result is, that the spokes or arms are exposed to a transverse strain, very similar to that of beams fixed at one end and loaded at the other; and as bad cast-iron is a very brittle material, and any sort of iron is generally considered good enough for a wheel which "has nothing to do but turn round," it is not wonderful to find a fly-wheel spun clean off its nave now and then, centrifugal force all the time neither aiding nor abetting in the matter.

"The mode in which a fly-wheel is constructed, has, apart from all considerations connected with design or shape, a very material influence on its strength. Invariably made of cast-iron, with the exception of the arms, now and then of wrought iron, or even wood, it is obvious that, without due care, a very serious amount of initial strain may be thrown on the rim or spokes by the act of contraction in cooling. Very large wheels, as a rule, always are cast in segments, subsequently bolted together; even this precaution is not always effective, as two, or even more, spokes, and a section of the boss, in the case of moderately sized wheels especially, are sometimes cast in one with the segment, the contraction of which, by drawing the outer ends of the spokes together, exposes them to an injurious transverse strain near the boss. It is always better to cast the rim wholly distinct from the arms. Whether these are or are not to be one with the boss, is a mere matter of convenience. At the Dowlais Ironworks are two fly-wheels each twenty feet in diameter. The rims of these wheels, 12 inches square in cross section, are cast in one piece attached to the arms by dove-tail jaws and blocking. This mode of construction is very good, and we doubt if it is much more expensive than the method of casting the rim in distinct sections; the cost of the bolts, and a certain amount of indispensable fitting before the wheel is completed, going far to balance the increased trouble and inconvenience of getting a ring of cast-iron 20 feet or so in diameter, into place. It is obviously inapplicable in cases where the wheel has to be transported any considerable distance from the foundry.

"[illegible] a fly-wheel is constructed, very light arms are an ev[illegible]ious design. It is true that a certain

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weight of iron placed in the rim might be more effective in maintaining equality of speed than if placed in a spoke, but transverse strength of arm is a far more important consideration than any little gain in this way can be. In the present day, this principle of construction is much more neglected than it was once. A spider fly-wheel may be very elegant to look at, but it is anything but a safe companion, except with very uniform resistances. It is worth considering, too, whether it would not be good policy to shrink a wrought-iron hoop on to all wheels intended for rolling mills, or situations where they are likely to be exposed to sudden changes of speed. Such an expedient would cost very little money, as the cheaper pig-irons might then be used for casting the rims at least, with perfect safety. The combination of wrought with cast iron in many structures, is worthy of more extended adoption than it has yet received. Had the Hartley engine beam been hooped with wrought-iron, as are the engine beams of American river steamers, we should, in all human probability, have had one mining disaster the less to lament.

"The breakage of small fly-wheels is a matter of every-day occurrence, and as the results, though seldom fatal or destructive, are excessively annoying, it is just as well that builders of portable engines and such machines should take all proper precautions to prevent their recurrence. Wheels of the kind are almost invariably cast entire, and for the most part good iron is relied on to prevent them from going to pieces by contraction. Occasionally they break on the lathe, the first roughing cut being enough to reduce the cross section of the rim so far that the tension of contraction produces fracture. If such a system of construction must be persisted in, then care should be taken at least to cool the heated iron very slowly, and to employ an uneven number of arms, as three, five, or seven, so that direct strain may not be exerted across the wheel. Occasionally curved spokes are used. The theory is that the curve permits a certain amount of flexure. We doubt the efficacy of any expedient of the kind; unless the curvature is considerable, no bending can take place; and if it is considerable, the spoke is submitted to a transverse strain at or about the bend by the contraction of the rim, which cannot fail to operate injuriously. It might be found worth while to cast fly-wheels up to, say, six or eight feet in diameter, thus :—The rims and arms to be cast first, and when these had cooled down fairly, that is to say, in three or four hours, to cast the boss in such a way that the metal of the inner ends of the arms would be re-fused, and become one with the boss. Cast-iron paddle-shafts and the rolls of iron mills, are often mended by an operation similar in character. The roll is set vertically, with its broken end uppermost; a flask containing a sand mould of the part broken off is fixed on this end, and molten metal is poured into this, and allowed to escape at a hole in the bottom until the fractured end begins to show symptoms of fusion. Then the hole is stopped up and the process completed by filling the mould. Fly-wheel bosses could be easily and cheaply cast in the same way without the necessity for any very exceptional arrangements on the founder's part, and it is certain that, with proper care, the finished wheel would be free from initial tension in all its parts."

33. The following paragraphs, (*a*) and (*b*), fittings of various parts of steam engines, will be useful; they are from the "Scientific American."

a. "*Connections of slide-valves.*—The essential virtue in the mechanical adjustment of a slide-valve is that it shall open and close the ports at the proper time, and that it shall be steam tight. Other considerations present themselves, such as the proportions, friction, &c., but we confine our discussion of this topic to the connection between the stem and the valve itself. A slide-valve may be properly fitted to its bearing; but by reason of a badly designed or applied connection with the stem, it may be rendered inefficient. How many of our readers experienced in these matters are there who have not noticed that the slide-valve is (oftener than otherwise) worn winding, or all on one side, when there was no apparent reason for such disaster? The cause can generally be attributed to the stem and its connection. Let us examine the ordinary plans in use for working a valve. If we do so, we shall find that the form generally employed is a simple nut, in which the stem is screwed, fitted into a pocket on the valve. This kind of connection is in use on some very large engines, and it is not at all to be commended. The stem working through the stuffing-box, has a very material vibration, and does not, by any means, work in a straight line. The packing affords no protection whatever against the evil, and the stem may deviate measurably from travel in a true line, to the manifest injury and loss of economy in the engine.

"The supposition is, that the nut being easily fitted, will give a little up and down, and let the valve work fairly on its face. Such is not the case, however; and the stiffer the valve stem is, the greater the evil. It constitutes a lever which works on the stuffing-box as a fulcrum, and prizes the valve up so much that it wears harder in one place than another. The pressure of the steam is not sufficient to overcome the strain exerted on the valve stem by the several connections. Even when guides are provided, the same evil is not wholly obviated: as they are not always set in a direct line with the valve face. Another popular form of connecting a valve to its stem, is found in the square yoke fitting completely about the upper part of the valve, and in some cases provided with a tail which runs through the back end of the chest. The double stuffing-box is a good feature, as it insures a true linear movement of the valve stem; or, at least, one more correct than is ordinarily obtained. But without this provision, the valve is even more liable to tilt than with the single nut; for the reason that the surfaces in contact are greater. Slide-valves are also driven by a nut lying in the centre of the top through which the stem passes. This is perhaps the best form of applying the stem for general use; as it ensures a direct pull from the centre of the object moved, and does not create an undue twisting or straining of the valve itself. Too often the face and seat of a valve seem to indicate a true surface by their polished appearance; but upon examination by proper instruments it will be found that they are not so. The slide-valve, as a means of controlling the energies of the rest of the machinery, should be carefully and frequently examined, to see if it is in perfect order, as much loss results by its imperfect action. A leaky valve destroys not only its own face, but that of the cylinder also; and the latter is renewed only at an expenditure of much time and labour."

33. *b. On Packing Metallic Rods.*—"The rods about steam engines which work through vessels or chambers containing steam or liquids are fitted with glands and stuffing-boxes; in the latter the packing is placed, and the gland compresses it against the

rod, so as to form a perfectly steam-tight and yet an easily-working joint. All this is well known to mechanics and engineers, but so many plans for, and such erroneous ideas prevail respecting the performance of this duty, that we have thought a little discussion on the subject not inappropriate.

"To judge from the number of scored, three-sided, bent, and otherwise damaged piston and valve rods which we have seen at various times about steam engines, there would appear to be a necessity for some radical reform. To insure ease of action and economy of work, an engine should be very carefully packed, for the absorption of power from this source is enormous in a large engine, and would scarcely be believed. We have seen engineers in charge of large low-pressure engines take a wrench 3 feet long in the handle, apparently made especially for the purpose, and heave down the nuts on the standing bolts with main force, merely in order to check the escape of a small jet of steam. Such practices are reprehensible from the fact that the expenditure of force to accomplish the desired end is a proof that something is wrong, either in the design of the engine or the execution of the duty discussed. Faulty design may be briefly alluded to; where piston-rods issue through cylinder heads, the bottom of the stuffing-box, which is bored to admit the rod, is often made too large; there is too much clearance. No rule can be laid down for the size of the hole; engineering common sense must tell when the aperture is too large or too small; but from the first evil—too much clearance—many other evils spring. The packing is exposed to an unnecessary pressure of steam, which requires the enormous tension obtained by a long wrench to prevent leakages; it is sooner destroyed by being burned out; in consequence of the friction it necessitates a great expenditure of oil, absorbs power, and is also liable to be drawn in during the down stroke of the piston, and thus cause *thrums* and ravellings to get under the valves, or make dirt and grit in the cylinders. Unequal compression of the packing gland, caused by reckless screwing down of the same, together with the use of improper substances, such as old tarred rope, rough coir, or jute, also scant clearance in the cylinder head, and the absence of brass bushes in the same, is the cause of the scratched and damaged piston-rods previously spoken of. When a gland is screwed up it should be carefully measured all round so as to insure perfect accuracy. A rule will not do; a pair of inside calipers should be employed, and the engineer should set the gland as accurately as if he were about to re-bore it in the lathe; then it will be certainly right, and the piston-rod will be clean, bright, smooth, and true, as it should be.

"A kind of packing in very general use is jute; this is a very good substance when braided into an eight-strand, square gasket, and well slushed with tallow. Some men use a central core of indiarubber, but this is not necessary, in our opinion; another kind used for packing small rods is a piece of square rubber, well overlaid with cotton lampwick; this kind has gone out of favour lately, probably from the high price of the material. Still another sort is a compound of indiarubber and brass wire gauze, for which a patent has been issued, and which is highly spoken of. Metallic packing has also been used in connection with small rods with some success; indiarubber, in the form of several layers of canvas coated with it, rolled up like a sausage, has also been employed as packing, and is, as we can testify, a most excellent article.

"It matters little what the nature of the material is so that it is soft, close in texture, and uniform in quality, without knots or hard layers. Jute is very often full of grit, and should be washed before it is used; care ought to be taken to keep gaskets off the floor when they are being braided, otherwise the rod will be scratched by the dirt accumulated. If the bottom of the stuffing-box is too large, from wear or design, take two turns of lead pipe, or such a length as will encircle the rod twice, draw a gasket through the bore of it, and drive the pipe down about the rod with a wooden drift; no other material than wood should ever be used in packing an engine, even to the mallet which drives the packing home. The packing should be renewed as soon as it is worn out, which can be told when the amount of pressure required by the nuts to preserve the joint is too great, and by leakage. When an engineer cannot screw down the gland on a 100-inch cylinder with a wrench 20 inches long in the handle, and by the force of one hand, or arm, there is some defect or fault that needs remedy. Of course, far less power is required when the rods are smaller. Smooth and true rods and tight joints are the pride of every good engineer, and no pains should be spared to have every engine in such a condition."

34. In the designing and construction of steam engines unnecessary to say that the closest attention should be paid t points connected with the *valves and valve gearing.* Upor proper setting of the valves, indeed, depends the economical w ing of the engine; not seldom, indeed, is defective valve wor be met with, the result of which is that a large proportion of effective force of the steam is lost, simply being passed thr the cylinders uselessly. A very capital paper, on "The va and valve gearing of steam engines," was read lately before "Institution of Engineers in Scotland" by Mr. W. Inglis, of w the following is an abstract:—"The valves generally used," Mr. Inglis, "for the distribution of steam in the steam engine be divided into two classes,—viz., sliding valves and lifting val To the latter class belong the double-beat balance valves. An the former may be classed all valves which open and close ports by sliding over the valve faces.

"It is essentially necessary in any arrangement of valves they should admit and release the steam to the cylinder at proper times, and that any escape of steam should be preve when the ports are closed. Another point of great importanc that the valves should be capable of being moved easily, and the amount of power required for working them should be as s as possible. In the common arrangement of slide valves, pressure tending to press the valves to the face is always so g that a very considerable power is required to move them; notwithstanding that various means have been designed to rel the valves of this pressure, yet practically the difficulty ca only partially overcome. The friction caused by this pres not only renders the moving of the valves difficult, and ind rapid wear on the valve faces and connections, but, what is haps more important, it limits to a great extent the size of ports in large engines.

"In this paper the writer's principal object is to describe rangements of double-beat valves and American Corliss va which he has designed for several steam engines. Both t systems of valves possess the important peculiarity of requi much less power to work them than ordinary slide valves. Dou beat valves can be so nearly balanced as to permit of their b moved with great ease, and in this respect, perhaps, canno surpassed. One disadvantage, however, which prevents their being adopted for quick-working engines, is that they are not at all suited for high speeds, on account of the noise and concussion caused by the valves falling into their seats when worked quickly. The system of valves known as Corliss valves consists of a series of cylindrical slides, which receive a rocking motion from central valve spindles, the spindles being worked by levers fitted on their ends. The valves are placed near the ends of the cylinder, each cylinder having two induction and two eduction valves.

"As in the arrangement of double-beat valves, the steam and exhaust valves are separate; but in the Corliss system there are also separate ports or passages for the admission and eduction of the steam. Another peculiarity of the Corliss system is the method of giving a very quick motion to the valves when being opened or closed; but when the ports are nearly full open, the valves move very slowly, as they also do when the ports are closed. This is usually accomplished by an arrangement of levers set on a central disc plate, and fitted in such positions that, when one steam valve is receiving its motion, and while the lever working it is at its most effective point for making the valve travel quickly, the lever giving motion to the opposite steam valve will be at or near its dead point.

"The same relative motions are imparted to the exhaust-valves. The steam valves are opened against the resistance of springs. The valves can be made to cut off the steam at any point up to half stroke by being liberated from the valve-rods, when they are instantly closed by the action of the springs. . . . .

"It is necessary, when the valves are of brass, that the connection between the top and bottom discs should be of cast-iron, otherwise, on account of the difference of expansion between brass and iron, the valves would not fit down on their seats when heated by the steam. Double-beat valves, either of iron or brass, are always more or less affected by the difference in the expansion of the valves and casing. The best way to ensure their being tight is to grind them up in their places when the chests are heated by steam. . . . .

"The engine was designed by the writer for driving a paddle steamer having feathering wheels, and was fitted with the arrangement of Corliss valves. Being a beam engine, it was designed somewhat after the usual style of American engines—the frame of wrought-iron plates—and the valves and gearing are the only parts which differ materially from the usual arrangements. The engine was constructed at Montreal, Canada, in 1861. In this engine the valves and passages for admitting steam to the cylinder are separate and distinct from the exhausting valves and passages, the cylinder being provided with two steam valves and two exhaust valves. There is a hand wheel for regulating the point at which the steam valves are liberated from the rods and the steam cut off. The point at which steam will be cut off from the cylinder can be varied in this way from about half-stroke down to a point when no steam is admitted. At whatever point the steam may be cut off, the exhaust valves open to the full extent of the port, their motion not being affected by the closing of the steam valves. The cylinder of this engine is 60 inches diameter × 8 feet stroke. The engine makes about 32 revolutions per minute with 40 lbs. steam, developing over 1,500 indicated horse power. The steam ports are 50 inches × 4 inches, and the exhaust ports 50 inches × 6 inches. The boat being a river steamer requiring to stop frequently, it was necessary that the engineer should be able to move the valves quickly, and have them fully under control for stopping, reversing, &c. No engine of such a large size as this one had previously been fitted with this system of valves; and it was expected that, as the valves were large, a man would be unable to work them with a starting bar. The writer, therefore, designed a small cylinder, to be worked by water from the boilers, for giving motion to the valves when the eccentric-rod was disconnected; but when the engine was completed, it was found that, with a starting bar about 5 feet long inserted in the wrist-plate, one man was quite able to move the valves; and this plan has been adhered to in preference to the small cylinder. The valves are found to wear well, remain tight, and give perfect satisfaction. . . . . .

"In all cases where the power required is variable, and where a governor has to be used, it must be apparent that the method of regulating the speed of the engine, by varying the point of cut-off, is far superior to the method more usually adopted of effecting the regulation by a throttle-valve. By having the point of suppression under the control of the governor, the full benefit of expansion is obtained at all times.

"The Corliss valves are particularly suited for horizontal engines, on account of the facility afforded for the escape of water from the cylinders. The exhaust-valves being situated at the lowest point, the water escapes at once when the ports are opened at each side."

35. In close connection with the subject discussed in last paragraph is the arrangement and construction of "*link motion*," the making of which constitutes one of the finest pieces of mechanical workshop labour. The following article bearing on it is from the "Scientific American;" it is entitled—"*Link Motion; The Relative Proportions of Slides and Steam Ports:*"—Mr. Albert Aston, of the Naval Engineering Corps, in a paper to the *Franklin Institute Journal*, has the following interesting information:—

"The best way of finding the position of the link for intermediate points of cutting off is as follows:—When the engines are set up and the valve-gear adjusted (the valve-chest cover being off if practicable), turn the shaft until the cross-head arrives at the point desired. Then move the link until the steam port is just closed, and mark the position of the catch on the guard, or whatever other device may be adopted. Next, turn the shaft until the cross-head is in a corresponding position on the return stroke; move the link until the port is closed, and mark the position of the catch. Cut the notch midway between the marks on the guard, and proceed in the same manner for the other points of cutting off.

"The only remaining question is that of the exhaust lap. If the exhaust lap was equal to the steam lap, the exhaust port would be closed at the same time as the steam port, which would cause excessive cushioning. If, on the contrary, there was no exhaust lap, the exhaust port would be open long before the steam port, and, consequently, before the piston had arrived at the end of its stroke. The loss due to this too early release of the steam is more serious than that due to cushioning, for it is all a loss of power; whereas the compressed vapour partially or wholly fills the port and clearance, which would otherwise have to be supplied with fresh steam from the boiler. In fact, if the expansion were carried *down* to the back pressure, there would be no loss of economic effect by the cushioning, however excessive. The best relative proportion which these two losses should bear to each other, is evidently that in which the sum of the two would be a minimum. This could be easily determined by means of the differential calculus if the curve traced on the indicator card by the escaping steam, and which is dependent on the proportion between the valve-opening and the cylinder capacity, and the speed of the piston between the point of release and the end of its stroke could be known, and if the compressed vapour followed Mariotte's or any known law; but as the exhausting curve cannot be easily determined, and as the required condition is never fulfilled by the cushioning steam, accurate calculation is out of the question. It should be remembered, however, that the valve should open long enough before the end of the stroke, to allow the piston to commence its return stroke with the maximum vacuum, and that the cushioning is not perceptible on the indicator card until some time after the exhaust port is actually closed, owing to the rapid condensation of the compressed vapour; and were it not for the atmospheric air mixed with the steam in the cylinder, the cushion curve would be much less than it is actually found to be, and a much earlier closing of the exhaust would be practicable. The problem is also affected by the absolute amount of back pressure; but it is found, from the inspection of a large number of indicator cards, that the most satisfactory diagrams are obtained when the exhaust lap is about one-half the steam lap.

"It is practically desirable to keep the stroke of the valve as small as possible, the steam ports should be made as narrow as possible, the requisite area being made up by length. This will cause more resistance to the passage of the steam, but the area can be slightly increased to compensate it.

"As the steam is not required to enter the cylinder as quickly as it should leave it, the steam side of the valve should only uncover about three-fourths of the width of the port. The exhaust side should always give the full opening, which it will do if the exhaust lap is properly proportioned to the steam lap. The opening of the port on the steam side of the valve is what must be used with the foregoing formulas. A good rule for *finding* the area, in square inches, of the steam port, is to multiply the square of the diameter of the cylinder in inches by the velocity of the piston in feet per minute, and divide by 4,000.

"It might also be observed that the length of the link from centre to centre should be at least three times the stroke of the valve, and that the best radius for its centre line is the distance from the centre of the pin to the centre of the eccentric."

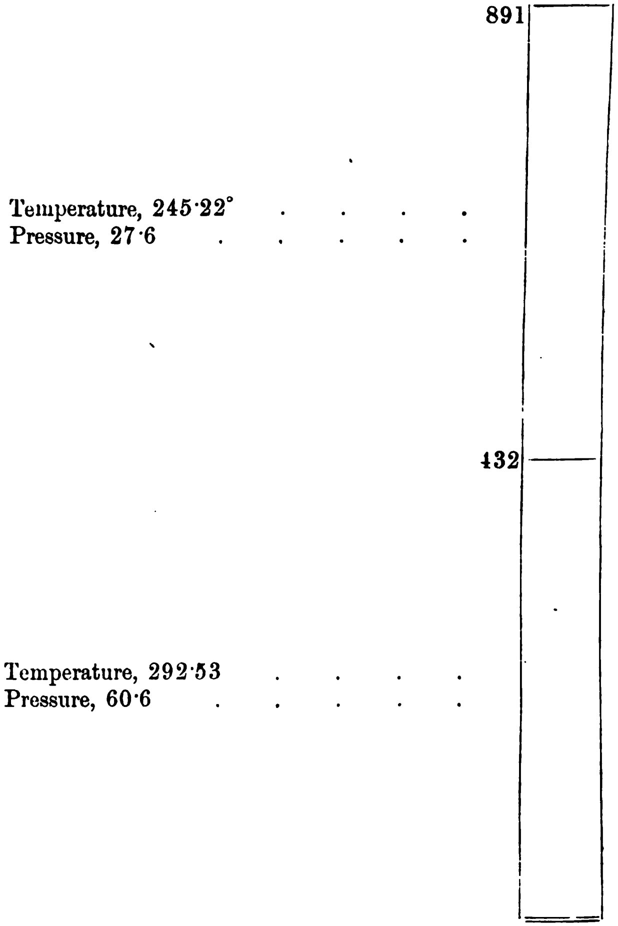
36. A vast deal has been both written and said on the subject of *expansion of steam*, and less both of the one and the other might have been done, without much loss to practical science, as the result of much of it has been simply "the darkening of counsel by words." The article here following from the pages of the "Scientific American" on this subject will be interesting and suggestive.

"We published last week a corrected table of the first approximate results obtained by Fairbairn and Tate in their experiments undertaken to determine the density of steam when formed at different temperatures, and on another page of this number will be found a more extended table of the final results from their repeated and careful observations. From the extreme delicacy of the apparatus employed and from the high reputation of the experimenters, these results will be universally accepted as entirely reliable. If a cubic inch of water is placed in vacuo in a vessel of 432 inches capacity, it will all be converted into steam at a temperature of 292·53° Fah., and the steam will exert a pressure against each square inch of the walls of the vessel equal to 60·6 pounds. Again, if a cubic inch of water is placed in a vessel of 891 cubic inches capacity, it will all be evaporated at a temperature of 245·22°, and the pressure will be 27·6 pounds per square inch.

"Now the question is, if we form steam at a higher pressure, so that a cubic inch of water will fill a vessel of 432 cubic inches, and allow this steam to expand to a volume of 891 cubic inches, what will be the pressure? There is no doubt that if we bring the fluid to the temperature of saturated steam at this relative volume, 245·22°, we shall have the corresponding pressure of 27·6 pounds per square inch.

"But the question is, *what will be the temperature and pressure if the steam is allowed to expand with only the heat that it contains?*

"If this question could be answered we should have a theory



of expansion. But there are difficulties in the way of determining the point which would seem to be insurmountable. They baffle the genius of Regnault, and have not been overcome by any other experimenter. If the attempt is made to *measure the temperature* and pressure of the expanded steam, it is necessary to confine the steam in a close vessel, and then it is impossible to prevent it from either absorbing heat from the walls of the vessel, or imparting heat to them.

"No practical mode having been discovered of measuring the pressure of expanded steam, various attempts have been made to arrive at it by reasoning from facts that can be observed. Regnault ascertained that water in being changed into steam at the atmospheric pressure, or at a temperature of 212°, absorbs and renders latent 966·6° of heat, while in being evaporated at 339° it absorbs 877·3°. If we take a pound of water each degree will represent a unit, and we have,

	Units of latent heat.	Total heat.
1 pound of steam at 212°	966·6	1178·6
1 pound of steam at 339°	877·3	1216·8
Differences, . . 127°	89·3	38·2

"Steam at a temperature of 339° exerts a pressure of about 101 pounds per inch, and at 212° of about 15 pounds per inch. As a pound of steam at 339° contains 38·2 units of heat more than a pound at 212°, we should suppose that in allowing it to expand down to 15 pounds' pressure, we should have not only sufficient heat to keep it all in a state of vapour, but a surplus of 38·2 units, so that the steam would be superheated, and its pressure would be more than 15 pounds to the inch; provided always that no heat is consumed in the performance of work.

"Isherwood, in his Engineering Precedents, Vol. XI., argues that instead of being superheated, a portion of the steam would be condensed. He says the condensation 'results from the fact, that although the total heat of steam of higher pressure is greater than the total heat of steam of lower pressure, yet as the latent heat of the latter increases in a much higher ratio than its total heat diminishes, and as this increase in the latent heat is at the expense of the sensible heat, it becomes a cooling process, and produces the condensation stated.' In a later work, Experimental Researches in Steam Engineering, Mr. Isherwood argues the point at much greater length, and comes to the same conclusion.

"Though we have the greatest respect for Mr. Isherwood's opinions, especially in *questions* relating to the expansion of steam, we are unable to see how the inference in this case follows from the premises. Though the temperature of the steam would be reduced, yet as the boiling point would be reduced by the diminution of the pressure still more, we cannot understand why there should be any condensation.

"Tyndal, on the other hand, argues that expansion where no work is done is not a cooling process, believing this to be demonstrated by an experiment of Guy Lusac's. Two air-tight vessels were connected by a pipe which had a stop-cock in the middle. One vessel was filled with compressed air, and the other was exhausted. On opening the stop-cock and allowing the compressed air to expand so as to fill both vessels, the temperature was reduced in the vessels from which the air passed, but it was raised to precisely the same extent in the other vessels; so that on the restoration of the equilibrium no change of temperature had resulted from expansion.

"If this law applies to steam, on expanding a pound of steam formed at 339° to the volume of a pound formed at 212°, it would be superheated not merely by the addition of 38·2 units, but to the temperature of 339°, and it would have a corresponding pressure.

"Professor William John Macquorn Rankine, in his learned work on the steam engine, seems to consider the varying pressure in the cylinder of a steam engine as measured by the indicator the best data yet obtained for determining the law of expansion. Professor Rankine would probably appreciate more fully than any other person the entire unsuitableness of a steam cylinder as an instrument for measuring the diminishing pressure of expanding steam. The very frequent exposure of the interior of the cylinder to a temperature far below that of the steam, would not merely modify the pressure, it would so completely change it as to utterly destroy the value of this apparatus as an instrument for making this measurement.

"The theory of expansion in its present condition seems to be merely a collection of conflicting speculations."

37. The *Locomotive* engine is questionless the finest exemplification which modern engineering has yet afforded of a wonderful concentration of great power in small space, of the finest adaptation of mechanical means to a desired end. If, indeed, we consider

what the power expressed in one of our best locomotives is, the circumstances under which it is called upon to do its work, frequently, indeed, we may say usually, adverse to that regular working which is the best guarantee of safety and economy for engines of the stationary class, it is difficult to over-estimate either the scientific genius which has conceived, or the mechanical skill which has realized, the fine adjustment of parts, their arrangement, and the close adaptation of mechanical appliances best calculated to give out the effect desiderated which a locomotive of the first class exemplifies. We take it, in fact, as pretty well established, that a locomotive belongs to the highest class of mechanical engineering, and that a professional man, thoroughly up to all the points of construction, as well as those of the management of a locomotive, is competent to undertake the design and the execution of almost any other class or kind of engineering work. It is not surprising, therefore, to find, as we do find, that to a certain class, of the finest mechanical mind, the locomotive, and all connected with it, possesses a degree of fascination which prompts them to give to its development all the powers of their scientific genius, and all the results of their mechanical skill. Hence is to be traced the astonishing progress which has of late been witnessed in this department of engineering—a progress as remarkable in its social as it is in its engineering features. But it is ever the prerogative of true genius to doubt of perfection having been attained, and ever its privilege to push forward to "fresh fields and pastures new." Much, therefore, as has been done in bringing the locomotive to its present high condition of efficiency, much remains yet to be done to bring it to a higher; and this truth, believed in by many of our leading men, is urging them to still greater efforts in the march of improvement. In what direction these efforts are being made the following papers of the year will best show. The first of them is from the "Engineer," and is entitled

38. *The Motion of Locomotive Engines.* — "The nature of the advancing or receding motion of a locomotive engine upon the rails is less simple than at first sight appears. It is customary to regard the motions of a locomotive engine exactly as if it were fixed, and turned its wheels upon a definite centre. But however the respective results may correspond, the action of the two classes of engines requires a different mode of investigation.

So far as the transmission of the steam pressure on the pistons is concerned, the driving wheels, if acted on by no other force than that transmitted through the connecting-rod, and although the engine was in forward gear, would be rolled backward when the crank was below the axle, and drawn forward only while the piston was moving away from the axle. If the axle were free to move horizontally in the axle guards, it would thus visibly move from one side to the other at each half revolution, and, although the effect is unseen, the pressure within the axle boxes does thus act alternately in opposite directions at each revolution. If, again, the connecting-rods, instead of acting upon crank-pins within the engine, exerted their force against immovable points external to it, the whole body of the engine would be pressed forward on one stroke, and backward on the other, and, in each case, with the full pressure acting upon the front and back cylinder covers respectively.

"The driving wheel may be, and, indeed, must be, considered as a lever, the fulcrum of which is on the rail. In order to deal with exact quantities, let us suppose the diameter of the wheel to be 6 feet, and the length of stroke 2 feet. When, in forward gear, the crank-pin is below the axle, the whole pressure of the steam, transmitted from the piston, will be first exerted upon the crank, and thus upon the axle, tending to press it backward, with a force inversely as its distance, compared with that of the crank, from the rail. In this case the crank is two feet from the rail (the common fulcrum of progressive motion), and the axle is 3 feet. Thus, the axle will be pressed backward with a force as 2 : 3, or two-thirds that upon the piston. Were the wheel otherwise disconnected from the engine, it would at first be rolled bodily backwards, and with the force first estimated. But being embraced by the axle boxes, the axle is acted upon directly by the whole forward pressure of the steam upon the front cylinder cover, and thus the wheel must move forward with a force equal to the difference of the two already considered. It is needless to say that it will be moved forward with a force of $1 - \frac{2}{3} = \frac{1}{3}$ that acting upon the piston. We may now look at the crank when placed above the axle, the position in which it is occasionally supposed, by those fresh in the matter, that the engine moves forward with greatest force. Still, considering the rail as the fulcrum, and the engine in forward gear, the pressure exerted upon the piston tends to draw the axle forward with a force as much greater than that upon the crank-pin as the latter is further above the rail than the axle. In this case the force at the axle is to that at the crank-pin as 4 : 3, or one-third greater than that at the crank. But from this is to be deducted the full backward pressure against the back cover, leaving the nett progressive force one-third of the pressure upon the piston, or exactly the same as when the crank was below the axle. We have here considered but one of the two pistons, but the mode of action is necessarily the same for both, and it is easy to allow for their alternate effect. It is not, of course, to be supposed that the constant progressive effect, in the particular case assumed, will be one-third of the full pressure upon the piston. This is only the case when the crank is at right angles, or nearly so, to the centre line (or prolonged axis of the piston-rod), and when, therefore, it is acting with its full leverage. When the crank is in the same line as the piston-rod, the engine receives no progressive force, as the opposite and equal pressures upon the piston and cylinder head are transmitted with the same leverage to the axle. With a driving wheel of a diameter equal to three times the length of the stroke, as in the case already supposed, the mean progressive force of the engine will (irrespective of friction) be as much less than one-third the pressure on the piston as twice the length of the stroke is less than the circumference of the circle described by the centre of the crank-pin. This circumference is necessarily 1·570795 times the length of the double stroke, and as the piston only acquires the full velocity of the crank-pin at two points in each revolution, the highest speed of the piston will be, say, 1·57 times its mean speed. Thus, with our 6-feet wheel and 2-feet stroke, at 60 miles an hour, the mean velocity of the piston would be 1,120 feet per minute, its range of velocity at each stroke being from nothing to 1,120 × 1·570795 = 1,760 feet per minute. This consideration is often overlooked by those who treat of the influence and practicability of high piston speed, the latter being almost invariably taken at its mean rate over the whole stroke, whereas its maximum rate, near the middle of the stroke, is always greater than the mean rate, in the proportion of 22 to 14 nearly. The maximum rate of motion may be directly inferred from the ratio of the half circumference to the diameter of the crank-pin path, or, in the case of a locomotive engine, it may be taken directly from the wheel, considered as a lever turning on the rail. With the 6-feet wheel and 1-foot crank, at 60 miles an hour, the crank, when exactly above the axle, will be moving through space at the rate of $\frac{4}{3}5280$ feet per minute, or 1,760 feet per minute faster than the axle, while, when the crank is exactly below the axle, it will be moving through space with a velocity of $\frac{2}{3}5280$, or 1,760 feet per minute less than that of the axle—in either case with a velocity of 1,760 feet per minute, as referred to an axle in fixed bearings.

"By this mode of investigating the motion of locomotive engines, the action of counterweights may be better understood than when referred, as is usual, to wheels revolving in fixed bearings. The practical effect is undoubtedly the same, but it is not so easy to understand the effect of counterweight in a rolling wheel, except it be treated as a lever turning at one end upon the rail. The difficulty is, apparently, increased by a very simple experiment. To a wheel with a rim of uniform section, and already in perfect balance, apply a heavy counterweight at one side, and just within the rim. Place this wheel upon a level surface, and with the weight at the bottom. It is then easy to rock the wheel to and fro. But if the counterweight be turned to the top, the effort necessary for rolling will then be unmistakably greater. Now, one is at first tempted to argue that, as the same weight had comparatively little momentum while at the bottom of the wheel, but a comparatively great momentum when placed at the top, therefore equal weights at opposite points in the rim cannot properly balance each other. Nor, indeed, if the wheel were rolled forward simply as a hoop, without connection with a carriage, could the opposite weights balance each other, and, if heavy, they would cause visible irregularity of onward motion. But, as soon as the wheel is connected by its axle to an engine within which the power for rolling it is exerted, the onward motion becomes regular. Taking the 6-feet wheel and 1-foot crank at 60 miles an hour, the crank-pin, when below the axle, will be moving through space (or with reference to the surface of the ground beneath the rails) at a rate of 1,760 feet per minute less than that of the axle. So far as the 'momentum of the reciprocating parts' is here concerned, the axle may be considered as forcing its way forward in opposition to their inertia. The virtual effect is to hold the engine back with a force equal to the momentum of the reciprocating parts acting through the leverage of the cranks at the same effective velocity upon a wheel turning within fixed bearings. When the crank rises above the axle, the wheel will be accelerated in the same ratio by the momentum in question. And as the crank on opposite sides of the axle is capable of producing opposite and equal effects, it necessarily follows that, so far as the fore and aft motion is concerned, a counterweight, exactly balancing the weight of the reciprocating parts when at rest, will ensure the steady onward progress of the engine. This is irrespective of the centrifugal force which the counterweight expends upon the rail, and which is so destructive to tyres.

"The manner, however, in which the reciprocating parts communicate their momentum to the mass of the engine has yet to be considered. In the first half of each stroke the velocity of the piston is constantly increasing, and in the last half as constantly diminishing. Now, while the speed of the piston is being accelerated, it is clear that it cannot, through any momentum of its own, move the wheel faster than it is already moving under the influence of the steam alone, and hence can cause no jerk in either direction. No expenditure of the momentum of the reciprocating parts can commence until they have attained their maximum velocity, which is 1·57 times their mean velocity, and which time practically corresponds to half stroke of the piston. It is then, if at all, that any disturbance due to unbalanced momentum must commence. But it must not be forgotten, that as the reciprocating parts, by their inertia, oppose a certain resistance to motion, the steam, in this case, is meanwhile acting upon the cylinder cover to push the engine bodily backward. If we can suppose a piston, rods, &c., of 50 tons weight, while that of the other parts of the engine was but 25 tons, it is clear that, before the former could be got into motion, the 'engine' would be pushed bodily backward when taking steam under the back cylinder cover, or bodily forward when taking steam under the front cover. On the last half of each stroke, the momentum of the reciprocating parts is expended upon the engine in addition to any consideration of the pressure upon either the piston or cylinder cover. Lead or compression, or both, may improve the working of the engine by anticipating the effect of diametrical play in the axle brasses, &c., but neither lead nor compression can remove the influence of the unbalanced momentum of the piston-rods, &c. While the velocity of the piston is increasing, from the beginning of the stroke to mid-stroke, the cylinder cover pressure will have the advantage over the piston pressure, while, during the last half of the stroke, the piston will have the advantage over the cylinder cover. The maximum velocity of the piston in express engines is often upwards of 20 feet per second, the mean speed being, say, 800 feet per minute, and it should be borne in mind that, at this velocity, the force stored up in the piston and its appendages would alone raise them vertically 6 feet 3 inches in the air, a force necessarily equal to what would be expended on their striking an anvil after falling from that height. The conclusion is that proper counterweights, properly placed, are indispensable to the steadiness of locomotives."

39. The rapid development of the railway system has caused districts to be provided with all its advantages, which, in the early days of its history, would have been considered quite beyond the reach of its influence, and this chiefly through the engineering difficulties involved by the local peculiarities of the district, or through the heavy cost which the main system of construction involved. Now, however, such districts are "marked out" or being "marked out," and gradients which would have been considered, if not impossible, yet any thing but economical in working, are being met, and met successfully, in practice. *The working of the very steep gradients or inclines* which are now often met with, has involved the necessity of introducing engines specially adapted for the heavy work they have to perform. It is probably on the continent that most has been done in this way and in connection with it the following paper, which was read by M. Combes at the Academy of Sciences, will be read with interest.

"Mons. Siguier recently introduced to the notice of the Academy experiments, now making in England, of a new kind of locomotive engine, for use on steeply inclined railway lines.

"Instead of deriving the necessary adhesion, as in the generally adopted system, from the friction of the driving wheels, the ne engine derives it from a pair of horizontal wheels, pressing between them a third central rail, placed between them like an iron bar between two rollers, with the difference that here the bar remains still, and the roller receives the motion.

"The pressure of the wheels against this rail is regulated by a sort of pincers, the arms of which are drawn near to one another by the traction force exerted on the trains, so that the pressure on the rail and the consequent friction, the source of adhesion would always be sufficient, and never more than necessary, to prevent the slipping and to propel the train.

"This system is, on first sight, as attractive as ingenious. There is no doubt, however, that its execution must involve serious difficulties, though, perhaps, not more than are common to all mechanical conceptions.

"This important question of the construction of locomotives available for steep ascents and sharp curves is susceptible of several solutions. It has for a long time received the attention of engineers engaged in traffic railways; but they have never consented to abandon the old principle.

"The opening of the Soemmering railway, and of the line from Genoa to Turin, crossing the Appenines, and other instances which might be cited, show that their efforts have not been unfruitful. The company of the Northern of France railway, at the suggestion of M. Petiet, directing engineer of the works, have entered actively into this line of experiment.

"They have constructed ten locomotives of great power, the whole weight of which is employed for adhesion, which can run in curves 80 metres only in radius, and which are suitable equally for drawing heavy goods trains on a level or gently-sloping incline line, and for drawing lighter trains on steep inclines.

"These engines have four cylinders and six axles, coupled in two groups of three, each commanded by a pair of cylinders. The wheels are small, having a diameter of 1·065m., so that the fire-box of the boiler overhangs them, allowing 3·33 square metres of fire-grate. The total heating surface is 221 square metres, and surpasses in extent that of the most powerful engines hitherto constructed. In working trim this engine carries 8,000 kilogrammes of water, and 2,200 kilogrammes of fuel. Its total weight is then nearly 60,000 kilos., equally distributed upon the six axles and twelve wheels, each one of which presses upon the rail with a weight of 5,000 kilos. The distance of the extreme axles, *i. e.*, the wheel-base, is 6 metres. To facilitate working in small curves the following appliances have been made:—

"The flanges of those wheels fixed to the two intermediate driving axles of each group are reduced in thickness. The four other axles have a longitudinal play of 46 millimetres, and the two extreme axles of each group are bound together by a horizontal beam turning round an axis in the plumb line of the intermediate axle, which obliges one to move in a longitudinal line, left or right, just as the one to which it is connected does, and *vice versa.* Thus the proper position of the wheels on the rails is facilitated, although the axles are always kept parallel.

"The railway from Chaunay to Saint Gobain, 14,500 metres of line, presents, in the first place, starting from Chaunay, ascents and descents of 18 millimetres, and curves of a minimum radius of 275 metres. At St. Gobain, it terminates by an incline of 18 millimetres, and curves of 220 m. radius. The St. Gobain terminus itself consists of two contrary sweeps of 125 m. radius in a line of 200 m. The line runs on into the glass manufactures, and forms a complete semi-circle of 80 m. radius and an ascent of 25 millimetres.

"During eight days the above-described engine did all the work of this line from Chaunay to St. Gobain, and ran, in the 80 m. curve, as easily as the four-coupled axle locomotives formerly in use there. The following are the data and the result of the experiment of January 21st last:—

"The train to be drawn was composed of twenty-one vehicles, vans, coal-waggons, and passenger carriages, weighing altogether 267,000 kilogrammes. The speed of progress of the trial train was noted at every hectometric post on the 18 millimetric ascent. The first 1,200 metres were run at an average speed of 20 kilos. per hour. Towards the twelfth kilometric post, the engine wheels slipped and glided on the rails; adhesion was at its last limit. Yet there was no complete stoppage, but the average speed, over a course of 800 metres, was only 8·3 kilos. an hour, and the minimum speed as low as 1·43 metre a second, or 5·15 kilos. an hour.

"Subsequently the train resumed a speed of 20 kilos. an hour, and ran the remaining 1,100 metres to the station, which include some slight curves, at a rate of 17 kilos. Arrived at the St. Gobian station, the engine placed itself at the end of a small waggon train, and pushed it into the works, over the 80 metre curve, on a 25 millimetric incline. At the end of this curve, the waggon brakes being jammed, the engine was made to execute several manœuvres on the spot, backing and advancing, without damage to any part, and without any appearance of strain.

"This trial demonstrates that this new locomotive, with four cylinders and six axles, coupled in groups of three, and furnished with beams, after Beugniot's system, can run in sharp curves; that its highest power of adhesion, even in an unfavourable condition of the rails (as was the case in our experiment), is nearly equal to $\frac{13}{100}$ of the total weight of the engine, and balances a resistance of about 7,300 kilog. Lastly, that the engine which has drawn up an 18 millimetric incline a train 267 tons gross weight, could also drag a train of 100 tons gross weight, independently of its own weight, at the speed of 17 to 20 kilos. an hour, on an incline of 40 millimetres, with curves of a minimum radius of 250 metres."

DIVISION THIRD.

STEAM FIRE-ENGINES.

40. When we consider the vast interests involved in the preservation from the ravages of fire of the property of the inhabitants of our large towns, it is easy to understand the importance of all means tending certainly and economically to ensure this. And if this is so taken on the lowest grounds relating to the wealth, how much more important an aspect does the subject assume when we consider it in relation to the lives of our town inhabitants. While having to congratulate ourselves on that increase of efficiency in all the details of what are called "Our Fire-engine Establishments," which the last few years have witnessed—an efficiency which is fast bringing nearer to the highest standard of perfection those measures which are taken to subdue fires which break out, or to prevent them spreading over large areas—we have nevertheless no great reason—if, indeed, any—to congratulate our-

selves upon an increase in the number or the value of those appliances which tend best to prevent the breaking out of fires in our various structures, domestic or otherwise. Indeed, when we see the mode in which, from day to day, houses of all classes are "run up," the recklessness with which inflammable materials are used in their construction, and, not only so, but the placing of these in the best way calculated to ensure the rapid spread of fire if it once gets hold of any portion, the wonder is, not that houses are saved from total destruction, but that, when once on fire, the fire can ever be got under. And that, under such circumstances so favourable to the extremely rapid development of fire, fire is so frequently mastered, is the best evidence of the high state of efficiency into which not only our fire establishments have been placed, but in that of the machines, without which all other organization would be but comparatively inoperative. Indeed, when we take as types of the two forms of fire-engines the "old parish" and the most recent form of "steam fire-engine," we have reason to congratulate ourselves on the fact that our mechanicians, if they have—as doubtless they have—neglected for some time this branch of engineering, are atoning amply for it by the fine work with which they are now enriching it. Before giving these papers on the subject of fire-engines, it will be an appropriate, as it is a useful, introduction to them, to present the following report on—

41. *The fires of London in* 1863, "which was issued in the early part of 1864 by Captain Eyre M. Shaw to the Committee for Managing the London Fire-engine Establishment:—

"The total number of calls received during the year 1863 has been 1,624. Of these 81 were false alarms, 139 proved to be only chimney alarms, and 1,404 were fires, of which 39 resulted in total destruction of buildings, &c., 310 in serious damage, and 1,055 in slight damage.

"The fires of 1863, compared with those of 1862, show an increase of 101, and, compared with the average of the previous 30 years, the increase is 582.

"I have appended several classified tables, with particulars of trade, causes, &c., &c.

"These lists do not comprise trifling damages by fires not sufficiently important to require the attendance of firemen; neither do they include the ordinary calls for chimneys on fire.

"The totally destroyed list—39—compared with that of 1862, shows an increase in number of 6; but, compared with the average proportion of the previous thirty years, there is a decrease of 9.

"Of the buildings destroyed, 4 were over 2 miles from the nearest station; 7 over 3 miles; 1 over 5; 2 over 6; 2 over 7; 1 over 8; 1 over 11; and 1 over 12 miles; 3 were lost for want of water; and 1 fell down before the fire could be extinguished. Of the 39, 18 were completely alight, and 17 others burned down before the arrival of the engines. Although this list is numerically in excess of that of last year, a very slight reference to it will show not only that in point of value the losses are for the most part trifling, but that the generality of the places destroyed are of that class which, when once on fire, can very rarely be saved by any exertions on the part of a Fire Brigade.

"During the past year the telegraph has been extended from the foremen's stations to those in their respective districts, thus completing the communication throughout the establishment from the chief station, in which I reside, to those most remote, in Ratcliff, Baker-street, Westminster, and Rotherhithe respectively. The system which I have adopted is of the simplest possible kind.

"From Watling-street I ordinarily communicate only with the foremen, and, through them, with the stations in their respective districts, but, by a simple contrivance, I can at any moment be placed in direct communication with any station, thus avoiding the delay caused by repeating messages at an intermediate point.

"I have adopted this mode not only in order to be able to collect the necessary force of men and engines at any given spot in the shortest possible time according to my requirements at the moment, but also for the purpose of avoiding the errors inseparable from a system of mere alarms as used in America, by which the whole force of a fire-brigade is liable to be constantly turned out for matters of very little consequence, it being an invariable rule that the importance of every fire is greatly exaggerated by momentary panic in the vicinity.

"The saving thus effected in the time and labour of the men, as compared with the old system of running with 'calls' and 'stops' from station to station, is, in itself, a great addition to the available strength of the establishment, and that at the very time when the services of skilled firemen are most needed; while the advantage of rapidly transmitting the calls, and thus ensuring the early arrival of men and engines at fires, is incalculable; besides which, I am now enabled to issue orders and conduct almost the whole of the duties of the establishment by this means in a much quicker and more satisfactory manner than formerly.

"The land steam engines continue to render valuable aid at all fires, large and small. These machines have been considerably improved during the past year, and are now adapted to throw jets of every size, from a quarter of an inch to an inch and a half. It is a remarkable fact, which ought to be noticed in connection with the subject of land steamers, that some of their best services have been at those fires which have resulted in total destruction of the premises which first took light, and, although they have been only about two years in operation, many instances can already be cited in which the property actually at risk and saved by their means has been, in point of value, upwards of a thousand per cent. in excess of that destroyed.

"The recent addition of three land steam fire-engines, taken on hire, has proved a most important accession to the strength of the establishment.

"The upper floating steam fire-engine is in excellent working order, but the lower floating engine is at present laid up, pending your final decision as to the improvements to be made in her. These engines are absolutely necessary for the protection of the enormous waterside property of the metropolis, and I most respectfully recommend that the question of the lower floating engine should occupy your earnest attention at an early date.

"I ought to mention that, notwithstanding the number of fires, wholly unparalleled either here or elsewhere, the labours of all ranks in the establishment, however severe, have, since the adoption of steam and telegraphic communication, become decidedly less arduous than in former years, when the number of fires was less.

"The new station in Bishopsgate-street, which, in consequence of the expiration of the lease of that in Jeffrey's-square, the committee found it necessary to obtain in September last, has bee completed, and its prominent situation, in one of the leadin thoroughfares, proves a great advantage in obtaining early call fires.

Notwithstanding the greatly increased number of fires, the list sualties for 1863 is five less than that of the previous year. I have received from the surgeon of the establishment a de- d report, from which the following is an extract:—

'By the accompanying paper you will perceive that there have 86 cases of illness, totally incapacitating the men from duty, ast 98 cases for the year 1862, but, although less in number, gret to say more severe in character. Of the total number, ave arisen from accident, and several of a very severe form, onstrating the hazardous nature of the employment.

'I have carefully noted the number of days that each man been away from duty on account of sickness, and find the age per day from accident to be $2\frac{1}{4}$ men, and from general ss $2\frac{3}{4}$, being a total loss of 5 men per day to the establ- nent throughout the year, and also that each man in the force id up $12\frac{1}{2}$ days. This is an average greater than we should ct to find in any other employment, but it is entirely owing e severe nature of some of the accidents.

'At the present time I am happy to say the general state ealth amongst the men is remarkably good, and, independently ose suffering from the effects of accidents, we have no case ing the slightest uneasiness.

'At the close of another year I have to congratulate you upon atal case having occurred.'

Accidents.	No. of cases.
Amputation (finger),	1
Burns,	4
Contusions,	4
Cuts and lacerated wounds,	8
Fractured pelvis, fractured shoulder joint, fractured ribs,	3
Injuries to back,	3
Lacerated urethra,	1
Punctured wounds,	2
Sprains and injuries to joints,	7
Total number of cases,	33

"In addition to these accidents there have been 53 cases of ordinary sickness, making a total of 86 cases during the year.

"The whole of the engines and other appliances at present in use have been carefully attended to, and are in thoroughly good working order.

"At the close of another year it has again become my pleasing duty to bear testimony to the general efficiency and excellent conduct of all ranks of the establishment, and to state my most sincere belief that the steadiness, unanimity, fearlessness, and zeal, with which they devote themselves to the arduous duties of their profession, fully entitle them to that confidence and liberality of which they receive such numerous instances at your hands.

"In conclusion, I beg to express my most sincere gratitude for the sympathy and support which I have received from you, individually and collectively, at all times, but more especially on the occasion of my recent accident; and at the same time I beg to assure you that no exertion shall be wanting on my part to merit a continuance of your confidence."

Among the tables appended to Captain Shaw's report the following are of interest:—

CAUSES OF FIRES IN 1863.

Airing linen,	41	Dog,		1
Asphalte boiling over,	1	Doubtful,		10
Bleaching nuts,	1	Drying fibre,		1
Boiler, overheat of,	4	,, firewood,		2
,, explosion of,	2	,, jute,		1
Brazier's fire,	1	Explosion of fireworks, &c.,		7
Burning rubbish,	1	Fat thrown on fire,		1
,, straw,	1	Fireplace, defect in,		2
,, waste paper,	2	,, blocked up,		4
,, white fire,	1	Fish falling on fire,		1
Candle,	227	Flue, heat from,	21	
Case of fusees falling,	1	,, defect in,	35	
Chair falling on fire,	1	,, blocked up,	8	
Charcoal fire,	1	,, foul,	29	
Chicory cylinder, overheat of,	1		—	93
Children playing with fire,	16	Flue adjoining, heat from,	6	
,, ,, fireworks,	1	,, defect in,	9	
,, ,, lucifers,	22	,, blocked up,	1	
Clothes coming in contact with fire,	2	,, foul,	8	
			—	
Copper fire,	1	Flue furnace, heat from,		
,, set on wood,	1	,, ,, defect in,		

Flue forge, overheat of,		1
Friction of lucifers, machinery, &c.,		5
Furnace, overheat of,		8
,, improperly set,		1
Gas,	42	
,, boys playing with,	1	
,, cooking apparatus,	1	
,, escape of,	35	
,, explosion of,	9	
,, explosion caused by escape in street,	2	
,, lighting,	10	
	—	100
Gasfitters at work,		1
Hearth, defect in,		1
,, timber under,		3
,, fire on,		2
Heat from furnace shaft,		2
Hot ashes,		24
,, metal,		2
,, plate,		2
,, plate adjoining,		1
Illumination,		2
Incendiarism,		4
Ink boiling over,		1
Intoxication,		7
Ironing,		1
Lamp,		5
,, upsetting,		3
Light thrown down area,		5
Lighted paper,		3
,, sawdust,		1
Lime slacking,		7
Lucifers,		26
Naphtha upsetting,		1
Oil cask leaking,		1
Oven,		5
Pan of varnish splitting,		1
Paper used to fan fire,		1
Petroleum, testing,		1
Phosphorus,		1
Pipe stove,		10
Poker falling out of fire,		1
Rags, overheat of,		1
Reading in bed,		1
Smoking tobacco,		31
Spark from fire,	97	
,, furnace,	2	
,, thrashing machine,	1	
,, moulding,	1	
,, casting,	1	
,, hot plate fire,	1	
,, engine,	1	
,, forge,	2	
,, flue,	1	
	—	107
Spirits, drawing off,		1
Spontaneous ignition,		5
Still leaking,		3
Stove, defect in,	1	
,, drying,	14	
,, gas,	2	
,, heat from,	2	
,, improperly set,	2	
,, ironing,	4	
,, portable,	1	
	—	26
Stove adjoining, heat from,		1
Tar, fat, glue, oil, resin, japan, and pitch boiling over,		15
Vat overflowing,		1
Woman falling into fire,		1
Workmen's fire,		2
Unknown,		487
Total,		1,404

COMPARATIVE TABLE OF FIRES.

Philadelphia	approximate annual aver.,	363	Brooklyn,	approximate annual aver.,	83
New York,	,, ,,	331	Troy,	,, ,,	42
Paris,	,, ,,	300	Charleston,	,, ,,	31
Berlin,	,, ,,	260	Liverpool fires in 1863,		297
Hamburg,	,, ,,	244	Manchester	,,	238
St. Louis,	,, ,,	189	Glasgow,	,,	221
Boston,	,, ,,	172	Dublin,	,,	174
St. Petersburg,	,,	140	Birmingham	,,	139
Montreal,	,, ,,	104	Edinburgh,	,,	127

Sheffield fires in 1863,	51	Birkenhead fires in 1863,	8
Leeds, „	47	York, „	11
Hull, „	26	Exeter, „	10
Bristol, „	25	Waterford, „	5
Cork, „	23	Yarmouth, „	4
Sunderland, „	22	Tynemouth, „	3
Belfast, „	17	London, „	1,404

42. The following paper from the "Engineer" ably takes up some of the leading points of *steam fire-engine construction and working*, and alludes to certain recent trials which possess some features of practical interest.

"Mechanical engineers have for some time looked with interest upon steam fire-engines as presenting the most powerful combination of engine and boiler, when their total weight is considered. A large locomotive engine, weighing 35 tons, has been known to work, for a short time, at the rate of 1,000-horse power, equal to nearly 1½-horse power for each 112 lb. of its weight. But no locomotive of one-tenth the weight, say 3½ tons, could, upon the usual system, be made to work up to 100-horse power. The steam fire-engines, however, of 32 cwt., are now worked up to 32-horse power, a result probably not yet attained in any other application of the steam engine. It is no doubt probable that the fire-engines are too light for great durability if worked constantly, but their work is only occasional, and it is even preferable to incur a somewhat increased cost for repairs than to add more weight than is necessary to enable the engine to do its work properly.

"The engine with which Messrs. Shand, Mason, and Co. obtained the gold medal and 500 guilder prize, on the 12th instant, at Middleburg, Holland, weighed 32 cwt., and had a single 7 in. steam cylinder, with a stroke of piston of 8 in. Before it went out from their works the makers subjected this engine to a series of careful experiments as to its power, and took a number of diagrams with Richards' Indicator, the only one properly applicable at 165 revolutions per minute. In one instance, with steam of 145 lb. per square inch, a water pressure under a 1⅛ in. jet of 125 lb. per square inch, and at 165 revolutions per minute, an average effective pressure of 128·15 lb. per square inch was maintained upon the piston, with 5½ lb. back pressure, which can hardly be reckoned large. In this case 32¼ indicated horse-power were exerted, or 1-horse power for each hundredweight of the engine. In working at its full power through a $1\frac{1}{8}$ in. jet, the engine might be counted upon to throw 300 gallons per minute, and, indeed, it threw an average of 265 gallons per minute, into a hood 50 ft. distant from the branch pipe. American makers of steam fire-engines, with whom English firms have had occasion to compete, are to remember, when comparing these results with their own, that the gallons in which our quantities of water are expressed are invariably gallons of 10 lb. of water, whereas the United States gallon is our old wine gallon of 231 cubic inches, or almost exactly $8\frac{1}{3}$ lb. of water. The gallon in use in New York is 8 lb. of water only, and 300 imperial gallons correspond to 375 of these. Now, under a resistance of 125 lb. per square inch, equal to that of a column of water 287 ft. 6 in. high, the work done by the pump in forcing out 300 gallons of water per minute would be

$$\frac{300 \times 10 \times 287{\cdot}5}{33{,}000}$$

or 26·14-horse power, showing, upon this estimate, 19 per cent. loss between the steam expended and the work done by the pump. For this class of machinery such a result must be considered as excellent. It is true that the useful work exerted would not approach 26-horse power, but this in no way results from the construction of the engine. The water is sent out under a resistance which would raise it in a reservoir to a height of 287 ft. 6 in., supposing there be no resistance in the passage of escape. But as a jet, with the friction in the nozzle, and, more especially, against the resistance of the air, the water would not, probably, rise to a greater height than 160 ft., if, indeed, it would rise as high. If we take 150 ft. as the average lift, we have 13·6-horse power in useful work, or 42 per cent. of the indicated power. No improvement in fire-engines can, however, diminish the resistance of a jet of water against the air, notwithstanding that its exit may be eased by adopting the best form of nozzle, long since ascertained and in use. The engine is to be credited with the full water pressure in the air vessel, for it is this against which the pumps work; and this, therefore, is an exact measure of the resistance against which the water leaves the branch pipe. We *cannot* say that the engine under notice may not have discharged even more than 300 gallons per minute when in full work, but this is taken as a reasonable estimate, and it corresponds to a good degree of working efficiency in the machinery. Cornish pumping engines are thought to do well when the loss of power between the steam and the water is only 10 per cent.; and considering the great difference between these and high-speed steam fire-engines, a loss of 19 per cent., or even something more, would be nothing to wonder at. A speed of 220 ft. per minute, which was the highest attained in the trials, is nothing for a steam piston, but it is very fast for a water piston, intended for effective pumping, notwithstanding that the plungers of locomotive pumps, when worked as they sometimes are, at the full stroke of the piston, often attain a speed of 1,000 ft. per minute, and the direct-acting air pumps of marine engines are often worked at 420 ft. and even 500 ft. per minute, while in rare cases, as in Mr. Bourne's practice, they have been run at 700 ft. per minute. In neither of these cases, however, is economy of power of especial consequence, but in steam fire-engines it is everything.

"When in full work, with 145 lb. per square inch in the boiler, and at 165 revolutions per minute, the maximum effective pressure in the cylinder was 134½ lb., the full gross pressure being maintained for more than nine-tenths of the stroke. The steam was then cut off by a slight lap on the valve, while the exhaust opened apparently at about 97 per cent. of the stroke. The fall of pressure was almost instantaneous to, say, 20 lb. above the atmosphere, from which point it fell more gradually, approaching to within 2½ lb. of the atmospheric line at one point on the return stroke, the average back pressure being 5½ lb. There was a very slight compression for, say, 4 per cent. of the return stroke, when, with the least amount of lead, the steam rose suddenly. When working against a resistance like that of water, with which nothing can be counted upon for elasticity, and but little momentum, it is necessary, except a heavy fly-wheel be used, to work the steam at full stroke, or nearly so. Thus there can be but little lap, and the least amount of expansion, and the exhaust cannot be opened by more than a trifle before the end of stroke. It has been proposed to work steam expansively in fire-engines, but it is doubtful whether the saving which might thus be made in the boiler would compensate for the increased weight of cylinder, fly-wheel, and the moving parts directly connected with the piston. It is just possible that something may be gained by a further increase of pressure to, say, 200 lb., and it is certain, too, that a higher speed of piston would be desirable if no difficulty was found in working the water through the pump. A higher pressure, and, especially, a higher piston speed, would save a still further amount of weight, even when working expansively.

"The prize engine made good work on trial when working with 160 lb. steam, and at 154 revolutions per minute. The maximum cylinder pressure was 103½ lb., and the mean 97.15 lb. Here, however, the steam was throttled and thus wire-drawn, the mean pressure being 103 lb. on the first tenth of the stroke, 90½ lb. at the middle, and 68 lb. only in the last tenth. The whole indicated horse-power was 21¼, and with a jet of 1¼ in. a pressure of 95 lb. was maintained in the air vessel. We should have added that the back pressure was, in this case, very slight, falling to the atmospheric line during the last fourth of the return stroke.

"The Middleburg prize engine exhibits a great improvement upon earlier examples by the same makers. The engine formerly at Watling-street, and now removed to Bishopsgate-street station, weighs 27 cwt. It was made the subject of experiments, in May last, at the works of Messrs. Penn and Son, where the greatest horse-power developed was 15·36. The boiler pressure was then 100 lb., the average in the cylinder ($6\frac{9}{32}$ in. in diameter, and 7 in. stroke) being 75·4 lb. At 186 revolutions per minute the piston worked at the rate of 217 ft. The back pressure was very great—about 16 lb. per square inch. The engine discharged 204½ gallons per minute, through a 1⅛ in. jet. When working through an open branch with no jet the engine discharged 200 gallons of water per minute, and exerted 9·1 horse-power. The boiler pressure was 100 lb., the mean cylinder pressure 55·28 lb., and the back pressure, at only 150 revolutions, or 175 ft. of piston per minute, over 8 lb. The diagrams in these trials were not taken with Richards', but with Messrs. Penn's indicator, and they show how unsuited is the ordinary instrument to speeds of above 150 revolutions per minute.

Messrs. Shand, Mason, and Co., now have a steam fire-engine of only 24½ cwt. at Watling-street; and this, with a 6¼ in. cylinder, 7 in. stroke, and with 145 lb. steam, and at 156 revolutions, has worked to 18·3 indicated horse-power. The diagrams showed comparatively little back pressure, although enough to justify further attempts at its removal. A perfect steam fire-engine diagram should be nearly rectangular, and lie as near to the atmospheric line as possible. The best work done by the new engine at Watling-street was that of playing a $\frac{15}{16}$ in. jet under a water pressure of 115 lb. per square inch.

"The later examples of English steam fire-engine construction may safely be compared with any made abroad. Considering the great difference between the old hand-engines and those worked by steam, it is creditable to the makers of the former that they have directed their efforts, with so much readiness, and so much success, to the latter. In the States the construction of steam fire-engines is wholly in the hands of professed locomotive engine-makers, who have driven most of the former makers of hand-engines out of the market."

DIVISION FOURTH.

STEAM HAMMERS AND FORGING MACHINES.

43. Comparatively speaking, this class of machinery has only recently been developed, and, therefore, every point connected with it is received with particular interest by the engineering public. The subject cannot better be introduced to our readers than by the following paper from the *Mechanics' Magazine*, under the title of *Steam Hammers and the best foundations for them,* in which will be found a brief statement respecting their introduction into the practice of modern engineering; the defects, or supposed defects, which they possessed, with some extremely valuable hints as to working them economically, and of the best modes of securing firm foundations for them.

"Since the discovery and introduction of the arts of puddling and rolling wrought-iron, by the talented, but very ill-used Henry Cort, no invention connected with the forge has been fraught with more importance than that of the steam hammer. Its employment has led to vast and startling improvements in forging, and in smith's work of all descriptions. The steam hammer may, with truth, be said to have knocked down, and annihilated practical difficulties which only a quarter of a century ago were considered unconquerable. It has enabled the smith and the machinist to achieve triumphs which were once unhoped for, and apparently unattainable, whilst, by lessening the cost of both heavy and light forgings, it has stimulated the iron trade to a very material extent.

"The steam hammer is a docile and invaluable servant; but, like human servants, it demands proper treatment in order to develop its full efficiency and usefulness. It may be perverted to the worst purposes, and be made productive of the worst results, if entrusted to careless or 'unknowing hands.' For example, if the workman in charge of such an apparatus attempts to obtain from its action too much at a single heat of the forging in hand, he will probably damage the latter to a very considerable extent. The iron will inevitably, in such case, be crushed, mutilated, and probably crystallized to such a degree as to be deprived of its best elements, and thus rendered totally unfit for the purpose to which it is to be devoted. Great judgment, skill, and a well-practised eye on the part of the steam hammer manipulator, are essential to the making it productive of sound work.

"It was objected to the steam hammer on its first introduction, that it would lead the forgeman or smith into perilous temptation. By its aid, it was said, he could readily cover defects in forgings, whether arising from overheating or other causes. Like other merely theoretical objections to new inventions, this notion has been swept away by the practical use of the instrument, and a return from it to the hand hammer would be deemed as unwise as would be a relapse from the planing machine to the cold chisel. It has become a necessary concomitant to the forge, and improvements in its details and mode of action are alone to be hoped for or sought after. Its *principle* is fully established.

"We have said that care is required in dealing with the steam hammer, and one of the primary points to be looked to is unquestionably the obtaining of the proper degree of heat in the forging upon which it is to act. Overheating especially is the bane of forged work. Vain will be all attempts to remedy this vital evil. The best qualities of the material will be eliminated by it, and the finished forging will be but 'a mockery, a delusion,' and perhaps 'a snare.' It will never be sound or tough, although in appearance it may be both. Of course it is necessary that the quality of the iron in the first instance be good—that is to say, there should be present in it the minimum quantity of foreign matter, as sulphur, scoria, or oxides of any kind. This desideratum will be best effected by the most scrupulous attention to the fuel used for heating the forgings. It is a well understood fact, that if coals be used in the forge furnace which are impregnated with sulphurous or other foreign and deleterious matter, the forging will imbibe the poisonous particles and become vitiated accordingly. Perhaps the Belside Hartley and the Hastings Hartley coal are the best known kinds for forging purposes. They at least are freest from extraneous bodies. Having obtained the desiderata of good iron and good fuel for heating it, the next consideration should be to use both properly. The fire-box should never be *filled* with fuel, whatever the character of the material; for if it be so, the forging will occupy a long time in becoming properly heated, and a scale or crust will be generated on its surface. The homœopathic, rather than the allopathic, system of furnace treatment is undoubtedly the best. A lazy furnaceman may practise the latter, but a judicious one will certainly administer small quantities of fuel at frequent intervals, and thus add materially to the chances of obtaining a good forging.

"If this and other minor conditions be attended to, the iron, when duly heated, will present a semi-fluid or pasty appearance. In this state it is fit for welding, and no time should be lost in effecting that operation. When exposed to the air, oxidation, or scaling, as the common term is, rapidly commences, and no amount of sand, however carefully applied by the smith, will prevent the fatal contingency. A very small portion of the cleanest and purest sand obtainable may vitrify on the surface of the forging, and thus protect it, to some slight extent, from oxidation, but careful heating, and a prompt application of the steam *hammer*, are the best means of ensuring a sound weld.

"It is not requisite to dwell upon the fact that the fewer times a piece of smith's work is submitted to the fire the better, because few smiths are ignorant of it. It is a *sine-quâ-non*, indeed, to do as much at each heat as possible, and hence again the advantages of a quick eye and ready hand. It would be impossible to enumerate here the varieties of forgings, large and small, which may be, and are economically and effectively, produced by aid of the steam hammer. The interminable demands made upon the appliance in the establishment of an ordinary engineer, and the ready way in which they are responded to, prove it to be a veritable servant of all work, and literally a 'true friend at a pinch.' The class of smith-work in which the steam hammer is used to great advantage may be specified. It is that in which the welding on of swells or collars is the distinguishing feature. By hand labour this important branch of the smith's duty is always unsatisfactorily done. No dependence can be placed upon the work, however 'cunning' the hand of the manipulator. The steam hammer, on the contrary, with the assistance of proper tools, properly handled, never fails to make 'a good job' of such matters. The extensive use of blocks or dies in the shaping of small pieces of smiths'-work, and which tends to ensure sound and clean forgings, is due almost entirely to the steam hammer. It would be possible to add very lengthily to this list of valuable qualifications of the steam hammer, as an adjunct to both the peaceful, and the warlike sections of engineering—to do so, however, is superfluous. They are known and recognised by almost all practical men.

"Let us turn our attention, rather, to the best means of fixing or seating the apparatus, so as to ensure its stability and permanent usefulness. We have no hesitation in saying that, whatever the character of the soil may be, in the locality in which it is determined to place a steam hammer, the foundations for it should be composed of timber, the balks used ought not to be less than 10 in. or 15 in. square, and they should be from 20 ft. to 35 ft. long, according to the magnitude of the hammer. Framed together at right angles and bolted by rough spikes of iron, they should lie in at least six courses. The distance between the timbers must be left to the judgment of those to whom is confided the erection of the hammer, and depends somewhat on the nature of the sublying soil. The main object is to secure as large an area of surface foundation as circumstances will admit of. If this rule be attended to, there will be not only no subsidence after long working of the apparatus, but no tendency to that evil. The elastic nature of the timber courses will assuredly keep the bed of the hammer up to its original level, besides obviating the destructive jarring of the piston, &c., which sometimes manifests itself most disagreeably.

"It may be said that timber so employed cannot last very long; but many instances might be adduced of its having remained sound for over twenty years; and we have little doubt that carefully-selected pine, in a dry soil, would not deteriorate very much in half a century. It must be admitted that the foundation of a steam hammer has a great and important task to perform. Besides sustaining the weight of the apparatus when in a state of rest, it may have to sustain six times that weight if the hammer be in operation—to say nothing of the alternating shocks resulting from each impact upon the forging. Concrete may be used if the bottom upon which the timbers rest be soft, but if it be so introduced, care must be taken to put in a stratum of sufficient thickness, or it will crack, and fail to perform its mission.

"In some cases, it might not be improper to diminish the size of the timbers towards the surface of the ground. This would have the effect of concentrating, so to speak, the effect of the blows, and thus prevent an undue elasticity. The introduction of piles as foundations for steam hammers cannot, except in rare instances, be attended with practical good. Horizontal timbers, laid in courses, and covering a wide area, form, as we think, the best possible foundations for them. Thus provided, steam hammers will give out their powers most efficiently, their durability will be enhanced, and the cost of reparation will be minimized."

44. *Forging machines by pressure* have not been before thought of, and are not even yet appreciated as they deserve, because the fundamental principle upon which all successful forging of wrought-iron depends—namely, the law of arrangement of its integrant crystals, and hence the methods by which fibre, *i. e.*, elongated crystals can be produced and their disposition in length *determined*—is scarcely at all known; and if known, has not

yet been familiarized enough to practical men, so that they have not come to apply it in considering the construction of tools and methods of working.

There are many persons more or less connected with metallurgy who can discourse about "fibre" in iron, and who know some things about it accurately enough—so that they know it when they see it—that fibrous iron is tougher than crystalline—that fibre is generally found in certain makes of iron—that it is much more difficult to produce in some makes than others—that it is better produced by rolling than hammering, &c.; and who would probably make, besides, other propositions on the subject of doubtful, or more than doubtful, capability of proof, but who, if asked to say precisely *what is fibre*, or in what does crystalline iron (such as Swedish commonly appears) consist, and in what does such iron differ from fibrous iron, would find themselves completely at fault, and, perhaps, discover to themselves, for the first time, that they had been long talking and *acting* about something they could not define—that is, of the nature of which they had no clear idea.

While affirming that by the aid of the forging machine, actuated by pressure, we can produce fibre in masses of iron however large, we shall consider this subject of "fibre" in the words of an article from the "Practical Mechanic's Journal."

"I. All crystallizable bodies whatsoever, crystallizing or cooling from a high temperature, whether that of fusion or below it, have their constituent integrant crystals so arranged, that their principal axes (*i.e.*, the longest axes of symmetry) are in the directions of least pressure within the mass.

"This proposition may be stated more generally, and embracing a still wider truth of nature, but for our present purpose it is sufficient.

"II. All simple metals, in a state approaching chemical purity, are crystalline bodies, and when in mass and cooled from fusion, or a temperature near it, have their integrant crystals arranged in obedience to the above law.

"III. If the mass of metal, while cooling, be acted upon by no external force except gravity, and that of the free mutual attraction of its own particles, the principal axes of the crystals will be found, when the *mass* is cold, to have arranged themselves in the directions in which the wave of heat has passed off from the surface of the cooling mass.

"In a perfectly still atmosphere this is the same as saying, that the principal axes are found to be arranged perpendicularly to the bounding surfaces or contour of the mass. Thus a ball cast in iron (still more remarkably if cast in antimony or bismuth, or other such metals of great crystalline development) when broken through is found to have its crystals arranged as radii of the sphere, and hence perpendicular to the bounding surface of the sphere—that is, *in the lines of least pressure* within the mass—the pressure being that of contraction of the exterior cooling upon the interior—and *perpendicular to the surface of the escaping heat wave*, which here is a spherical shell, parallel to the surface of the cooling metallic ball.

"IV. If the mass of softened and heated metal be also acted upon while cooling, by extraneous forces, such as mechanical pressure, the final arrangement of the principal axes of the crystals is determined in accordance with the first law, still in the directions of least pressure within the mass; but these directions are now dependent upon the extraneous pressures (from without) as well as upon the interior pressures from within to (due contraction by cooling) act conjointly.

"Thus, in a cooling billet or parallelopiped of wrought-iron, the directions of the crystals within it depend upon A, the directions in which it has been compressed and extended under the hammer, and upon B, the final contractions in its cooling to the temperature of the atmosphere.

"V. Metallic crystals retain the property of malleability, and when aggregated in mass with their principal axes parallel, these may be elongated to any extent. *The parallel crystals so elongated constitute fibre.*

"Thus, in a billet (of Swedish or Low Moor iron for example) of 2 or 3 inches diameter, which presents nothing but a merely uniform mass of small crystals like lump sugar, when heated and passed once or twice through the rolls, these become all arranged in lines parallel to the length of the billet, that is in the direction of least pressure within the mass, which is one perpendicular to the grip of the rolls; and as the billet is extended into a bar, *these* crystals are elongated, and the bar becomes fibrous.

"VI. The extent of development of fibre, therefore, (with a given make of iron) depends upon the relative extent of distortion in one direction of the original form.

"We say 'with a given make of iron,' because some wrought-iron crystallizes much more readily and fully than others, with the causes of which, however, we are not here concerned—and those whose crystalline development is best—develop fibre best. If no other internal forces were brought into play by contraction in cooling of the bar, equal distortion relatively would produce equal amount of fibre, whether the bar were large or small. But as in *very large* bars these internal forces of contraction by cooling are great enough to become effective, so in such, a partial re-arrangement of the longitudinal fibre (*i.e.*, of the principal axes of the elongated crystals), takes place while cooling, and these in accordance with law I. The uniformity of the fibre is thus often more or less interfered with or even destroyed as the *large* bar cools. Thus it is that wire, rivet-iron, &c., present the finest examples of fibre. The elongation of crystals is the greatest in these small diameters, and their diameters are relatively so small that no internal strains by cooling are powerful enough in their small bulk to produce sensible re-arrangement of crystalline axis.

"Such in brief are the true physical laws of fibre in iron—stated so far, and so far only, as regards their production by rolling or forging, &c., in wrought-iron—and when clearly grasped, it will be found that the production of fibrous iron is no longer a mystery or a chance, sometimes to be hit upon, and sometimes missed, without our being able to say why; but that it can be *commanded* to any extent, and in whatever direction we may predetermine, by suitable applications of adequate external force to the softened metallic crystallizable mass.

"If fibre is to be developed fully and regularly in any piece of wrought-iron, however, the pressures applied to produce distortion (*i.e.* elongation) must be adequate, in relation to the size of the mass, and must be regularly and uniformly applied, and constantly, from beginning to end, in the same direction.

"It is by reason of these conditions being fully answered by rolling, and being most imperfectly met by hammering, that by the former process alone, can perfect uniform longitudinal fibre be produced in any wrought-iron.

"Rolling by the rolling mill is a process, however, that so far as existing machinery goes, has found its superior limit, for round bars or cylinders, at about 9 or 10 inches diameter, and even for plates or rectangular slabs at some 4 or 5 feet wide by 6 to 12 inches thick; and at these sizes, the relative distortion at each pinch of the rolls is so slight, that the production thus of fibre is almost nill.

"A billet of say 3 inches diameter and 3 feet long, is rolled hot into ½-inch rivet-iron, of which the cylinder will make when rolled out 36 × 3 = 108 feet long. Let us suppose this done uniformly by passing 10 times through the rolls; the relative distortion at each pinch is $\frac{36}{10} = \frac{1}{3\cdot6}$ of the preceding form.

"Again, a billet of 9 inches diameter and 3 feet long, is rolled into a 3-inch merchant round bar. It will be 27 feet long, and if it has been passed through the rolls 10 times also, the relative distortion at each pinch is $\frac{9}{10} = \frac{1}{0\cdot09}$ — or only 0·04 of what it was in the preceding example. We can easily see, therefore, that the amount of fibre produced in the latter case will be greatly less than in the former one; and, practically, this is to understate the case, because a far more powerful pinch is enabled to be given, when rolling small rod-iron, than is ever ventured in rolling heavy round bars, having regard to the chance of breaking machinery.

"But now the two bars are let to cool, and without going minutely into the subject of the internal strains or pressures produced by contraction, as unnecessary and for which we have not space, we may say that the distortion due to this may be proved to be greatly the more in the bar of large diameter, so that on the whole, in the big bar the fibre is originally worst developed, and in it, also, it is most disturbed subsequently in cooling.

"The latter condition must for ever come into play, in very large bars, as a disturbing element of structure, so that if we had the means of making, by colossal rolling or other machinery, a rod of rolled iron, of, say, a foot in diameter, that while hot should be as perfectly fibrous as a Staffordshire rivet-rod of half an inch, it yet would lose much of its fibre as it rapidly cooled in air, and *when* cold, if we broke it through, we should find crystalline planes, cutting across the fibres in many places, in directions transverse to the axis of the bar.

"This may be mitigated by very slow cooling—cooling in an annealing oven, in fact—diffused over a long period, but it can only be mitigated.

"We suppose we are not called upon to prove, on first principles, that fibre would be *desirable* in every mass of iron we employ structurally, however large, and most so where impulsive or rapidly applied and varying forces are those to which the material is subjected, as for the forgings now employed in iron ships, the parts of marine engines, of cannon, for armour plates, &c. Nor need we repeat that all these, as at present, produced under the steam hammer, are very little better than so much cast-iron. Not only have those vast masses outgrown even the forging powers of the steam hammer, so that the metal is defective in soundness, but no power of steam or other hammering can produce uniformity of fibre, or anything as to internal arrangement, except a confused aggregation of crystalline planes, with axes constantly varying during the progress of the forging, and at last, when it is finished, lying in all possible directions within the mass.

"To fix our ideas, however, as to the value of fibre, we may state that Mr. Edwin Clarke's experiments gave a mean of 20 tons per square inch *with* the fibre, and 16 tons per square inch *transverse* to the fibre, in boiler plate, and that the ultimate extension at rupture was twice as much in the first as in the second case. It therefore follows that the value of the co-efficient T_r, that is to say, the 'work done' to produce rupture, which is the true measure of the resistance of iron in all cases, is in each case thus—

	T_r.
With the fibre, or in the line of the principal axes of the constituent crystals, . .	= 224·84
Transverse to the same, . . .	= 30·47

or about $7\frac{1}{3}:1$——

"The latter co-efficient is also about that which the best ex-riments give for the resistance of wrought-iron in great forgings (shafts, &c., &c.), so that if we could only make the latter fibrous, we should increase their *value more* than *seven fold*.

"This arises from the fact that

"VII. In iron (and no doubt in all metals) the principal axes of the metallic crystals are also the axes of maximum elasticity.

"The co-efficient of which, we may remark, appears to increase in value rapidly with the absolute elongation of the crystalline axes, by lamination, by pressure, or wire drawing, &c., as the crystals assume the distortion form of fibre.

"Here, then, is the future of the forging machine—this its destiny, to give us as good, or nearly as good, material in the largest, as we are already able to obtain in the smallest size of wrought-iron.

"To effect this, it presents us with two chief conditions, alike wanting to the rolling-mill and to the steam hammer, between which it seems to come in, as a sort of immense middle term, viz., power adequate to any assignable requirement of squeeze, both in force and range, and perfect uniformity of action in a determinate direction, which may continue until the piece shall assume its final or finished form. Thus, by the necessary change of form operating throughout the mass, movements shall be produced simultaneously in all its particles, and so fibre become developed *in the direction of greatest extension*, in accordance with the laws we have developed.

"This view of the important function of the forging press, we apprehend, has been grasped by Mr. Haswell, of Vienna, who has probably become acquainted with the exacter notions of metallurgic science which are familiar in Germany, though so little met with amongst ourselves.

"In any case, this is the all-important direction in which to look at the machine. It is one, at the same time, that has certainly so far quite escaped recognition in Great Britain, for the idea of a forging machine by pressure is not by any means new."

"Mr. Haswell's press consists of," says the "Engineer," "a very large horizontal steam cylinder, the piston within which, by means of a rod or ram projecting through each cover, works two very large force pumps for getting up the pressure in the press; this has a large ram, upon which the water is forced to bring it down, and a smaller ram above, connected by a crosshead and side rods to the larger ram, to bring the latter up again after each blow. The various valves are worked by means of small steam pistons in supplementary cylinders. Mr. Haswell states that this press will deliver its blows with nearly the rapidity of a steam hammer, and we understand that he has brought a 11-inch square ingot of Bessemer steel down to 4 inches at a single pressure, the largest steam hammers employed in Sheffield having nothing like this amount of power. Mr. Haswell, too, has pressed out a locomotive piston *and rod*, at one stroke, from a single bloom.

"Henry Dubbs, in 1853, patented 'A method of forging iron and steel by the application of hydraulic pressure by gradual compression, in place of by sudden blows or concussion' (No. 2,116, 1853), and proposed to apply his method to making locomotive engine and other wheels, tyres, cranks, cranked and straight axles, &c., &c.; but he does not suggest, by one syllable, that he entertained the least idea that in his method lay concealed the power of improving the quality of the iron in the act of forging it.

"Two new forms of forging press have since been produced besides that of Haswell, viz., that of Messrs. Shanks & Co. (patented 1862, No. 2,908), for improvements in hydrostatic presses; and Mr. E. B. Wilson's patent (1862, No. 3,398) for another form of the machine. . . .

"Messrs. Shanks & Co. describe their machine as follows:—Our improvement consists in making a hydrostatic press worked by steam power, in such a manner as to exert the direct pressure of the steam upon the water in the main cylinder of the press, by opening a free communication between this cylinder and the boiler, and move the ram by this direct pressure until the resistance of the object operated upon be equal to this pressure, at which moment steam is admitted under a large piston operating on a ram of smaller diameter in communication with the main ram, so that the motion of the lesser ram produces on the larger one an increased pressure in the ratio of their respective areas.

"Messrs. Shanks' design is for a press," says the same authority, "intended to exert a pressure of 3,000 tons, through a dis-
nce or stroke of 5 inches. He has a vertical steam cylinder,
feet in diameter, and having an $8\frac{3}{4}$-inch piston-rod, or ram,
rking with the full stroke of the piston, or 5 feet, through
upper side. With steam of 200 lb. pressure per square inch
on the under side of *the piston*, this ram will rise with a force

of about 250 tons. Water will be pressed over at this pressur equal to upwards of $4\frac{1}{4}$ tons per square inch, upon a 30-inc piston formed upon the head of the ram of the forging press, thi ram descending 5 inches for the 5-feet rise of the pump-ram o the upper side of the steam piston. The ram of the press ha an annular area upon its under side, and upon this a constant pressure of very high steam is maintained to bring up the ram after each stroke. The water employed in forcing down the ram returns then into the chamber of the $8\frac{3}{4}$-inch pump-ram, circulating to and fro at each stroke without loss. There is no doubt that, upon this arrangement, any required number of strokes of the press-ram could be made per minute, and the pressure, moreover, could always be nicely graduated according to the requirements of the work. A motion of 5 inches, with an adjustable anvil, is considered quite sufficient for all work.

"Mr. E. B. Wilson's machine, which, under the title of 'Machinery for forging and pressing metals,' he denominates his Patent Combination Press, the water cylinder, or ram, is reduced to a comparatively small size, and the pressure from it is increased by the intervention of the lever. This machine cannot be further described without the aid of drawings, but for a full description of such, we refer our readers either to the patent specification—the numbers of which are given above—or to the *Practical Mechanic's Journal*, Parts 184—186.

"Besides the above forging presses, we understand Mr. Bessemer is also bringing out a powerful one for his large works about to be erected near London. The following are the conclusions come to on the subject by the writer in the *Practical Mechanic's Journal* :—'To us it appears that so far, Haswell's is the best forging machine produced; but we are by no means of opinion that a perfect machine has yet been designed by any one. Such a forging machine would, as we conceive, demand that the following conditions should be fulfilled:—

1. The power should admit of indefinite variations and extensions, up to the limits of strength of the parts.
2. This must be independent of the length of stroke at any moment, or of the range between ram and anvil.
3. The movement of the ram should admit of variation in velocity, without a necessarily corresponding reduction in power. That is to say, the nature of the squeeze required

is something between a blow and a slow squeeze, and it should be capable of having, at will, more of the blow, or more of the squeeze.

4. The time consumed in raising the ram after the squeeze should be the least possible — certainly as quick as in the steam hammer.
5. There must be no time lost in giving the squeeze, *i. e.*, in the coming down of the ram. This will be indispensable in presses to be applied to welding on the great scale.

"'These two last conditions will be more difficult to fulfil with lever than with direct acting presses, however constructed. We might add to these some other conditions that must be met, and that involve no important difficulties, in order that the machine may be applicable to the production of fibre in forgings on the great scale—as, for example, in armour plates and gun moulds, to which it appears to us these machines present the offer of striking ameliorations.'"

◆

DIVISION FIFTH.

CABLES, CHAINS, AND ANCHORS.

45. Nothing is of greater importance in mechanical engineering than the manufacture of chains, so that they will be certain to resist the strains to which they are subject. In every case where a chain is applied, some article or weighty piece of merchandise is being raised, sometimes of a valuable and fragile nature; in other cases, a heavy piece of machinery is being lowered into the hold of a ship, or the ship itself may be riding a gale at anchor. In all such cases, the total safety of both life and property depends on the soundness of such chains or cables, and anchor or hooks; this being the case, too much care cannot be exercised in the manufacture, and too rigid an examination and proof cannot be applied to them. In this department is the axiom specially worthy of remembrance—the strength of any body is decided by its weakest part.

46. Lately, this matter has been much agitated among underwriters and shipowners, and the consequence has been the erection of a most efficient proof-house by Lloyds, where they have undertaken, for a trifling sum, to prove all chain cables and anchors

brought to them for that purpose. This proof-house was erected nearly two years ago, under the superintendence of T. M. Gladstone, C.E., in the New Road, Poplar, London. The following is a description from the "Engineer:"—

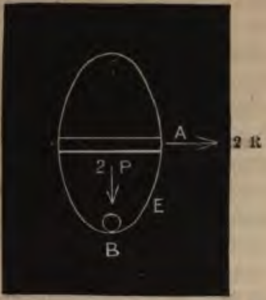
"Heretofore chain cables have been tested in lengths of 12½ fathoms only for the navy, and 15 fathoms for the merchant service, these lengths being afterwards connected by shackles up to any length required. Mr. Gladstone prefers, however, to prove from 60 to 75 fathoms at a time, and the proving-house, of galvanised iron, is nearly, or quite, 500 feet long. At the southern end are the offices, weighing machine, hydraulic press, and pumps. A railway extends the whole length of the building, and there is also an iron trough, about 18 inches deep, running the same distance, and in which the cable is placed when under strain. All the mechanical operations of handling and proving chains and anchors are performed by a steam travelling apparatus, designed by Mr. Gladstone, and called the Dromedary. This is a substantially made steam crane, mounted upon a four-wheeled truck, and, furthermore, provided with means for its own propulsion as a locomotive, and also for underrunning cables, and for driving a set of hydraulic pumps. As a crane, this machine will lift, swing, and lower 10 tons. Stationed near the pumps, and working through a universal joint, it will, in a few minutes, get up any required strain up to 300 tons in a length of 75 fathoms of cable, and in other ways it is so serviceable that but six or seven men, including engineman, smith, and labourers, are employed in the entire work of bringing in a cable or anchor from the docks, and testing, repairing, and delivering it again. The cost of the Dromedary, we are informed, is but £650. The cable is hauled out of a barge afloat by a light windlass, and coiled upon a truck. This is taken by the Dromedary into the proving-house, and slowly down the line of rails abreast of the trough in which the chain is to be laid for proof. During this journey of the truck, which occupies but a few minutes, over the distance of 450 feet, the cable is let off, by the same light windlass, and deposited upon the floor. A large broad-grooved sheave, suspended from the jib of the Dromedary, is then got under the cable, and with the sheave properly adjusted in its position, the Dromedary underruns the *whole* length of 75 fathoms in about 2 minutes, thus hoisting the cable into the trough without its being touched by hand. The trough is nearly, or quite, 2 feet wide, and has iron sides of a total section of nearly 60 square inches. These are fastened by stout flanges at the bottom to the heads of piles, driven deeply into the 'made ground.' At every 15 fathoms there is a cross-bar, so that 15, 30, 45, 60, or 75 fathoms may be tested as required, the longer lengths being preferred for convenience. The cable, being made fast at one end to one of the cross-bars of the trough, and at the other to the cross-head of the hydraulic press, is ready for testing. The hydraulic press is horizontal, and forms one end of the trough. It has a bore of 16 inches, and a piston-rod of 8 inches diameter, the annular area for pressure being thus about 150 square inches. The press cylinder is long enough to allow of a 10-feet stroke. The highest intended pressure is 2 tons per square inch, equal to a total strain of 300 tons, but the 2¼-inch cables of a 3,000-ton ship require a proof strain of but 91 tons, and the proof of even the Great Eastern's cables is but 167 tons. The permanent friction of the press, which friction is not much affected by the pressure to which it may be worked, is 11 cwt., and it is seldom that a greater pressure than half a ton per square inch requires to be applied by the pumps. The Dromedary being run up alongside these, and a universal joint slipped upon the pump-shaft, the pressure is quickly got up. A machine for exactly weighing the strain applied is fixed in a room near by, and from which there is a view of the whole length of the cable. The pressure of the water is received through a small copper pipe upon the end of a gun-metal plunger, ¾ of an inch in diameter, attached to a scale beam provided with moveable weights. The strain is increased until the scale beam rises under the proof weight, when the cable is struck four or five smart blows with a sledge hammer at about the middle of its length. No accidents have yet happened to the workman striking these blows; but we should suggest a falling weight, to be released by a trigger tripped by a long cord. The strain is kept on three or ur minutes, during which the cable is carefully examined roughout. When breaks occur, it is almost always at a weld, d a large number of links never welded through one-tenth of eir cross section have already been found since the proofs com- enced last November."

47. At the Society of Arts a very interesting and able paper on the *Testing of Chain Cables* was read by Mr. F. A. Paget, C.E., of which the following is an abstract. After alluding to the importance of the subject, and to the difference of opinion amongst practical men as to the points involved in the strength of a cable, and as to the tests to which they are to be subjected; and to the fact that there is a remarkable loss of the original strength of the iron in forming it into the links of a chain cable, Mr. Paget proceeds to show the several reasons why this loss of strength is sustained. Of these he says the principal are—"1st, The mechanical shape of the link; 2d, The crushing stress undergone by the insides of the crowns; 3d, The deterioration in strength of the iron through its being bent; 4th, The loss of strength at the welds.

"In the first place, each link is, when the cable is pulled in the direction of its length, subjected to a transverse strain at each of its ends or crowns, and is somewhat in the condition of a curved beam loaded in the middle. An originally curved beam is, with regard to bending stress, in the same condition, at any cross-section at right angles to its neutral surface, as a straight beam under the same moment of flexure. The moment of flexure of one end of a common unstayed link can be expressed in inch-pounds by multiplying half the span, or half the distance in the clear, by the load in pounds. In the case of the stayed link, however, the moment of thrust of the cross-stay has to be subtracted from the moment of the bending force. The mechanically weakest part of any link is thus at the crowns.

"For the sake of simplicity, let us suppose the cross-sectional area of the link as infinitely small compared with its major and minor axes, and suppose it provided with a cross-stay. Let 2P denote the whole pulling force; 2R the thrust of the stay; T the tension at A. For the equilibrium of the quarter link, B, E, A, we have the forces P, R, T, and the forces at B, arising from the left-hand quarter at A. From symmetry this must be horizontal (in the figure), and we must therefore have:—Force at $B = R$, and $T = P$. The moment of the bending force at B is therefore not $P \times oA$, but only $P \times oA - R \times oB$. On the other hand, when the link is on the point of breaking by opening at B, the tension will not be equal to the ultimate tension through-

Fig. 3.



out the section at B, but only at the lowest point, and when this has given way a little, the tension, previously supported, is thrown on a fibre higher up, which then gives way, and so on. Hence the strength is less than if the tension were throughout the section as great as possible.

Fig. 4.

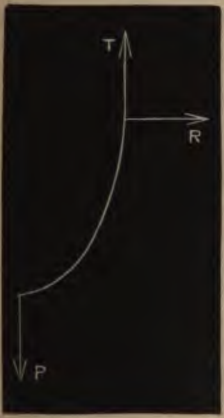
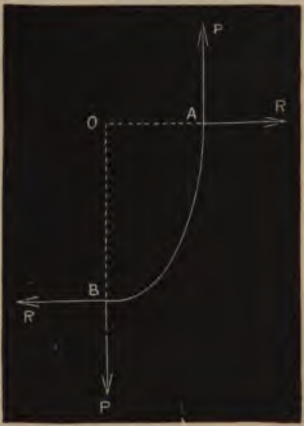


Fig. 5.



"Now, it is a curious fact, that all the writers on the strength of materials, from Professor Peter Barlow, Mr. Edwin Clark, and others, down to General Morin, in 1862, give the strength of a link furnished with a cross-stay to be equal to that of the iron of which the link is made.

"In a mathematical sense, the contact between the links is only at a point, because it is a case of two cylinders touching each other at right angles. Under a load, this point will spread out to a surface of an area given by the amount of the load and by the compressibility of the iron. This surface will then probably increase, in the case of a 1 in. cable under a load of nine tons, up to more than half a square inch. And thus at the ends, the softer and more ductile the iron, the sooner will it be worn away in practice, and the progressive deterioration caused by this crushing action will also be furthered by the friction."

After glancing at a few of the points which apparently are concerned in the cause of a cylindrical bar of iron being reduced in strength by being bent into a curved form, and after expressing the opinion that—although much of it rests upon unproved assumptions —"the molecular arrangement of the iron at the crown of the link is in the worst condition for resisting the tensile and compressive strains on each side of a neutral axis, that make up the compound action of a transverse stress"—Mr. Paget proceeds to point out, that although it thus appears that the crown of the link is the weakest part, it is, however, "very far from being practically the case. Each link has, of course, to be welded up, and the weld is in one of the sides, with a long scarf, in order to get a large welding surface. When we recollect that there are, in round numbers, 1,800 links, and, consequently, 1,800 welds, in a 1-in. hundred-fathom chain cable, and also that the efficiency of the cable depends on each individual link, the paramount importance of the welds is obvious. In nine cases out of ten, while in use and while being tested, the links are found to give way at the sides. Breakages would have a tendency to occur at the welds with good iron but bad workmanship, and in the iron, and not in the weld, if good workmanship but bad iron be employed. The uncertainty of welds is, in any case, well known to practical men. Mr. Kirkaldy has made some eighteen experiments on the relative strengths of welded joints in wrought-iron. Some of these welds were made by a chain-maker. Only six of the specimens broke *solid* away from the weld, and in every case there was a loss of ultimate breaking strength, averaging from 2·6 to 43 per cent., the mean being nearly 20 per cent. As with almost everything else belonging to the subject of chain cables, one of the witnesses before the Committee of 1860 raised the question whether the position at one of the sides was the best for the weld. Mr. Smale, of Woolwich, proposed to weld the link at the crown, as there would thus be more room for the smith, and any bad weld would be less hidden by the cross-stay. The crown is, however, as we have seen, *ab initio*, the weakest part of the link. Besides, if a weld at the side gave way, the other half might catch and save the cable; at the same time, however, a sudden giving way at the weld would cause an instantaneous distortion, and probably rupture, of the opposite side, as the sudden 'run' of the cable would act with an impulsive force. In fact, when iron cables were first introduced, the welds were made at the crown, but the plan had to be given up. It is clear enough that there are, *cæteris paribus*, three weak places in a link where any effects of stress would first show themselves—the two crowns and the weld at the side.

"We thus see what a powerful element of uncertainty is brought by the uncertainties of workmanship, into such an apparently simple thing as a chain cable. When, however, we remember that the very best wrought-iron of commerce is, to use the words of the well-known metallurgist, Saint-Claire Deville, but a metallic sponge, like platinum, the pores of which have been simply closed up by pressure or percussion; that, in one word, ordinary wrought-iron has never, as wrought-iron, been fused, it will be seen that the uncertainties qualifying the material itself are still greater. Mr. Mallet thus found that while the original hammered slab of a very large forged mass had a breaking strength of 24 tons to the square inch, it fell progressively to 17 and 16 tons at the different places of the mass, down to even as low as 6½ tons in some parts. Unless this iron had been burnt, its tenacity could doubtless have been restored, and if drawn into wire, its breaking weight might have been increased to perhaps 90 tons to the square inch—at least before annealing. An average of 188 experiments made by Mr. Kirkaldy on rolled bars, gave a maximum breaking strength of 30¾ tons, and a minimum of nearly 20 tons to the square inch. These influences of the manufacture merely on the quality of wrought-iron, are almost independent of the chemical constitution of any individual bar. For instance, until it be proved to the contrary, there are many reasons for the general belief that the cold shortness of wrought-iron is due to the presence of silicon and carbon; and its hot shortness to that of sulphur. A fractional per-centage of copper also makes wrought-iron hot short. In truth, there are probably no two bars or parts of a bar of an exactly similar chemical composition, or in an exactly similar state of molecular aggregation, and therefore of an exactly similar breaking strength or elastic limit. Even these are only a few of the elements of uncertainty in structural materials. But when we further take into account the varied strains of extension, compression, distortion, twisting, and bending, to which mechanical structures are more or less subject; that the work done by a gradually applied load is doubled if this load be applied suddenly; that the impulsive strain of a moving load is generally more or less intensified by vibration; and that the varied shapes and arrangements intended to receive these strains must be often as much fixed by financial as by scientific considerations, then the reason that the best engineering practice makes the ultimate strength of a wrought-iron structure from four to six times the working load must be even popularly evident. But these factors of safety are not sufficient. The structure must be tested as searchingly, and as far as is consistent with safety—as far as is possible without injuring the material and its relation to the structure. In our case this limit is, in the main, given by the limit of elasticity of wrought-iron under extension, as this limit is less for wrought-iron than that of compression. It is also self-evident that the mode of testing adopted ought to approximate as nearly as practicable with the kind of stress the object is intended to undergo in practice. It is also evident that if circumstances allow us to exceed this limit, if, in fact, we can push the test as far as the breaking strength of a portion or of an individual piece of the object, we shall obtain the safest amount of information about its qualities. In this way guns and plates . . . . are both tested to destruction. . . . . If the numerous experiments that have now been made on iron do prove anything, it is that the breaking strength does not *indicate the* quality—the breaking strength must be taken conjointly with the elongation. The true measure of the mechanical value of wrought-iron is simply the sum of the products of the successive loads and the increments of elongation—in other words, the resilience of the bar or the deflection of the beam, or the work performed in producing the stretch or deflection. We thus see the value of Poncelet's symbols T_e and T_r, advocated with much ability in England by Mr. Mallet. Upon the just balance of strength of fibre, or high breaking strength, and extensibility or ductility, depends the mechanical or structural value of iron.

"The navy test for chain cables is stated to be the result of a number of careful experiments by the late Sir Samuel Brown, and it was adopted by the Admiralty in 1831, when chain cables were fairly established in the royal service. The test adopted by the French navy is almost exactly the same, and in Russia and the States it is exactly the same, as both those countries use our own measures and weights. Every chain cable is proved by a gradually applied stress of 630 lb. for each circular one-eighth of an inch of the area of the bolt of which the cable is made, or 11·46 tons to the square inch on each side of the link.

"Assuming that a link is subjected in practice to a tensile stress, and as the proof strength is generally fixed at double the working stress, this would correspond to nearly 5¾ tons on the square inch. There is thus a very close correspondence between the working stress assumed for chain cables and the Board of Trade limit of 5 tons to the square inch, imposed about sixteen years ago, for both the tension and compression of the wrought-iron of railway structures. The chain cable of a ship is also evidently subjected to impulsive forces. It is true that a ship, when struck by a sea, in most cases merely lifts the weight of her chain, the catenary curve of which thus acts as a kind of water brake; but a very heavy sea must occasionally bring a sudden pull on the cable, and in shoal water the sudden strain must be almost solely taken up by the resilience of the cable, or rather by the deflection of the series of beams composing the cables. Much security is, however, afforded by the fact that a cable is generally only strained during a brief interval of time. But few cables can stand a sudden nip at the hawse-pipe; and we thus see that lateral as well as longitudinal strength is occasionally required in a cable. . . . . When the *cable itself* is placed under the dead pull of the press, it is tested in three different ways. It is fi strained up to 11·46 tons in the square inch sectional area acr the double section of the link. While for about three or fo minutes under this stress, the cable is subjected at different par of its length to blows from a round-faced hammer. Differe sized hammers are adopted in proportion to the size of the chai and each fathom generally receives one blow. Each link is the carefully examined. Two or three links are broken up to detec by its bluish tinge, if the iron has been at all burnt in the worl ing, and also to make some estimate of the quality of the iro from the surface of the fracture, and the other appearances know to engineers. Some difference of opinion also exists, both i France and in England, as to the amount of security afforded b these tests, and whether the test of 11·46 tons on the square incl and more especially the blows of the sledge, do or do not inju the cable. . . . . .

"Now, there can be no doubt that the proof of 11·46 tons t the square inch is not enough of itself to test the quality of th workmanship, or, more definitely, the perfection of the weld For this reason Mr. R. Bowman advocated before the 1860 con mittee an increase of the test. It is clear that, as the sides a only tested up to little more than 11·46 tons, and as they woul break at only, say, 24 tons to the square inch, less than on half the sectional area of the iron would stand the test if applie only tensionally. As, however, through the cross-bending strai at the two ends, the link slightly tends to assume the shape a lozenge, the weld is more severely tested than would at fir appear. There is a certain difficulty in detecting a bad wel upon the nature of which some practical light has been throw by some experiments of Mr. Kirkaldy's on bars grooved roun their circumferences. The matter generally had been previousl investigated by the writers on elasticity, but Mr. Kirkaldy wa the first to practically test the question. Bars grooved at an particular part down to a given diameter, gave a much high ultimate breaking strength than bars of a diameter all throug equal to that at the reduced part of the grooved bar. The wid parts on each side resisted the tendency to draw out, and a gre apparent strength was thus obtained. The extent of this appare *gain* was as much as 37½ per cent. in some of the pieces, whil the average gave 18·63 per cent. in favour of the grooved specimen. Here, again, we see the falsity of taking merely the breaking strength into account, for although the breaking strengths were thus increased, the elongation and the contraction of area attendant on elongation were proportionately less. It will thus be seen that a bad weld may be impaired by a strain in excess of the elastic limit due to the quality of the iron and the cross sectional area of the solid metal; and that, although it is thus injured, it may not show signs of the injury. On the other hand, some security is given that a bad weld may be detected, from the fact that rolled iron is well known to be somewhat hardened by being hammered, and the welded-up side of the link would thus be less extensible than the opposite parallel side, and would thereby be rather more strained. It is evident, however, that though the test can scarcely be too high for the welds alone, the proof of more than 14 tons to the square inch, proposed by M. David, would clearly be too high for the cable. M. David, indeed, stated that he tested his cables up to this amount, but it appears that the pressure he used was not accurately measured. Indeed, there is no doubt that very few cables would stand the ordinary proof if repeated sufficiently often, or if it were put on and eased off a succession of times, upon the plan shown by Dr. Rankine. As it is, the permanent set taken by cables is, on an average, from 4 feet to 6 feet in 90. But the best proof that this single application of the test for a short time does not injure good chain cables, is seen in the fact that it has been adopted all over the world for more than 30 years. We are, however, in a dilemma. To increase the proof would evidently be to injure the link, while the detection of a bad weld has, in any case, to encounter the difficulties just mentioned. These questions can only be met by a most careful inspection of each individual link. The quality of the iron can also be very closely tested by breaking up two or three links. The most searching tests, however, are the hammer blows given while the chain is under tension. Adapting a well-known and excellent illustration, this will be at once ident when we remember that a $1\frac{3}{4}$-inch chain cable, made of ass, would give the same ultimate gradually-applied breaking rength as a 1-inch iron cable, but it would not be likely to stand e hammer test. On the other hand, a cable of indiarubber, although not to be broken by the hammer, would at last be torn in two by the press. In fact, the hammer test approaches nearer than any other to the kind of work that will have to be done by the cable when at sea. Besides, the mere form of a chain renders it, *per se*, liable to continual shocks and jerks, and this must be encountered by a special quality of material, and that this material has really been used must be shown in the proving-house."

Mr. Paget proceeds to point out a few very interesting facts connected with the changes in the condition of iron through changes in the temperature to which it is subjected; and, after stating that the points involved are of the utmost importance in practice, he refers to the *re-testing* of chain cables, on which he has the following:—

"The question as to the re-testing of cables that have been in use for a certain time is yet unsettled, but the inquiry is of scarcely less importance than that of the first testing. There are many applications of wrought-iron in which it is subjected to impulsive stresses, often more or less accompanied by vibrations, and in which, nevertheless, the detail or structure has to conform to certain narrow limits of size and weight. Such is the case with most applications of chains; for instance, to cranes, inclines, forge-slings, &c. Such is the case, also, more or less, with railway axles, the axles of carriages on rough common roads, the gags of helve hammers, the porter bars fixed to the blooms while under the hammer, the iron wires of some pianofortes, and many similar applications of wrought-iron. The simple fact that only one-half of the gradually-applied stress required to produce the proof strain will, if applied suddenly, of itself produce the proof strain (which, if exceeded, would injure the piece), goes a long way in explaining the matter. Where great interests of life and property are involved in the safe action of these applications of iron, the irresistible logic of facts has sometimes caused preparatory allowances to be made for these 'fatigues of the metal.' The axles of the London omnibuses are stated to be always renewed after having run a certain fixed mileage. This system is also carried out with the carriages of the Messageries Générales, the axles of which are changed after having run a limit of 40,000 kilomètres. The Honourable the Corporation of the Trinity

House entirely renews all the moorings of the light ships every four years—one-fourth of the number yearly. This limit of time gives the measure of the perfect efficiency of a good cable, well proportioned to its work, and in constant use day and night. Cables in ordinary ships are, of course, much less, or rather much more slowly, subject to deterioration. We have seen that M. David fixed the time after which a cable in ordinary use should be tested at ten or twelve years. Mr. Macdonald, of the Liverpool testing-house, stated, before the 1860 committee, that he would examine a cable after any long voyage—such as to India or Australia. The late Mr. Green, the great shipowner, explained that this was done with the mooring tackle of all his ships. An experienced pilot, Mr. G. J. Thompson, said that it should be made imperative to re-test chain cables every six years, and Mr. Smale fixed this limit at seven years. Mr. J. R. Clarke, however, the chief clerk of the store-office, stated that there were many sound cables in store twenty years old. It is clear that it would be very difficult to fix a limit of time that could be applied to all classes of ships. The cables in the royal ships are scarcely so often or so severely tried by use as those of some merchant vessels. A cable might remain good for many years, and yet at last be injured in a single storm. Apart from accidents, such as abrasion on rocks, or against a sharp-cornered anchor-stock, or similar causes, there are three main conditions affecting the duration of cables, and furthering their progressive deterioration under wear—First, the friction and abrasion at the crowns; second, rust and corrosion by the sea water; third, undue strains on the cable, and in excess of the compressive and tensile elastic limits of the materials. The average amount of abrasion and consequent wear at the crowns could only be determined by a statistical comparison of the deterioration of a number of cables, worked under similar circumstances, through a certain period of time. No full observation of this kind seems to have been yet made. The same appears to be the case with the deterioration of iron cables by rust and corrosion. Mr. Mallet has observed 'that the metallic destruction by corrosion of iron in sea water is a maximum in clear sea water of the temperature of 115° Fahr., that it is nearly as great in foul sea water, and is a minimum in clear fresh river water.' It *also appears* that the finer and more equable the quality of the iron, the slower is its corrosion. The alternative action of the air and the sea water on ordinary cables mus have great influence in their deterioration. Again, at a depth of, say, 100 fathoms, there would be a pressure of nearly 17 tons on the square foot, and this pressure would search out any slight crevice, or any slightly defective weld that had escaped the test. It is at these places that the corrosive action of the water is most felt. It is a well-ascertained fact that the spongy mass of mechanically-compressed crystals we call wrought-iron is porous as water can be forced through it at comparatively moderate pressures. It is also well known that the hydrated oxide of iron we term rust performs the part of an electro-negative element when in contact with metallic iron, which is then electro-positive. When iron is rusting in the air, the moisture of the atmosphere is the exciting liquid, but this voltaic action must be greatly intensified in the presence of sea water. I have noticed the interesting fact—which deserves more investigation than I have yet been able to give it—that in the links of a great number of chains the wrought-iron is much more eaten away at the sides, where it is in contact with the cast-iron cross-stay. The same action was stated, in a number of the *Times* of last year, to have been observed on the wrought-iron tie-rods in contact with the plates of a cast-iron sea water tank which burst last June at Woolwich. I had lately occasion to examine a number of old chains, after they had been cleaned, and after the rust had been knocked off with a hammer. All the cast-iron cross-stays, almost without an exception, were slack. Each link was thus temporarily reduced to the condition of an unstayed link, the ultimate strength of which, compared with a stayed link, is generally taken to be in the ratio of 7 to 9. When the cable is in use, the progress of this undoubtedly voltaic action in weakening them will be aided by mechanical causes. The rust generated between the cross-stay and the sides of the link will be more or less washed out by the surge of the cable; a sufficient longitudinal stress would cause the virtually unstayed link to collapse on the stay; the sea water would again search out the chinks; would again decompose the material; and the deterioration of the cable thus chemically and mechanically weakened, would progressiv advance in successive increments that would render its ultim destruction a mere matter of time. This action would be, of course, more felt in a cable in constant use, such as those of the Honourable the Corporation of Trinity House; and whether zincing, which is stated by Dr. Percy to prevent rust, would be of any use, or whether other means, which will doubtless occur to many here, might prevent, or at least modify, this action, is perhaps a question worthy of investigation by the able men comprising the Trinity Board. There is, however, no need to search amongst the mysterious forces of nature for the main cause that leads to the ultimate destruction of a cable, or of any other application of iron, under like conditions. The primary cause of the destruction of a cable is simply due to the limit of elasticity of its material being exceeded. All chains are, by their very structure and special uses, subject to jerks and shocks; any country blacksmith knows that a chain that can stand a dead pull would give way under the same weight if suddenly applied; and we all know that a careless labourer at the winch handle of a crane sometimes breaks down a good chain by a heedless jerk. Little more than 5½ tons to the square inch, if suddenly applied, would at once bring on the proof strain of 11·46 tons; and although the dead weight of a cable is its great safeguard—so much so, in fact, that if the cable out of the hawser could be weighted at different parts of its length, this would be an advantage—yet, nevertheless, the safe load of about 2¾ tons, under an impulsive stress, to the square inch, must be often exceeded in practice. The safe load under an impulsive stress is, in truth, rather less, as the assumption is based upon the usual notion, which assimilates a cross-stayed link to a couple of bars. . . .

"Whatever be the internal effect of the lateral contraction induced by excessive tensile strains, it would be of the utmost importance to settle, once and for all, whether *re-annealing* can restore the living force of resistance of iron, and, therefore, of a cable. Mr. T. M. Gladstone, C.E., recommended this plan before the committee of 1860. Mr. Smale, then of Woolwich, said that this would be like Burnetising rotten wood. Dr. Noad, in a letter to the *Times*, about eight years ago, stated that he had taken away the brittleness of an old chain by keeping it for twenty-four hours in a furnace. The late Mr. Glynn recommended that a crane *chain should* be annealed every three years.

At the North Roskear mine, in Cornwall, it is stated by M. Moissonet that the pit chains are withdrawn from the shaft after every six months' use, are rolled in a heap, then covered with a sort of cylindrical furnace, and brought to a red heat. According to an account translated from the Russian into the *Polytechnisches Centralblatt*, the chain cables for the Russian government, after being brought to a dark-red heat immediately after testing, are then tarred—a plan which is said to prevent rusting, as the tar thus takes a firmer hold on the iron. But many things may be done with charcoal iron that it would not be safe to attempt with our ordinary iron. Baudriment appears to believe that all metals only acquire determinate qualities by proper annealing, and that a cherry red heat is necessary for annealing wrought-iron. According to the experiment by the Franklin Institute, wrought-iron is perfectly annealed at a clear bright red. The experiments of both Baudriment and the Franklin Institute show that the ultimate tenacity of iron is considerably diminished by annealing, but, unfortunately, in neither case was the elongation noticed. Poncelet has shown that his co-efficient T_e, of elasticity is increased with annealed-iron, but that the co-efficient of rupture, T_r, is diminished. This refers to wires, and no complete experiments appear to have been yet made on the effect of annealing on bars. It is a question whether the extra ductility conferred on the links by the process of annealing would not, while rendering them more ductile, at the same time lead to the changing their form. At any rate, at least some of the cast-iron cross-stays would be rendered less able to withstand distortion. At the same time, the question ought to be settled, and to cables comparatively uninjured by corrosion, the process might prove of great value. The conditions of size in a cable are peculiarly favourable to the use of annealing. Great as the advantage would be in the successful application of annealing to large forgings, there are several well-authenticated instances of massive crystals being developed in the interior of the mass by the long-continued action of a red heat. General Morin thus mentions an instance of the production of crystals, with facets from four to five millimetres in breadth, in a charcoal iron bar originally of fine, soft, fibrous texture."

48. The extended use in practical engineering of *iron and*

steel wire ropes—as in steam-ploughing, in collieries, &c., &c., renders it of great importance that all questions affecting its strength and economical working should be well understood. The following is an abstract of an article from the 'Engineer,' which discusses in a very clear manner many of the most important of these. For the *article in extenso* see *No.* of *Engineer* for Aug. 26, 1864.

"If a wire rope, instead of being a set of spirally-laid wires, were made of a bundle of parallel wires, only the wires on the outside would stretch when wound on a drum, and these wires would, therefore, be broken, or at least strained in excess of the limit of elasticity. The spiral form, however, by which one and the same wire is wound in and out, equalises the tension for the different wires. The first wire ropes appear to have been made in Germany about thirty years ago. They were made without any core, and of strands consisting of four wires each. The absence of a core required the use of wires of a small diameter, and it also limited the size of the rope. It is difficult to make a rope of a rather large size, and it is scarcely possible to form a strand of a larger number of wires than four, without the use of a core. The core keeps the spirals of wire in their places, and when the core in a wire rope gives way, a kink generally forms itself at the place, which easily leads to a rupture of the rope when it is bent round the drum. A hempen cord, or a rather thicker wire, forms the core of the strands, while another hempen core is placed in the centre of the rope. The strands form spirals round the core, which is straight. The tension on the rope increases the pitch of the spirals, while the core undergoes a longitudinal strain. It is pretty clear that, under ordinary conditions, the core is more liable to give way, as it cannot yield so easily to the strain. It is not improbable that when, as with smaller ropes, no hempen core is used, a better rope would be made by carefully putting more elastic iron or steel towards the inside. Of course there is a great difference in the practice of the different makers, and in the forms of ropes intended for different purposes. The Admiralty wire ropes for standing rigging have been made for many years of a greater number of small wires than is used for ropes of equal girth made by private makers. Most of, for *instance, Newall* and Co.'s ropes are made of the same number of wires for ropes of very different diameters, but the thicknesses of the wires increase more rapidly, and at a more regular rate, than the Admiralty rope. An ordinary $3\frac{1}{2}$-in. girth rope, for many purposes, is generally made of six strands of six wires each; and a 3-in. girth rope is sometimes made of six strands of nine wires each. Round wire ropes, very commonly employed in Cornwall, are of $3\frac{1}{2}$-in., 4-in., and $4\frac{1}{2}$-in. girth. Flat wire ropes are united by means of annealed wire threads in and out of the strands.

"The breaking strengths of wire ropes by different manufacturers vary very considerably, and some experiments made at Liverpool show a difference in the proportion of 15·0, 16·3, 18·39, and 20·45 for wire ropes of the same size from different makers. The greater number of these breakages took place at the splices, which, on an average, appear to cause a loss of about 13 per cent. in the total breaking strength of the rope. The most trustworthy experiments as to breaking strain are those made years ago by the order of the Admiralty on galvanised round wire rope for rigging. These strengths give what a piece of rope should stand when placed in the hydraulic testing machine. A printed card, now before us, by an eminent maker, shows on comparison a suspicious difference in the numbers it gives as the 'Admiralty test,' and a more correct table in our possession. It is needless to say that some of the breaking strengths are given lower than those required by the Admiralty, and in the smaller numbers this amounts to a considerable extent. The Admiralty table gives the strength of a galvanised wire rope of 2-in. girth as equivalent to that of a $\frac{1}{2}$-in. chain, viz., a breaking strength of 6·35 tons; a rope of 4-in. girth as equivalent to a $\frac{31}{32}$ chain, or a breaking strength of 19·30 tons. In all these cases, elongation—that indispensable element in a true estimation of the strength of materials—is neglected, or at least not given. The same is the case in the very few experiments that have been made and published on the strength of steel wire rope. The breaking strength of 3-in. galvanised iron wire rope is given by the Admiralty experiments at 12 tons, but, according to experiments at Liverpool, some steel wire rope, made of Clay's patent puddled steel, only broke at 16 tons 5 cwt. An examination of the tables of the strength of steel wire rope, compared with that of iron wire, issued by the different makers, will show that the girth of steel wire rope is generally *one-third* less than that of iron wire rope of equal strength. These results have also been confirmed by some experiments made in Germany. Iron wire rope has generally rather more than half the weight of hempen rope of the same breaking strength.

While the strength of a wire rope depends upon the quality of the wire, and of the manufacture, its duration will depend upon the care taken in its usage, and the mechanical provisions against any undue strains. The temporary elongation under stress of wire ropes has not been exactly measured, but it is certain that this elongation is slight. The power of resistance in wire rope is thus small, and this partly accounts for the remarkably high factor of safety allowed for wire ropes in their ordinary applications. M. Moissenet's careful observations in the mines of Cornwall show that the wire ropes there employed are not loaded with as much as 15 per cent. of the breaking load. In the tables issued by the different makers, the ratios of working load to breaking strength approximate very closely to this amount; but with smaller ropes, such as those of 1 in. or 2 in. girth, the ratio of working to breaking load is given at about one-seventh. Neglecting the weight of the rope itself, it is not loaded with more than one-twelfth of its breaking strength in the very carefully conducted collieries of Germany. The weight of the cages, and of the coal and trams, is taken as a static load; but of course the rope, in the ascent and descent of the cage, is subjected to a variety of impulsive forces, which are only slightly absorbed by the resilience of the rope itself. There is, however, some elasticity in the pine-wood balks carrying the pit drums, and there is also generally a draw-spring between the rope and the cage. All this does not entirely prevent injury to the rope in the immediate neighbourhood of the cage. Before the cage-guides, in which the cage is now made to slide, came into general use, the employment of wire ropes had in many cases to be given up, on account of the jerking to and fro of the cage in the pit bringing injurious strains on the rope. Similar jerks, producing similar effects on the wire rope in the immediate neighbourhood of the steam plough, are also there felt, and more especially when ploughing heavy or stony land. *A suspension* bridge made of wire rope would also have to undergo a somewhat similar action if place under the influence of such moving loads as a railway train, o a body of troops in marching order. One of the great advantages of steel wire rope, besides the gain in strength of one-thir and consequent diminution of its weight to the same amount, i its superior elasticity. A rope made of steel wire at once return to its former shape after being bent, which is not always the cas with iron wire rope, especially if the iron be rather soft. Whe in the form of wire, iron is peculiarly subject to injury by bein bent. The bending to and fro of the rope has great influenc on its deterioration, and this influence is much less felt wit steel. In this regard the diameter of the drums cannot be mad too large. Steel is also much less liable to injury by rust in comparison with iron. The very great surface presented by wire rope to the atmosphere renders rust one of the most important influences towards its deterioration and ultimate destruction. A simple calculation will show the very great influence that a comparatively small amount of rust has on the strength of wire, and when once rust begins to form itself, its progress is furthered by a galvanic action between itself and the metal. Miners are very careful to keep their wire ropes well covered with a composition, which sometimes consists of $\frac{6}{9}$ths of rosin, $\frac{3}{9}$ths oil, and $\frac{1}{9}$th tallow, and the amount increases the weight of the rope by about one-tenth. The steel ropes used in steam ploughing suffer very much from corrosion, and particularly if a rope be stowed away in a wet state. The liability to corrosion has been the great impediment to the use of wire rope for suspension bridges; but it is stated, that Mr. Roebling, the builder of the wire rope bridge of Niagara Falls, has discovered a kind of enamel, the composition of which is his secret, and which he has applied to that bridge. We do not know whether this coating would answer for ropes working on drums. In addition to preserving ropes from rust, grease must also act in increasing the flexibility of ropes, as the wires can thus glide to and fro with less friction, and in this way also the duration of the rope may be increased by careful lubrication. The duration of wire ropes is thus affected by such a variety of circumstances that the results of no two ropes employed in different pits could exactly agree. It is seldom that a *wire* rope, well-proportioned to its work, working on drums of large diameter, and kept in a well lubricated state, lasts much longer than three years. M. Moissenet cites the case of the South Francis mine, where they wind from two shafts in conjunction. One, Marriott's shaft, is vertical for 30 fathoms, and then underlies at the rate of 18 in. in the fathom to the bottom, which is 176 fathoms deep. The second, Pascoe's shaft, is vertical for 54 fathoms, when it underlies 2 ft. in a fathom for 6 fathoms. It is again vertical to the 84th fathom level, from which it again underlies at the rate of 2 ft. to a fathom to the bottom (116 fathoms). In October, 1861, the quantity of stuff wound up was 1,100 tons, from an average depth of 126 fathoms. At the greatest depth the rope would have a maximum load of 14 per cent. of the breaking strain. When M. Moissenet inspected Pascoe's shaft, the rope had been in use for three years, and was still in good condition. In Karsten's Archiv (2 Reihe, xiv., 110), there is an account of an experiment, by a Her Klotz, on wire rope made of wire thoroughly annealed previous to being worked into rope. These ropes only lasted from six to twelve months, while ropes made of unannealed wire lasted, under similar conditions, eleven, thirteen, and seventeen months. The ropes of annealed wire had, however, much more elasticity, and were not so subject to breaking.

"One of the most striking things in steam ploughing to a mechanic, are the extraordinary distances—400 or 600 yards, or more—to which the power is carried by means of the steel wire rope. A careful and extensive series of experiments, conducted by two French engineers, and described in the April number of the *Bulletin de la Société Industrielle de Mulhouse* throw distinct light on this matter. They found that:—1. The losses of effect in transmitting power by means of wire rope were very small compared with the losses of effect in conveying power by ordinary shafting; 2. The losses mainly occur in the friction of the bearings of the drums; 3. They are independent of the amount of the power conveyed, but increase directly as the speeds; 4. They are not in proportion to the length of the communication, but the losses of effect that occur in longer lengths simply take place in the friction of the bearings of the guiding pulleys. These exact experimental deductions confirm the rough estimate which might be formed by an engineer inspecting a steam-ploughing field. Wire ropes are used in some parts of the Continent to convey power to such distances as 800, and even 4,000 feet. Fifteen horse power have thus been conveyed to a distance of 1,900 feet, with a loss of only 3-horse power; and 64-horse power have been taken 800 ft. with only 2-horse power of loss.

"It is much to be regretted that in measuring wire some more definite standard than the mysterious measures of the Birmingham wire gauge is not adopted. There can be no doubt that the discrepancies in breaking strength we have noticed between the wire ropes made by different makers are to some extent due to inaccuracies affecting the diameters of the wires. What can be more unsystematic than the indefinite marks ranging from '0000' to No. 36 of the Birmingham wire gauge? From the want of a definite numeric standard, referable to a standard measure, many 'Birmingham wire-gauges' in common use differ from each other. Then there is the Birmingham gauge for sheet metals, and the Lancashire gauge for steel wires, affording together a total of nearly 200 undefined dimensions. Nor are these sufficient; for nearly every trade has some special arbitrary gauge of its own, such as those of the button-makers, the nail-makers, and gun-makers. But none of these gauges are so indefinite as the 'full' and 'bare' dimensions that are still to be seen on the drawings of some first-class works. The Permissive Bill for the use of metric measures, passed this session, would appear to point to a remedy for these abuses. At any rate, it would be easy to determine, once and for all, the exact values of the Birmingham wire gauge in millimètres."

49. While *iron has been much used in the rigging of ships*, as a substitute for hemp ropes, it is but comparatively recent that it has been adopted for the spars. Mr. J. G. Lawrie of Glasgow, read before the Scottish Shipbuilders Society, a paper on *iron and steel spars*, of which we here give an abstract. We regret that space precludes our giving the discussion which followed the reading of the paper, or the very excellent and valuable "notes," "tables," and "formulæ" with which the report is enriched. We can therefore only refer the reader to the pages of the "Engineer," under date of Sept. 2d, 1864, where he will find these given in full. "In *considering* the propriety of using iron and steel spars in substitution

for those of timber, it is desirable to compare their strength; and for that purpose we take the fore-mast and lower yard of a ship of 1,000 tons register, and these spars are selected in illustration of the different descriptions of spars. The mast measures 77 ft. 9 in. long, × 30 in. at the partners, and the yard 74 ft. 9 in. long, × 18½ in. in the slings. The mast is of iron, and not steel, the thickness of the plates being $\frac{7}{16}$ths of an inch at the partners, tapered to $\frac{6}{16}$ths of an inch at the head and heel, having the longitudinal seams double riveted, the butts of the $\frac{7}{16}$-in. plates quadruple riveted, and of the $\frac{6}{16}$-in. plates triple riveted, with butt straps $\frac{1}{16}$th of an inch thicker than the plates, by 18 in. and 15 in. wide respectively, for the quadruple and triple riveting. The yard is of steel, the thickness of the plates being $\frac{5}{16}$ths of an inch at the slings, tapered to $\frac{3}{16}$ths of an inch at the arms—having the longitudinal seams single riveted, the butts of the $\frac{5}{16}$-in. plates triple riveted, and the remainder double riveted, the plates overlapping the butts.

"The strength of a timber mast plainly depends most materially on the quality of the timber, and its freeness from defects, whether apparent or latent. The strength of a built timber mast is not greater than that of a solid mast, except to the extent that it is freer of flaws, and made of perhaps sounder timber, because smaller. It must not be forgot, however, that the strength of a built timber mast is lessened by the bolts for fastening the logs together. Assuming that the timber of which the mast is made, is such that a piece 12 in. square and 12 ft. long between the supports, would carry safely seven tons on the centre, the strength of a timber mast is nearly as much as that of an iron mast, made, as above described, of iron which will carry safely in extension eight tons to the square inch, the iron mast being one-half per cent. stronger than the timber mast. Pitch pine selected ought to carry seven tons on the centre of a beam 12 in. square and 12 ft. between the supports, when it is new; but it is impossible to know how many mast pieces are of that quality, nor how long they will continue to be so.

"Assuming that the timber yard is made of this quality of timber, and that the steel yard is made, as above described, of steel which will carry safely in extension thirteen tons to the square inch, the steel yard is nearly twice as strong as the timber yard—the steel yard being stronger than the timber yard in the proportion of 19 to 10.

"Another important inquiry in the comparison of iron and steel spars with those of timber is their relative weight.

"The pitch pine solid mast weighs 6 tons 3 cwt. nearly; the built timber mast, 6 tons $13\frac{1}{2}$ cwt.; and the iron mast, 5 tons 5 cwt.

"The pitch pine solid yard weighs 1 ton 16 cwt.; the built timber yard, 1 ton $19\frac{1}{2}$ cwt; and the steel yard, 1 ton 13 cwt.

"In these calculations of weight, the pitch pine is taken at 46 lb. to the cube foot, which the writer believes is below the average weight of that timber, and the advantage of lightness is therefore even more in favour of iron and steel spars than appears from these statements.

"Another matter for comparison is the durability of spars.

"If iron masts are kept properly painted, there is scarcely a limit to their last. There is no difficulty in painting them externally, nor is it insuperable to repaint lower masts internally, either by an apparatus contrived for the purpose, or, as their diameter is considerable, by a painter being let down inside. With respect to all the other spars, whether of iron or steel, none of which are used, like the lower masts, as ventilators, they are easily painted externally from time to time; and if they are plugged air-tight, so as to exclude the action of the atmosphere, the original painting will continue good, and renewal will be rarely necessary.

"When iron or steel spars are new, their soundness is known, as the quality and condition of the material is tolerably well ascertained in making the spars; and when the spars are not new their condition and strength are easily examined. The soundness of timber spars, on the other hand, is by no means so easily known or maintained. In the first instance there is considerable uncertainty about the soundness of any spar piece, notwithstanding all the examination that can be made; and even if sound when new, the durability is in no case equal to that of a plate of iron or steel. There is, besides, a great difference in the last of different spar pieces, owing either to original quality or to decay arising from exposure to different climates; and the last of a pitch pine spar may be put at from five to fifteen years.

"Thus it will be acknowledged that, while at any time the condition of iron or steel spars is easily ascertained, it is difficult to know with certainty the condition of any timber spar, especially after it has been in use for some time; and in sending a ship to sea with the one kind of spars or with the other, there is all the difference betwixt knowing precisely the fitness of the one, and knowing almost nothing about the fitness of the other—a difference that is most important to underwriters, and eventually to shipowners.

"There is a fourth important element in the comparison of the spars—'the cost.'

"The price of iron, or steel, or timber spars plainly depends, to some extent, on the price of iron, steel, and timber, and these vary from time to time. In the calculations for this paper, which are given in detail in a note, the prices of these articles are taken as follows:—

Iron plates . . .	at £13 per ton.
Steel plates . . .	at £20 per ton.
Timber for solid masts and yards,	at 6s. to 2s. 6d. per foot.
Timber for built masts and yards,	at 4s. to 2s. 6d. per foot.

"And with these prices the following are the results:—

Solid timber mast,	£184
Built timber mast,	187
Iron mast,	92
Solid timber yard,	71
Built timber yard,	78
Steel yard,	47

—showing a large advantage in the iron and steel spars. It is true that this advantage will be somewhat modified by the changes that occur in the price of material; but, by an examination of the detail of the calculations, it appears that the advantage will usually be not less in favour of the iron and steel spars than these figures indicate.

"Thus, in strength, weight, durability, and cost, it would appear that timber spars are much behind those of iron and steel.

"In a ship of 1,000 tons the difference of weight for lower masts and bowsprit of iron; top-masts, lower yards, double fore and main topsail yards, and single mizen topsail yard, of steel, will be about 7 tons 17 cwt., and the difference of cost will be about £500, being a saving to the shipowner of 10s. per ton.

"The use of iron and steel spars has been for some ti dually making way; but recently the scarcity and price pine has induced their more rapid introduction than wou bably, in other circumstances, have taken place—a result from the American war; and there are grounds now to belie for the future, pitch pine, or any other kind of timber sp not again be in demand. No doubt, some men will, for prefer timber spars to those of iron and steel, just as when timber ships and hemp cables were being supplar those of iron; but it appears to the writer that, without ing the change much, these men will only perform the mile-posts, by marking its progress, and that there seems no doubt that the days of large or heavy timber sp numbered."

DIVISION SIXTH.

RAILWAYS.

50. Our railway system has grown into such gigantic dim that it has assumed a power social—and shall we say poli far exceeding that which even its most sanguine suppor the early days of its history, ever dreamed it likely to Practically a gigantic monopoly of the transit of passengers the goods of our commerce and manufactures, it is evide cumbent upon the public to see that this monopoly is ex in a way fair to the interests of the public; and that eve should be done which can be done, to make the interests public well served in all that respects the safety as well economy of travelling. That railway reform is really, in cases, needed, is true enough, although it is also true th way directors do not deserve all the blame which is throw them by an impatient public. On the subject of railway and specially upon the "*trim of trains in transit*," the has the following:—

"The two modes of ensuring something like safety to gers, to which we lately drew attention as probably the b *the* whole, which can be suggested, namely, either a regular

an's beat along the train, or, short of that, glass compartments,
ve both been adopted by the Board of Trade in a circular just
ued to the secretaries of railways. In this communication the
rds of the committee of Privy Council for Trade, by their se-
etary, Mr. Booth, say :—

"'Several expedients have been suggested, as calculated, in
me degree, to further the desired object.

"'One expedient for guarding against offences in railway-
rriages which has been proposed, is that of placing windows
tween the compartments of each carriage. As these windows
ight be provided with curtains (?), the privacy of the carriages
ed not ordinarily be interfered with.

"'As an expedient for providing means of communication be-
ween the *guard* and the *passengers*, it has been suggested that
very vehicle forming part of a passenger train should be fur-
ished with a footboard and handrails, which would admit of the
uard (or, in case of emergency, other persons) passing along the
ain.

"'It appears to my lords deserving of consideration whether
is expedient, guarded, of course, by carefully-framed regulations
prevent abuse, might not be generally adopted with very bene-
ial effects.

"'The use a cord running along the train, by means of which
e *guard* can attract the attention of the *engine-driver*, has now
isted on some lines so long as to prove that there is no diffi-
lty in *its* application.

"'I am to request that my lords may be favoured with the
inion of the directors as to the practical value of arrangements
the nature specified, and also with any suggestions which the
rectors may think adapted to accomplish the ends which my
rds have in view.

"'I am also to request that my lords may be informed what
eans are in practice on your line for effecting communication be-
een different portions of a train while in motion.'

"It is to be earnestly hoped that this communication will lead
a complete reform in the present mal-arrangements. Indeed,
mething *must* be done. The public will not submit any longer
be robbed and murdered merely that the pockets of railway
areholders may be spared. Should railway directors refuse to

do anything effectual now, they may find themselves in the n very pleasant predicament of being charged with being accessor before the fact, to some of those great crimes which are onl rendered possible by their inexcusable neglect to provide th public with the sure means of preventing them.

" Before many years have passed, indeed, the working manag ment of our railways must be greatly changed and improved i more ways than one, in order to prevent a large and increasin loss of human life and damage to human limbs. To a remarkabl extent the railway system is spreading in all directions, and th spaces which at one time were thought far more than sufficien for any traffic which might be required at termini, stations, an junctions, are now found to be dangerously restricted. In man instances the chief stations have become crowded scenes of con fusion, and the junctions places of extreme danger; take, for in stance, the Stepney junction on the North London Railway through which the trains run to and fro in various direction with startling rapidity, (we would like to know how many train pass the platform in a day, and the average number of minute which elapse between each). It is clear to the most casual ob server, that, in order to prevent some terrible calamity, everythin depends upon the vigilance of two or three persons: a singl instance of want of carefulness or watchfulness on their part, o the least failure in the signals, must inevitably lead to seriou damage. We are bound so say, however, that this station seem to be managed with both ability and watchfulness; and that th master, in his activity and politeness, is a sort of Palmerston o station-managers. It is satisfactory to observe, throughout th length of this line, the improved civility of all the officials— since, in years past, we were obliged more than once to complain of want of attention and rudeness of manner. The announcement of the various stations is also far more distinct than formerly. But it is not specially with those who have direction of railway traffic that we have now particularly to do, it is rather with the general system, which causes conjestion and confusion at s many points,—which, in an ill-judged spirit of economy, causes one junction or station to be applied to far too many uses, and prevents the introduction of necessary alterations in carriages and *signals.* The underpayment and overworking of those *employé* whom, in the present state of affairs, the lives of the public e mainly intrusted, is another point urgently needing reform.

"When glancing at the growth of the English railways, it is orth while to remark, that all the arrangements were, in a great easure, the result of chance, and the offspring of necessities hich were developed by degrees, as an entirely new plan of nveyance was brought into working trim. Just as the noblest ders of our architecture are the development and improvement the simple and rude wooden houses of antiquity, so the car- ages, &c., on our railways are the promptings of peculiar re- uirements, which however, in principle, have been but little hanged. When George Stephenson planned the Stockton and arlington railway, it was intended, almost entirely, for the onveyance of coal and other minerals. It was little thought, in hose days, that the railway would supersede the stage-coach in he conveyance of passengers; but when this line was opened, orkpeople and persons going to and fro on market-days, availed hemselves, in the first instance, of a passage on the trucks, ithout payment. The demand for this manner of travelling uddenly increased, and a charge was made; but, for a long time, here were not even covered carriages for passengers, although r goods which required care covered vans were provided, which ere made without any attempt at ornament, or the picturesque form. They were simply large boxes made of sufficient rength to suit the intended purpose; and even now the chief art of the railway passenger-carriages have been but little hanged in their general plan. In England, where the railway ystem was originated and brought into working order, the rrangement of the carriages is not so good as in many places broad, where improvements on our more antiquated system have een made. Here we, by chance, were led to adopt a plan of he moment, and have stuck to it, repudiating improvement. It to this that attention should now be especially directed: the arious incidents which have excited the public notice during he last month or two, show the necessity for this; and the ages of the newspapers contain all kinds of suggestions of means r meeting the evil. The chief difficulty seems to be the cost hich would be required to alter the carriages now in use, or to place them with those *of a better* construction; but, as we have said, something *must* be done; and it is to be hoped the Board of Trade will persist in the effort to induce railway directors to do what is so urgently requisite."

51. Mr. Bridges Adams, the well-known engineer, has done the public good service by drawing attention to many points of useful railway reform. On this subject he has recently been writing a series of most suggestive articles in the "Scientific Review," from one of which we take the following on *carriages*, &c.:—

"With regard to trains—*i. e.*, carriages and waggons for the conveyance of passengers and goods, so as to reduce their resistance to the minimum, and give the greatest comfort and convenience—there are several principles to recognise. First, to obtain in each vehicle the greatest amount of floor area with a given number of wheels; for the larger and longer the vehicle the steadier it will be, and the less will be the proportionate dead weight. Moreover, in case of collision, the damage will be confined to fracturing the portion struck; for the carriages, if of great length, will not be thurst upwards from the rails and mount on each other in a broken heap, as is the case with short carriages; nor will they, on any of the lines, act so mischievously as short carriages; nor will they offer so much resistance to unfavourable head or side winds. The length need only be limited by the capacity for going round curves, and they may be constructed forty to fifty feet in length, while perfectly adapted for curves of two chains radius, the axles all working radially to curves, and rectangularly to straight lines. As a rule, long carriages may be made proportionately wider to the gauge of the rails than short ones, and there is no difficulty in making them double the width of the gauge.

"This would, on the 4 ft. 8½ in. gauge, give carriages 9 ft. 6 in. total width; but there is another consideration: the 4 ft. 8½ in. gauge was originally adopted because that was the width of carts on common roads, measuring to the outsides of the tyres. That this would not have been the width had the question been better understood, we may assume from the fact that the same engineers who made the 4 ft. 8½ in. gauge for England have taken a 5 ft. 6 in. gauge for India; and there is no doubt that the 5 ft. 6 in. gives a better proportion for the structure of locomotive engines, although skill and contrivance can accomplish the structure of good engines on the 4 ft. 8½ in. And thus, the earlier roads having been made to the narrow gauge, the others have followed suit, with the exception of the Great Western system; for a break of gauge has been generally held to be an unmixed evil. And so it is if the traffic be all of one kind. But if we once admit that it is desirable, on the score of safety and convenience, to use separate lines for fast passenger traffic, the break of gauge becomes at once desirable, in order to prevent the possibility of irregularities; for we may be assured that indications of gain will infallibly overcome the warnings of risk where they interfere. If the law should determine that it is desirable to have separate passenger lines, it would be desirable to have for them the 5 ft. 6 in. gauge.

"In this case it would be practicable to use vehicles 50 feet long by 11 feet wide, containing about 180 square yards of floor area. This space would contain about 154 third-class passengers, or 120 second-class passengers, or 80 first-class. But if a communication is to be kept up between guard and engine-driver and passengers throughout the train, the only effective method is by a central passage way throughout the train, with sliding doors at the ends of each carriage; and, in such case, the passengers would be reduced to 132 third-class, 100 second-class, and 64 first-class —the third being open throughout; the second partitioned off half height, like pews in a church; and the first having closed cabins for four persons each on either side the passage way. Thus, three carriages would contain about 300 passengers, borne on 24 wheels. Or one composite might take 16 first-class, 36 second, and 56 third; total, 108.

"In these arrangements the chances of murder or robbery would be removed—assistance could be given in case of illness, and there might be a closet in the train. Moreover, the communication with the engine would give the practicability of warming by pipes; and hot tea and coffee or other refreshments to the passengers, by having a steward on board for long journeys. All these things would remove the necessity for frequent stoppages, and very rapid travelling might be accomplished. Gas for lighting is now a common thing in vehicles, and need not be dwelt on.

"Long and wide carriages are commonly used in America, constructed on what is *commonly known* as the Bogey principle—

i. e., a group of four wheels, very close together, is attached to the carriage at each end—the body and frame being supported on a central point equidistant from the four wheels, and the springs are rarely efficient. The wheels are very close together, and swivel round on the centre pivot, being guided only by the rails. In this arrangement there is a tendency on curves for the leading wheels to grind against the outer rail, causing the axles to recoil and place themselves abnormal to the curves. And it is necessary to make the centre framings of the body, and also of the bogey, very strong, in order to carry the load. But it is very practicable to suspend the framework by elastic springs from the axle-boxes, with long swinging shackles, and guide the wheels by curved quadrants, so as to make the movement of the wheels exactly true, and keep the axles normal to the curves and straight lines. And by this mode the load may be suspended equally between the four wheels, so as to divide the load and prevent blows. And brakes may be attached to the wheel frames following the courses of the wheels on curved lines, and preventing all jar on the bodies—the brakes being made either self-acting, or being worked by the engine-driver, so as to leave the guard wholly free to attend to his business with the passengers and luggage; and the wheels may, by proper construction of their tires, be made to revolve just as much or as little, separately, as is needful to prevent slip or grind.

"What holds good of passenger carriages holds good of waggons also—the longer and larger they can be made the better, provided the wheels are so guided as to run true on curves and straight lines. Long timber or iron bars, or boilers, or machinery, might thus be carried, without the clumsy arrangement of saddles on separate waggons. And coals may be carried in bulk with great advantage, especially with good and efficient springs; for the amount of waste in coal is very great by the hard and uneasy movement of ordinary waggons; and, moreover, the resistance to traction is thus materially lessened.

"We think that there can be no doubt of the desirability making locomotive engines single machines, instead of duplicat them with tenders, for the obvious reason that they may either end foremost with equal facility; and that varying *load on* the engine—not the distribution of the load—by consumption of the water, is a less evil than carrying a lumbering tender behind. It is also desirable that the whole weight of the engine should, for the purpose of economy, be applied upon driving-wheels with adhesive power. Mr. Sturrock, on the Great Northern, thinks this desirable even with a separate tender, by applying cylinders and connecting-rods thereto. The great difficulty of tank engines—that is to say, engines with water and fuel all on one solid frame—has been the almost impossibility of geting the frame long and large enough to carry a sufficient quantity of fuel and water for a long journey, with, at the same time, a possibility of working even on very moderate curves without getting off the line. And if the engine be very long, it is essential also to increase the number of the wheels, and there is a considerable advantage in increasing the number of the wheels for the purpose of lightening the load on each pair, although it will be found that, by the use of spring tires, six tons on a wheel will be quite as easy as four tons on an ordinary wheel.

"The difficulty of going round curves with a long engine is quite got rid of by the principle of radial axle-boxes. A 22-feet wheel base will roll round a curve of $1\frac{1}{2}$ chain with eight wheels, four of them being drivers, or round a curve of 3 chains with ten wheels, six of them being drivers. But in either case there are still four wheels merely carrying a load without being drivers. Many plans have been resorted to to make all the wheels drivers with a curvilinear capacity. One of them is the French system of a 12-wheel engine, which is, in fact, two engines on six wheels, with a pair of cylinders to each, the two engines being coupled by a long boiler on two centre pins, round which the engines swivel like a large tree on two timber trucks.

"It may be, therefore, taken as a third axiom in railway economy, that the longer and larger the vehicles, the less will be the dead weight in proportion to the paying load; and provided that the wheels be arranged so that the tires do not slide or grind on curves, and the axles be normally radial to curves and rec- ngular to straight lines, the less will be the resistance to traction d the greater will be the steadiness and safety.

"With regard to separate passenger lines, to a certain extent ey exist already; as, for example, the Blackwall, Brighton, Me- politan, and others; *and there* can be no doubt that it would be highly dangerous to crowd them with goods, as is the cas with the northern lines. For long lines they can only be available where passenger traffic is very abundant, such as the routes to Birmingham, Manchester, Liverpool, London, and similar districts; and even the Great Western, now that it has begun to crowd its lines with narrow-gauge traffic in coals and goods, is beginning to enter upon its category of collisions with more rapidity than is desirable, and it will have to moderate its speed to render the mixture of passengers and goods trains at all safe. It is not to be supposed that goods lines are to abstain from carrying passengers altogether, but it must be at reduced speed, analogous to the passengers carried in the road waggons in past times; for to carry goods at high speeds must necessarily enhance the cost too much for large profits to be made.

"It may, therefore, be taken as a fourth axiom in railway economy, that goods lines working up to their maximum number of trains must be lines of comparatively slow speeds, in order not to absorb the profits in wear and tear, and risk and waste by collisions.

"But it would be a great advantage for such lines as require a moiety of goods and a moiety of passengers, and have not enough of either wholly to fill up their time, to improve the construction of their lines, engines, and trains. One simple plan would be to economise existing stock by coupling pairs of carriages rigidly together, and arranging the wheels and axles in groups at either end, for thus resistance to haulage would be lessened, and safety increased in many ways, at a very small cost. They would not be liable to leave the rails, they would not turn ends up in case of collision, and they would be very greatly strengthened against longitudinal shocks.

"One great drawback to railway travelling is the vibration caused by the wheels on the rails under the existing system of construction; a kind of vibration which does not exist in road carriages. The wheels are each pair fast on one shaft, and rub or sledge instead of rolling, creating a hoarse sound, multiplied by the continuity of metal in the wheels and axles. The effect is analogous to that of the rosin rubbed on the horse hair of a violin bow for the purpose of vibration, only the latter is pleasant, while the former is mischievous. If this grinding vibration were removed from railway wheels — which could be done by right construction—a large part of the evil of railway travelling, and a good deal of the unsafety, would be removed. And if the seat of each traveller were arranged to fold up, so that he could sit or stand at pleasure, the circulation of his blood on a long journey would be improved."

52. It is curious to notice the process of apparent death and after-resuscitation which some mechanical projects undergo; in some the interval between the two, or the length of the state of coma, so to speak, in which these remain is comparatively short, in others it is very long; so long, indeed, that men forget them altogether, so that when they are revived they are accepted as new, but when their history is gone into, and new they are found not to be, then is recollected the oft-repeated saying of the wisest of men, "there is nothing new under the sun." In some cases we also notice that projects tried at vast expense are, after a time, laid aside as altogether practically worthless; but which contain nevertheless the germs of valuable systems which lie hid for long yet are at length brought to life, and offer, when matured, much of practical value. Not seldom also do we find that an invention in itself thoroughly good is brought out at a period not fitted or prepared for its development, so that it dies out but only to be resuscitated when the time comes when there is a want for it. The mechanical project and the hour, is but another rendering of a well-known phrase. These thoughts have been brought up on considering the somewhat curious and suggestive history of the *Atmospheric Railway* and its later developments. These are alluded to in the following article from the "Mechanics' Magazine."

"Exactly fifty-four years ago, a Mr. Medhurst proposed that a brick tunnel should be built and applied to the conveyance of passengers at speeds never more than dreamt of before. Within the brick tunnel a pair of rails were to be laid, and on these rails a suitable vehicle, very similar in its general arrangements to an ordinary railway carriage, was to travel. The cross section of the brick tube, as proposed, would have been egg-shaped, with the maximum width above. The rails would have rested on projections springing from the side walls near the bottom. To the rear of the carriage a piston, so to speak, formed of boards suitably framed together, would have been affixed. This piston would have nearly fitted the tunnel. Whether any expedients were proposed by which the space between its edges and the brick-work could be made partially air-tight, we are not prepared to say. It is not likely that a scheme so perfect in principle as this was would be found wanting in detail. The carriage and piston thus provided, and put in place within the tube, air was to be forced in behind by means of a large pumping apparatus, very similar, we believe, in general design, to the blowing engines at present used at our iron-works. The pressure of the air thus pumped in would, it was contended, prove sufficient to propel the carriage with its load of passengers at very high speeds. *Mr. Medhurst lived before his time.* The scheme never got beyond a model, for obvious reasons. In the first place, the steam engine was not yet perfected, and the obtention of the necessary motive power for the blowing machinery was by no means easy. In the second place, people had a very great and perhaps natural antipathy to the idea of being placed within a tube, dark and cheerless, and blown to their destination; and thus a really valuable invention fell to the ground. It is easy, however, to see that Mr. Medhurst's was no ordinary mind. In this scheme we have the embodiment of nearly all that constitutes the modern railway—the iron rails, the high speeds, the accommodation for passengers, have a great deal in common with the present system of locomotion, and all this, be it observed, was designed twenty years before the Rainhill trials inaugurated the railway system. After Medhurst came Vallance and Pinkus, gentlemen who proposed certain alterations, the principal idea being involved in the reduction of the size of the tube; the alteration of its position with regard to the carriage, by placing it between the rails and below the floor; and the exhaustion of the air from the space in front of the piston, instead of its compression within the space behind; but this last had been already proposed by Medhurst, who seems to have left scarcely a point overlooked. Messrs. Vallance and Pinkus had no better success than Medhurst, and it remained for Messrs. Clegg and Samuda, years afterwards, to develop the system, on a practical scale, on the London and Croydon, and Dalkey and Kingstown railways. The atmospheric principle as tried on these lines is now well known to be wholly unsuitable to the demands of an extensive traffic, and as far as the country is concerned, the vacuum tube and the piston carriage have been banished for ever in favour of the locomotive. With the introduction, however, of the underground metropolitan railway system, the old scheme of Medhurst bids fair to be revived. Indeed, there is hardly room to doubt that it is, of all others, the most suitable for the exigencies of this species of traffic. In the pneumatic despatch we have, on a small scale, all that Medhurst proposed; and there can be no room to doubt, from the success which has already attended upon the labours of the company known by the same name, that the system can be extended to the conveyance of passengers without any practical difficulty whatever. During the last few months, too, Mr. Rammel, the inventor of the pneumatic dispatch scheme, has been labouring at the Crystal Palace to provide a model line—the first on which regular passengers have been conveyed—which would serve to bring all these advantages fairly before the public.

"The tube extends from the Sydenham entrance to the armoury near Penge-gate—a distance of about a quarter of a mile, and it is, in fact, a simple brick tunnel, 9 feet high and 8 feet wide—a size that renders it capable of containing an ordinary Great Western Railway carriage. That actually working in the tube at this moment is handsome and commodious. The piston is rendered partially air-tight by the use of a fringe of bristles, extending nearly to the brickwork of the tunnel and its floor. A fan, 20 feet in diameter, is employed to exhaust or to force in air, and perhaps it is impossible to devise any other expedient so well calculated to answer the required purpose. It must be remembered that either a plenum or a vacuum, equivalent to ·5 of an inch of mercury, is quite sufficient to propel even a heavy train at a high speed on a moderately level line. In the present instance, the motive power is supplied by an old locomotive borrowed from one of the railway companies, which is temporarily mounted on brickwork. The tires have been removed from the driving wheels, and these last put the fan in motion by straps.

"The line, we have said, is a quarter of a mile long; a very small portion of it, if any, is level, but it has in it a gradient of one in fifteen—an incline which no engineer would construct on an ordinary railway; and as it is not a level line, so it is not a straight one; *for it has curves* of only eight chains radius, which are shorter than those usually found in existing railways. The entire distance, 600 yards, is traversed in about 50 seconds, with an atmospheric pressure of but 2½ oz. The motion is, of course, easy and pleasant, and the ventilation ample, without being in any way excessive. All the mechanical arrangements are so simple, and must be so obvious, we imagine, that it is needless to dwell on them. We feel tolerably certain that the day is not very distant when metropolitan railway traffic can be conducted on this principle with so much success, as far as popular liking goes, that the locomotive will be unknown on underground lines." Amongst those connected with a science like that of Engineering, which abounds in so many "vexed questions," it is scarcely necessary to say that the above favourable view of the pneumatic tube railway is not universally held, but that, on the contrary, opinions most unfavourable to its practical success on a large scale have been promulgated in articles for which we have not space here. Be these opinions right or wrong, it is, at all events, a most suggestive fact, that while we write, the contract for the "tube railway" has been given out, and it will be laid down, partly along the Thames embankment, and across the Thames under water.

53. The experience of travellers during the first few weeks of the working of the Metropolitan Railway will have implanted in their memory a keen recollection of the discomforts of the passage through the tunnels, in the pungent, suffocating vapour which prevailed; and although these were speedily reduced, and the working has since then been such that comfort is more the rule than the exception, there is, nevertheless, so much that is yet unpleasant in underground railway travelling, that the attention of many of our practical men has been given to the endeavour to introduce a method of working the trains so that travelling will possess all the comfort and ease which can be given to it. Amongst the plans proposed is that of Mr. Barlow, who propounded his scheme in a paper recently read by him before the Inventors' Institute. "Mr. Barlow," says a writer in the "Scientific Review," "thinks that locomotive engines are misapplied on railways where the stations are frequent and the intervals short. He thinks that, on such a line as our Metropolitan Railway, better results, and certainly

much greater convenience to passengers, would be derived from dispensing with locomotives in the passenger traffic.

"It will be within the experience of many of our readers to have travelled in a carriage at the tail of an express train, to stations at which the express itself would never condescend to stop. In such cases, on approaching within a mile, or somewhat less than a mile, of the desired station, the last few carriages have been detached from the main body of the train, and, left to themselves, have glided swiftly and smoothly to their destination.

"The mode of progression in this last mile, when the carriages move independently of the locomotive, is that which Mr. Barlow desires to see adopted on our metropolitan lines. Of course, the carriages must be made to attain something like express speed before they can be expected to run alone over any reasonable distance. To effect this, Mr. Barlow proposes to lay down at each station a fixed system of machinery, capable of imparting to a train of carriages, during the first three or four hundred yards, as may be required, a rapid though gradual acceleration. The requisite impetus thus attained will bear the train to the next station. There the same process will be again performed, and, by a succession of rapid but easy flights, the journey from end to end be speedily and quietly accomplished. The question now arises, how is the train to acquire, at any one station, the momentum requisite to carry it with certainty to the next? Mr. Barlow purposes to apply the power of the rope. He would lay down between the rails an endless rope, passing round pulleys, like the cord of a window blind, over a distance of something like three hundred yards from the station. And he likens the motion which would thereby be acquired to that of a train moving from rest down an inclined plane of several hundred yards in length—a method of imparting locomotion not unfrequent in our mining districts. This, then, brings us face to face with the old question of locomotive *versus* rope and stationary engine. Mr. Barlow is an engineer, and he has all the fond admiration with which his class regard that very perfect instrument. In discussing its relative merits when applied in working long and short distances, he says:—'Where the distance between the stations or point of stoppage is considerable, or such that the great and important duty of the engine is to maintain the requisite speed, after that speed has been acquired, one of the first facts which inquiry establishes is that the locomotive engine is admirably adapted for this purpose. Whether we take the work performed by an express engine in a fast train, or a heavy goods engine drawing a slow train, in either case it results that, provided the distance between the stations is great, so that the engine can work for a considerable time, exercising its power at a fair working speed, the economical working of locomotive engines, comparing the work done with the fuel consumed, becomes manifest. When, however, the duty to be performed is that of working a line in which the stations are very close together, and the stoppages frequent, it then results that all, or nearly all, the work of the engine is expended in acquiring the travelling speed, and that, in fact, it has not ceased to accelerate its speed when it becomes necessary to shut off the steam and apply the breaks, so as to stop at the next station. In fact, the same engine which, in long stages, would make an average speed of 35 or 40 miles an hour, is capable, with frequent stations, of making an average speed of but 13 or 14 miles, even with a greatly reduced load.' In such a state of things the waste of power is enormous; and when the almost cruel wear and tear of material is taken into consideration, the employment of the locomotive becomes simply an abuse of a noble machine. Mr. Barlow estimates the loss, in such a case, as amounting to no less than nine-tenths of the whole power employed. He points out that, as in cases where the stoppages are frequent, the use of powerful engines is necessary, 'it follows that the weight of the engine becomes great in proportion to the rest of the train; and, therefore, if that weight can be dispensed with, much less power will suffice to give the same amount of speed; or with the same amount of power applied, a much greater speed will be attained.' These and other considerations, for which we must refer our readers to Mr. Barlow's able paper (p. 13), would alone be sufficient to prompt an inquiry whether any other more economical method can be adopted. Mr. Barlow confidently answers this inquiry in the affirmative; and he propounds the scheme which we have here attempted briefly to describe. As he justly remarks, 'frequent trains are, in the opinion of experienced persons, necessary to develop the omnibus traffic; and *there is* no reason why, with stationary power, from the improved velocity, they could not be made to run every three or four minutes, allowing sufficient time for one train to leave its station before the following train was allowed to start. This could not be done without locomotives treble in number to the stationary engines, even if there was required to be one stationary engine at every station.'

"In noticing the want of confidence which has hitherto been felt in regard to the rope system, he says that even where the rope extended from station to station, it was never known to fail so long as the engine power acted properly; and that where it has been used and abandoned, it has been owing more to the interference of such a length of rope with junctions and level crossings, than to any difficulties arising from the rope itself. But the difficulties inherent in the length and consequent weight of the rope, as hitherto used, do not arise in the application of Mr. Barlow's scheme. He only requires it over a short distance from each station, to give the train its initial motion.

"For ourselves, if only ropes can be procured of sufficient strength, and machinery be constructed with any pretensions to efficiency—matters not, we submit, in these days, of insurmountable difficulty—we see no reason why this scheme should not be eminently successful. Its manifest saving of power, to say nothing of the prevention of wear and tear, should be sufficient to recommend it to those financial interests which are of such paramount importance with shareholders; while the greatly increased speed and comfort which it would secure to passengers recommend it no less strongly to the public regard."

54. Up to a certain point in the history of railway working, the "*permanent way*," and the "*wheels*" of the carriages which were to run upon it, were tacitly accepted as being the best to be had, or that comparatively little improvement was, at all events, desiderated, so that the attention of engineers was principally directed to the improvement of the locomotive—not that details connected either with rails or with the wheels of the rolling stock were positively neglected, but certainly they received less of the care of the engineer than did the locomotive. Of late, however, the defects, or assumed defects, both of rails and wheels have attracted the attention of practical men, and much benefit has resulted, and will evidently yet result, therefrom. On the subject of the

permanent way, and the use of *steel* for the rails, the following is given in the "Railway News:"—

"One of the first and most important charges against revenue is that for the Maintenance and Renewal of Way. The way, or road, is the foundation of everything else on a railway. It must be well kept and regularly ballasted up; the sleepers must be in good condition, and the rails sound and firmly held in their places in the chairs; for, an uneven line, a decayed sleeper, a broken rail, or an imperfect chair, might at any moment involve a company in the most serious consequences. Especially is it necessary to have the road kept in the most perfect condition, where the speeds maintained are high. Hence the constant repairs, renewals, and relays of rails, chairs, and sleepers; and hence, also, the heavy item of expense, on this account, which is to be found in the half-yearly statements of every railway company. For, although engineers speak of the Permanent Way, it is really in anything but a 'permanent' condition. It is in a state of constant change and renovation; rapid in proportion to the weight and speed of the engines and carrying stock, and to the number of trains which the way has to bear.

"Here is a brief epitome of the charges for maintenance and renewal of some of the principal companies whose reports are before us:—

Names of Companies.	Miles maintained.	Last half-year.	Average per Mile.	Permanent Way Fund in Debt.
		£	£	£
London and North Western,	1,225	131,729	108	—
Great Northern, . . .	415	85,049	205	—
Midland, . . .	641	87,069	136	—
London and Brighton, .	230	26,535	116	57,211
London and South Western,	508	75,471	148	—
South Eastern, . . .	279	52,478	190	—
Great Eastern, . . .	664	93,416	140	86,992
North Eastern, . . .	1,095	95,047	87	—
Lancashire and Yorkshire, .	402	90,148	224	—
Caledonian, . . .	245	48,293	197	—
Glasgow and South Western,	198	36,332	183	19,684
North Staffordshire, . .	254	14,951	59	77,930
Bristol and Exeter, . .	121	17,214	142	—

"It will be observed that the average cost of maintaining and renewing lines varies considerably with different companies. In the case of a first-class main passenger line, such as the Great Northern, the road must be kept in the most perfect state, and expenses are high in proportion. Even the coal trains on the Great Northern must necessarily be run at high speeds, which nvolves a serious addition to the tear and wear of the road. The heavy merchandise traffic of the Lancashire and Yorkshire line lso involves very heavy repairs, the cost of which in the last half-ear seems to have been excessive; but that company adopts the ound plan of charging the repairs done during the half-year to he revenue of the half-year, thus avoiding the temptations of a uspense account. The Great Eastern Company, having been rawn into the establishment of a Permanent Way Fund, which ot into debt £86,992, adopted the decided course, at the last alf-yearly meeting, of charging the whole to capital, and thereby etting rid of the difficulty. It will be observed, from the above able, that the lowest average expenditure per mile is on the North Eastern railway, a large proportion of their mileage consting of coal lines, on which the traffic is run at comparatively ow speeds. The North Staffordshire maintenance is exceptionally ow; but that the road is nevertheless 'maintained' appears from the Permanent Way Fund, which owes to revenue as much as £77,930.

"The cost of maintaining a line is thus by no means uniform. It depends mainly on the number of trains run over it, the weight f the engines and vehicles of which the trains consist, and the peed at which those trains are run. Hence the heavy expendiure on all main and express lines, involving a constant necessity or repairs and renewals. The wear and tear of rails, points and rossings, and of all the materials of which 'permanent way' consists, is especially great at important stations, where the rails are apidly worn by the skidding of the wheels along them when the rake is applied. The surface iron soon becomes laminated by he enormous weight of the heavy engines constantly rolling and rinding over it; and the tear and wear is consequently excessive. In many cases the rails at stations require to be renewed after the apse of little more than a year; whereas, if laid down upon a ranch where the traffic is comparatively small, they may remain erviceable for fourteen years or more."

"Hence the demand which has of late arisen amongst railway companies for some material that shall stand the tear and wear of railway work of the severest kind better than any ordinary iron can do. It is found that steel is the only metal capable of fulfilling the requirements of a first-class rail. The experiments made by the London and North-Western Company at Crewe, Rugby, Stafford, and Camden-town, have proved very satisfactory. At Camden, in May, 1862, two miles of single line were laid down at a point where there is a great deal of shunting—one mile being laid with steel rails, the other with ordinary iron rails. The work done by the respective miles of steel and iron was equal, so that it is easy to compare the results. They are very striking and conclusive. The steel rails, which have not yet been turned, are at present working against the tenth face of iron rails; nor do the steel rails look as if they would require turning for some time to come. The same results have followed the experiments made at other stations. The steel rails have everywhere stood the severest tests in the way of heavy work, and are still serviceable; whilst the iron rails working against them have been worn to pieces over and over again. At Crewe, the two 35-feet steel rails exhibited in Mr. Bessemer's case at Kensington in 1862, have been put into the road, and are still good, whilst several sets of the ordinary iron rails have been worn out and renewed. Mr. Ramsbottom is even of opinion that, after all their heavy work, the Bessemer steel rails may be fit for showing at the Exhibition of 1872. In fine, so uniformly favourable have been the results of all trials made with steel as against iron—whether in the form of rails, tires, or axles—that the London and North Western Company have come to the conclusion of themselves erecting works for the manufacture of railway steel. The directors have, with this object, obtained powers from the proprietors to expend £54,000 at Crewe, where they expect to be able to turn out 10,000 tons of steel per annum.

"Although steel costs £15 15s., as against iron at £8 or £9, if the steel outlasts the iron more than ten times, as is above shown to be the case, the economy of their proceeding is obvious at a glance."

55. On the subject of *elastic railway wheels*, a very elaborate paper was read by Vaughan Prendred, Esq., C.E., before the So-

ciety of Engineers, of which the following is an abstract, for which we are indebted to the pages of the "Mechanics' Magazine:—

"The author commenced by stating that the subject of the paper he was about to read—'Elastic Railway Wheels,' or, more strictly, certain expedients for imparting elasticity to these important members of the railway system, was one possessing much interest; indeed, he thought he was justified in saying that the adoption of certain mechanical expedients for seating tyres elastically on the wheels to which they belonged, afforded fair promise of enabling important changes to be introduced into the present system of constructing permanent way; while experience had shown already that by their aid, the duration of engine tyres might be nearly, if not quite, doubled, especially on lines of rapid curvature, and that slipping or want of adhesion might be reduced to a minimum.

"The paramount object had in view in the formation of a railway, was the reduction to a minimum of those forces which retard the motion of wheel carriages. Setting aside for the moment every other consideration, he might, therefore, define a perfect railway as consisting of two unyielding bars—parallel—absolutely hard on their upper surface at least, and so secured to the sub-structure on which they were ultimately supported, as to be incapable of moving or deflecting under the action of any practical load which they might be called on to sustain. Such a railway, the author stated, would not only reduce the amount of tractive force required for the propulsion of trains or carriages to the lowest limit, but would also possess elements of permanence, which are wanting in any track constructed with timber sleepers, cast-iron chairs, &c., under existing arrangements; while, on the other hand, it would be open to certain objections, which have hitherto precluded its adoption.

"After describing a theoretical railway track formed of girders laid down on stone blocks, the author went on to say that, were it but possible to introduce the use of stone sleepers, and to per- the ballast to settle its own differences with the sleepers after own fashion, the expense of maintenance would be greatly ced. Good ballast always had a tendency to consolidate and me hard, but, under existing circumstances, this quality, h ought to be *of all things* the most desirable, is, on the contrary, regarded as a great evil, and no sooner does the ballast become hard, and the timber manifest a tendency really to sleep, than the navvy stirs them both up with his pick. This, we are told, is done to secure elasticity; but the ballast was not properly treated if compelled to become the elastic member of the system —to take a part for which it had no vocation, and could not properly assume. If it were not necessary that elasticity should be provided somewhere, a very excellent track indeed, might be made with stone blocks and rails bolted down directly to them, without chairs, and such a track would be infinitely more durable than any other involving the necessity for the use of wood in its construction, always provided that it were exempt from these destructive influences, to obviate the effects of which the elastic element is introduced; in other words, the author believed that the elastic element in our permanent way, as it is called, is the principal cause of its want of permanence, because wood rots and wears out, because nothing has been found as yet which is better than wood, under the given conditions, and because the mechanical arrangements are all so imperfect, and the bearing surfaces so small. that if that motion takes place among the parts which constitute an ordinary railway track which the element of elasticity is presupposed to permit, they quickly become loose, and the true rigidity on which the integrity of the entire structure depended, can only be approximately maintained by an excessive outlay of money and labour.

"The author then explained at some length the nature of the action which a rapidly revolving wheel exerted on the rail beneath it, showing that elasticity prevented percussive action, and that the elastic element may be applied with more mechanical propriety beneath the tyre, than beneath the rail, and with equally good effects; and went on to say, that the percussive action of railway wheels travelling at speed is due directly to their revolution, and is almost independent of any true jumping whatever, and that elasticity operates more as a *preventive* of percussion than as a cure. In other words, the suddenness of strain characteristic of percussion was prevented, as he had just endeavoured to show, instead of being absorbed or taken up, as might be the case, if the wheel were supposed to be lifted off the rail for a *space* and suffered to drop.

“No means had yet been discovered for preventing the effects
' percussion taking place between revolving wheels and the rail
hich supported them, but the introduction of elasticity, some-
here, into the system ; and experience showed that this elasticity
uld be introduced with the utmost advantage into the wheel,
beneath the tyre, instead of, or in addition to, elasticity be-
ath the rail or the sleeper, and if no better expedients for
curing this necessary element in track could be devised than
ose already in use, which depended for success on soft ballast,
costly destructible timber, then he believed it might yet be
ind advantageous to seat rails as rigidly as possible on heavy
ne sleepers, and to adopt some expedient beneath the tyres of
t the engine alone, but every wheel of the train, which should
pply that elasticity which would, in such a case, be absent from
e permanent way. This was, however, a point open to discus-
n, and he would therefore proceed to the consideration of
e various expedients which had been proposed from time to
ne for seating tyres elastically, or in some way imparting re-
ience in no ordinary degree to the wheels of vehicles. The
a of an elastic wheel was by no means new. Patent Office
ords showed that, with the first notion of propelling carriages
the adhesion of the wheels on which they rested, men sought
increase that adhesion by enlarging the surface in contact
th the ground, either by using a very broad wheel, or by adopt-
g certain expedients which would permit the wheel to depart
ghtly from a true circular shape, and become more or less oval.

“The author then gave a short history of the elastic wheel
eory, showing that Mr. T. Neville, the inventor of the multi-
bular boiler, had been one of the first to propose to use elastic
res to obtain increased adhesion, as early as 1825. After de-
ribing many inventions, the author went on to say that all
ose expedients were indirect, and more or less unlike the ar-
ngements adopted in modern railway practice ; but he found
at, in 1837, Sir George Cayley took out a patent which in-
uded nearly all that had been done since, in the idea at least,
not in the actual mode of application. Not only this, but he
und that, in 1831, he had suggested, in the pages of the ‘Me-
anics’ Magazine,’ an improvement in railway wheels, designed
reduce their *wear, which* possessed many points in common

with the Griggs' wheel. Sir George writes, 'If the wear and tear of railway conveyance be found too expensive, owing to the friction caused by such high pressure and great velocity, and that the use of springs to these carriages are not sufficient to remedy the evil; I think it probable that a dovetailed groove, filled with hard oak, driven in small pieces endways within the rim of the wheels, and then turned off in the lathe, might be serviceable, and could be cheaply renewed; these pieces might be secured by a foxwedge, as commonly practised in similar cases.' In Sir G. Cayley's patent he describes a wheel 'made with a deep flange, and to the opposite side of the tyre is secured a ring or annular plate of less depth than this flange; the space between the flange and the ring is to be occupied by a filling-up of hoof, or horn, or tough woods, or of other partially elastic substances, suitable for giving a slight degree of elasticity to the periphery, for diminishing the effects of percussion.'

"In 1839 Mr. W. Bridges Adams brought out a very ingenious elastic wheel, with spokes composed of steel rings, while the tyres were seated on wood blocks or felloes. Mr. Adams' wheels were tried under his own supervision, and at one time he had several sets running. The results obtained were not quite so satisfactory as he desired, principally because of certain practical difficulties met with in the construction of the wheel.

"Setting aside one or two isolated instances of the use of elastic wheels, he found that Mr. George S. Griggs, locomotive superintendent of the Boston and Providence Railway, United States, was the first to seat the tyres of his driving wheels elastically on a practical scale. The means he employed to effect this purpose are very simple. American locomotives almost invariably have cast-iron driving wheels, fitted with wrought-iron or steel tyres. The Griggs' wheel was made with a number of transverse dovetailed grooves, cast in the periphery; into these grooves blocks of thoroughly dried, hard wood, such as fine-grained old oak or hickory, were driven, so that the grain of the timber ran parallel with the axle, and across the periphery of the wheel. When these blocks had been driven into their places, the wheel was put into the lathe, and so much turned off them that only stood up above the surface, an eighth of an inch or so. tyre, previously turned up true inside and out, was then he and placed on the wheel, care being taken not to scorch the blocks on which it then bears, no metalic connection of any kind existing between the wheel and its tyre.

"The Griggs' wheel was brought out in 1857, and has been and is extensively used in America, with the best results.

"The 'Canton,' an engine on the Boston railway—as an example from many cited by the author—had run 133,373 miles; the tyres were now reduced to 1¼ inch in thickness. The four coupled drivers are 5 ft. diameter, and loaded with nearly 14 tons.

"The thinness to which tyres seated elastically on Mr. Griggs' plan had been worn was very remarkable, and such as we dare not attempt on a rigid seating. Yet the fracture of an engine tyre on the Boston and Providence road is all but unknown.

"Mr. Bridges Adams had lately introduced a very elegant arrangement. The rim of the wheel is turned slightly convex; the tyre is rolled with a groove on the inside. Into this groove two hoop springs, made in segments, and each about one-third of an inch thick, are placed, so as to break joint. These hoops are made of steel of the best quality. They bear only at their ends on the sides of the groove in the tyre, and the convex wheel rim, resting only on the centre of their breadth, is supported elastically. The tyre is secured in its place by a ring of iron sprung in at the back of the wheel. In a more recent modification, the rim of the wheel is turned perfectly flat, and only a single spring hoop is used, thickened in the centre of its cross section. This hoop is made in one piece, with the ends abutting, and forced on the wheel after being placed in the tyre by water pressure. The tyre of the first Adams' wheel, when unloaded, can be rotated on the wheel by hand, and a slight rocking motion of the wheel within the tyre is permitted, which enables the tyre always to adapt itself to the rail in the best possible manner. Wheels so fitted seldom or never slip. The area of surface between the spring and the tyre, and the spring and the wheel rim is so great, in consequence of the circular shape of the parts, that the wheel cannot turn with ease within the tyre when loaded; and this last, being elastically supported, yields slightly, becoming a little oblate, instead of remaining truly circular, and thereby acquires a better hold of the rail, consequent on an increase of bearing surface. Tyres usually break from tension; but the tyres in this case, being elastically supported, can scarcely be said to be in tension at all, and it was, therefore, very improbable that they should break even in intense frost. Indeed, two of these tyres had been cut across for the purpose of experiment, and in that state actually did three days' work drawing coal trains.

"The first trials of Mr. Adams' spring wheel were made on the North London Railway in 1858 or 1859. The spring tyres were applied to a set of disc wheels. The tyres were of Staffordshire iron, and ran a distance of 104,000 miles with very little wear. Low Moor tyres, rigidly seated on the same class of wheel, were completely worn out in running the same distance.

"The next trial was on the Eastern Counties line, in the early part of 1859, when Staffordshire tyres were fitted, on the Adams' system, to the four coupled wheels, 5 ft. 6 in. diameter, of a goods engine. The tyres were of the worst possible quality, and the springs very little better. These last broke and set so that they had to be removed, and thus far the experiment was a failure. In September, 1859, however, a pair of Cooper and Co.'s tyres, elastically seated on the same principle, were applied to the leading wheels of a tank engine, working the Woolwich branch of the same line. This branch abounds in sharp curves, one of them being but $5\frac{1}{2}$ chains radius, and another but $4\frac{3}{4}$ at the sharpest part. The engine had a 12 ft. wheel base, and the load on the spring wheels was $7\frac{1}{2}$ tons.

"The engine began working on September 21st, 1859, and the wheels ran, up to July 26th in the following year, a distance of 25,240 miles before being turned up. The wheels were put under again in September, 1860, and ran, up to January, 1861, a further distance of 8,776 miles. At this time the tyres got quite loose from the breakage of one or two of the springs, and the engine requiring repairs generally, was taken out of work for a time, and the spring tyres were not replaced. The same class of tyres put on in the ordinary way require re-turning when they have run but 8,000 to 10,000 miles, when the flanges are found much worn; afterwards, they must be turned up every 4,000 or 5,000 miles, until they are worn out.

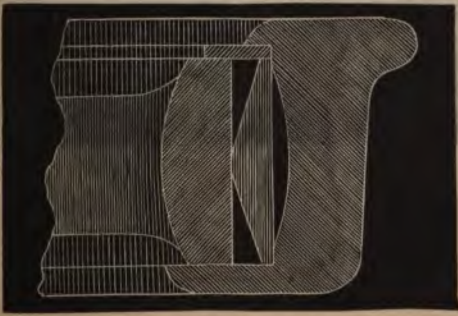
"Mr. Adams' tyres were largely used on the St. Helen's Railway, with great advantage. The author detailed at length the *results* obtained in the daily working of these tyres, showing that when Staffordshire iron was elastically seated, it actually gave a 3-5ths greater mileage than Krupps' steel rigidly seated.

"The last form of elastic seating to which he would call attention had been recently patented by Mr. Mansell. The wheel rim is first turned up, and then the inside of the tyre is bored out, so that when put in place a space of about one inch intervenes between the two surfaces all round. This space is filled with a ring of wood—teak being used by preference—on to which the tyre is forced, and secured in its place by six segments of iron on each side of the wheel. A groove is turned in each edge of the tyre, and a similar groove in each edge of the wheel-rim, into which raised ribs on these segments enter, while pins pass through the wood and secure the whole in place. These wheels have been so short a time in use, that many data do not exist about their performance as yet. A good many of them were running on the South Eastern Railway. On the Great Eastern Railway one engine had the leading wheels fitted on this plan; they had been running some months, and showed little signs of wear.

"An interesting discussion followed, in which Messrs. W. B. Adams, Z. Colburn, Ordish, Musey, and several other gentlemen took part. The paper was fully illustrated by diagrams."

Of these diagrams—as given in the report of the paper in the pages of the "Engineer"—we select three, figs. 6, and 7, showing

Fig. 6.



the arrangements introduced by Mr. Bridges Adams, and that of Mr. Mansell, all of which are described in the above given.

Fig. 7.

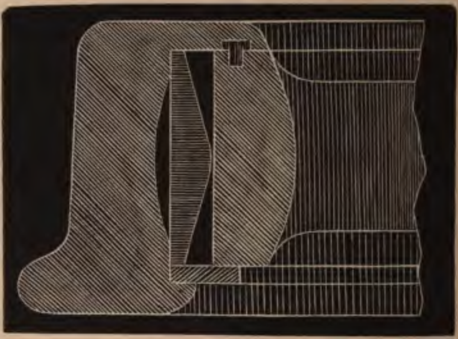
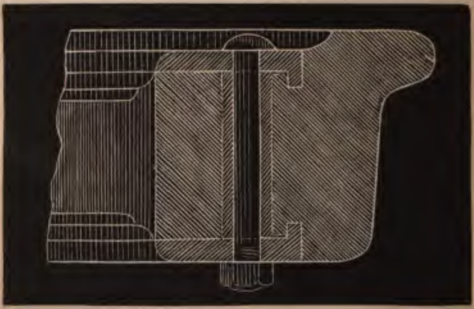


Fig. 8.



DIVISION SEVENTH.

SHIPS.

56. The principal class of naval architecture which has been engaging the attention of engineers and others has been that of iron-clad war-ships. To record the whole facts and figures connected with this department of ship-building (a department, indeed, which is in a decided state of transition) would be to fill volumes; we shall, therefore, confine ourselves only to the consideration of a few of the principal matters of importance in such department. The following article, on *Iron* v. *Wooden Ships*, we extract from the "Engineer:"—

"The question of iron *v.* wooden ships was discussed . . . . at great length, in the House of Commons. So practical a parliamentary debate, indeed, or one, at least, of so much interest to our profession, seldom takes place. An apparently strong case was made out on both sides, and although Ministers carried their point — that of laying down five new armour-plated timber ships—the practical consideration involved was by no means settled. For honourable members spoke much after the manner of counsel, each upon one side or the other of the case, and unfortunately there was no judicial summing up for the full guidance of the jury of members who did not speak at all. The notorious advantages of iron over wood, as a material for ship-building, do not appear to have been denied. and even the remarkable document lately penned by the Controller of the Navy, and made public by the Admiralty, did not, while condemning iron, deny these advantages. Indeed, the advocates of iron war-ships insist that Admiral Robinson's report contains within itself the best reasons in their favour and against timber ships. Yet, whatever conclusions may be logically warranted by this report, it cannot, especially when we bear in mind the selection already made by the Admiralty, be taken otherwise than as an official condemnation of iron ships of war. The Admiralty are perfectly aware that iron ships are lighter, stronger, and more durable than wooden ships; that the former afford more tonnage space *(especially in ships* with sharp ends), with the same external dimensions; that iron sterns are much better able to withstand the thrust and vibration of the screw, the former amounting, under full engine power, to between 60 tons and 70 tons in the large ships now building; that iron hulls are less likely to be set on fire by red-hot shot or shells (and the latter it appears can now be fired through the thickest armour plates); that iron ships can be greatly protected by bulkheads and water-tight compartments, and that injuries can be much more expeditiously and cheaply repaired than in the case of wood. All these facts are well known to and virtually admitted by the Controller of the Navy, and indeed by Lord Clarence Paget, and every speaking member of the Admiralty. So too, they must be perfectly aware that wooden ships will, after two or three years, soak up a weight of water often amounting to one-tenth of their own tonnage, thereby by so much increasing their displacement; and the Lords of the Admiralty must be furthermore aware that really good ship timber, such as English oak, is now very scarce, and that, already, the general adoption of foreign and mixed timber has diminished the 'life' of our wooden ships by nearly one half. And yet 'my Lords' prefer timber—inferior as it is to iron in so many points—because it has, on the other hand, certain advantages which, it is contended, iron does not possess. First of all, iron bottoms, especially when lying for a long time in harbour as war-ships, must foul to a great extent with barnacles, grass, oysters, &c., and thus their steaming or sailing qualities are most seriously impaired. This is especially the case in hot climates, although iron passenger ships and merchantmen, being so much more in motion, do not foul in the same degree. The coppering or yellow metal sheathing of a wooden ship, on the contrary, although not in itself noxious to marine plants and mollusca, is constantly dissolving away from the surface, so that nothing can obtain a permanent hold upon it. In the next place, when a ship unluckily goes upon a rock or other hard bottom, wood will unquestionably withstand a greater amount of thumping than iron. Naval men attach great importance to this fact, and they are ready enough to quote instances where iron ships have immediately filled or gone down after once striking a rock. The hole, too, knocked in the side of the Defence, and close to the water line, by one of the flukes of her anchor, was not forgotten, the other night, by Lord Clarence Paget. We are never tired of citing the long and complete endurance of the Great Briton, when aground in Dundrum Bay, but we must own that many other iron ships, like the Royal Charter, the Paramatta, the Colombo, and even the Prince Consort the other day, have broken up remarkably soon after striking. We do not forget that a number of iron ships, after having a hole knocked in them, thereby filling one compartment, have proceeded safely upon their voyages. Two or three cases of this kind were mentioned in the debate the other night, but others more striking might have been instanced. The Cunard steamship Persia, and the Canadian steamer North American, have crossed the Atlantic with their foreholds full of water. Yet wooden as well as iron ships may be made with water-tight bulkheads, and if there are not many, or any instances of this application among our own timber-built ships, we have only to look to the American wooden steamers formerly crossing the Atlantic, nearly every one of which, after the loss of the Collins' steamers Pacific and Arctic, were fitted with bulkheads. Again, too, the Controller of the Navy mentions that the compasses of iron ships are subject to deviations, which cannot occur on board timber-built ships; and he alleges furthermore that shot, on striking an iron ship, produce more and more dangerous splinters than in the case of wooden sides.

"We believe we have mentioned all the points upon which a superiority is claimed for wood as compared with iron. First, the timber-built coppered ship does not foul; second, it is alleged that it will hold out better when aground; third, it will not affect the magnetism of the needle, and lastly it is alleged that timber splinters cause less danger than results from the passage of a shot through the sides of an iron ship. Let us now briefly examine these four points. First of all, the comparison with which the Admiralty and the British public have to deal in this case is, not between timber built and iron ships, each *per se*, but between timber-built iron-plated ships, and iron ships coated with wood and armour plates. First, then, as to fouling:—Whatever may be the protection afforded by copper or yellow metal to an ordinary timber-built ship, it is as yet entirely unsettled whether copper will afford any protection whatever to an iron-plated timber ship. Sir Humphrey Davy found that oxide of copper was electro-negative to metallic copper, or, in other words, that when, as is necessarily the case in all copper sheathing, oxidation commences, a galvanic action is set up between the oxide and the pure metal, and that, in this action, the oxide is unaffected, while the pure metal is dissolved. So, too, sheathing nails and earthy matter adhering to copper plates are electro-negative, while the pure metal is, in itself, electro-positive. It is thus that the copper sheathing of ordinary timber ships is constantly dissolving away from the surface, thereby releasing all adhering matters. But as the copper is thus wasted, Sir Humphrey Davy proposed to introduce a line of zinc around the hull above, and in contact with, the sheathing. In this combination the copper became electro-negative, and the corrosion was confined to the zinc alone. But then the difficulty arose that the copper, no longer dissolved, became covered by seaweed and barnacles, which throve well upon it. So, to prevent this fouling, the zinc had to be given up and the copper left to gradual galvanic waste as before. Now, iron armour plates, in connection with copper sheathing, must be electro-positive, and the copper will not waste. And Sir Morton Peto told the House the other night that the French had already had a practical illustration of this truth, and that the iron-plated copper-sheathed La Gloire had forty tons of barnacles scraped from her bottom but a little while ago. Now, in this fact is contained a most important consideration in the question of armour-plated ships. For unless armour plates and copper-sheathing be kept from galvanic contact with each other, the former must waste while the latter is protected, and in this case copper must foul to the same extent as an ordinary iron bottom. Mr. Grantham has a plan for covering iron bottoms with planking and covering this again with copper sheathing. We cannot be quite sure, however, that in this case there is no galvanic contact between the iron and the copper, and although Mr. Grantham's plan has, we believe, been already carried out upon two or three iron ships we are unable to say whether it really affords any protection. But it is obvious that a small quantity of copper might be fixed directly to an iron bottom, thus rendering the latter electro-positive, so that it would, we may believe, dissolve away in the same manner as copper sheathing is now dissolved. *In this* case, an iron bottom would be always bright and free from weeds and shells, for the chemical waste of the iron in sea-water would, we may suppose, be somewhat different from that strongly adhesive oxide which forms in other situations. As, however, it would not appear desirable to produce corrosion of the bottom of an iron ship, it might be sheathed with iron plates of moderate thickness, say $\frac{1}{8}$in. more or less, and the corrosion thereby confined to the sheathing, which, we may suppose, would thus be kept clear. There are, of course, a number of paints, &c., recommended for the bottoms of iron ships, but none of these afford more than a very partial protection to vessels lying for a long time in harbours in warm climates.

"The next point to be considered is that timber bottoms will bear more thumping than iron when aground. If this is indeed the case, and it is necessary to build ships expressly to be run aground, it by no means follows that we should build wooden ships, but merely that we should cover an iron bottom with teak, which will not corrode the iron, and which, perhaps, may be coppered as Mr. Grantham proposes.

"As for the disturbance of the compass, it does not appear likely that a wooden ship with 1,000 tons of iron armour-plates on her sides, and several hundred tons of iron boilers and engines in her hold, would have any material advantage in this respect over a ship built throughout of iron, especially when it is well known that very little if any difficulty is now experienced in adjusting the compasses of iron ships.

"As to the alleged greater danger from iron than wooden splinters, we had always supposed that the danger was just the other way. When the Admiralty will erect and fire at two targets, the one representing the side of a wooden, and the other an iron ship, both targets being either armour-plated or not plated, it will doubtless be found that, under the same fire, the wooden splinters will be worse and every way more dangerous than the fragments of iron to anything behind the targets.

"As to the further question of building ships in Government dockyards or by private contract, we do not care to go fully into it. Admiral Robinson certainly committed a most imprudent act in casting slurs upon the iron ship-builders, but we cannot suppose that there is really any great danger that government ships will not still continue to be built of iron and in private yards.

If building is to be continued at all in the Government dockyards, it must, for the present at least, be mainly in wood; and we see no great cause for alarm in the iron trade or among iron ship-builders, because five new wooden ships are to be laid down. We may be sure that common sense and necessity will yet carry the day in favour of iron, and that while private builders will be largely employed, the Government establishments will be gradually adapted to work in iron also. The certainty that live shells may be fired through the thickest armour plates, to burst within the sides of a timber-built ship, will not, however, be very reassuring to the officers and men who will have to serve in the five vessels about to be commenced, and this fact, among many others of equal weight, leads us to hope that these wooden-sides may be the last of the kind to be constructed for the navy."

57. The chief difficulty in armour-plated ships seems to be *the protection of the bottom from fouling.* Government has offered a premium for a sheathing or other composition which will effectually prevent this. Several plans have been tested at Portsmouth, but none seems to have fairly prevented the mischief. On this subject the following is an abstract of a paper read before the Institution of Naval Architects by Mr. Hay :—

"The author remarked that a few years back the disadvantages arising from the oxidation and fouling of iron, and the consequent necessity for docking, as well as a loss of speed, almost led to a determination on the part of the Admiralty to discontinue the construction of iron sea-going ships. But at a time when the executive were debating about the sale of the whole of the iron ships the results of several experiments became known. A preparation of oxide of copper had been tried upon the Undine and several other vessels, and answered so well that the Government decided upon retaining those iron vessels which they had not sold. The author had tried many experiments that had occurred to him, but none stood the required tests so well as oxide of copper. An experiment was tried on the Rocket in May, 1845. On examination the results were found so satisfactory that, at the suggestion of Admiral Sir Hyde Parker, she was coated in Ju
1847, with alternate stripes of red lead and copper compositi
and when docked about the middle of 1848, she presente
curious appearance, many of the red lead patches being corro

aving weeds three or four feet long; while the patches of
osition were generally covered with a little slime, but there
either weed nor corrosion on them. A second experiment
ade in September, 1845, on H.M. yacht Fairy. Three differ-
inds of composition were then tried. With reference to the
two, one by a Mr. Owen, and the other by Baron Wetter-
, oxidation had gone on very rapidly, while with the third,
h consisted of a composition of pitch, naphtha, and copper
, chemically prepared by the author, no oxidation had taken
, and the only defect perceived in it was a partial flaking off
ioned by its being put on the bottom while in a wet state.
her experiment was tried on H.M. ship Recruit, in April,
. The copper oxide preparation was put on the port side,
burnt linseed oil and red lead on the starboard side, excepting
ce amidships, 4 ft. square, to which the oxide of copper pre-
ion was applied. On her return from the Tagus, the port
was found to have no adhesions, excepting about one dozen
barnacles; while the starboard side, excepting the space 4
uare, was covered with bushels of the *Lepus Anatifera*, or
barnacles. Of all the various compositions tried, oxide of
er had up to the present time been unequalled as a protector
e iron. The next best materials for protecting iron were the
rproof glue, and a varnish of foreign asphalte and mineral
dissolved in rectified naphtha, but these required great at-
on to the quality of materials, and also to the application of
. The basis of the anti-fouling preparation, which had for
past been used in H.M. service upon the author's recom-
lation, was sub-oxide of copper. The oxides of copper used
his purpose were the scales separated from sheets of copper
e 'pickling' process. These scales, after being pulverised,
mixed with a varnish made of vegetable pitch and rectified
tha. The author wished it to be understood that the pro-
re coating, when used with the oxide of copper anti-fouling
osition, was not intended merely to act as a non-conducting
um to prevent galvanic action, but to protect the iron from
ical action resulting from the action of air and sea-water on
ron. It appeared to him that this action was little under-
, judging from printed statements which occasionally ap-
d, and which attributed the loss and corrosion of iron to

galvanic action of copper preparations. The copper oxide paint could not act as a galvanic agent, as every particle of oxide of copper was insulated by the oil of varnish in which it was enveloped, and unlike preparations of a metallic character, which had been frequently tried, and required oxidation previous to combination with chloric acid, the oxide of copper was, as soon as uninsulated, ready for chemical combination with the elements of the sea-water. The author admitted that one great difficulty had existed since the first use of copper oxide—that of requiring careful supervision in its application, for when the varnish was made too thick it became locked up, and much of its usefulness was destroyed in not coming in contact with the sea-water; and, on the other hand, when the varnish was made too thin, the oxide sank to the bottom, and, if the mixture were not continually stirred, it got left there, and did not reach the ship. He had not, however, he stated, succeeded completely in suspending the copper oxide during its application. He takes the puce-coloured or sub-oxide of copper and roasts it till it takes up another equivalent of oxygen and is converted into black oxide. This is then boiled with linseed oil until it assumes its original pure colour as sub-oxide: the oil so treated becomes a quick drying oil, and is capable of suspending a large amount of copper oxide. In his plans for the anti-fouling composition the author included the application of zinc plates inside and outside of the hull of the ship to prevent oxidation from abrasion or other causes. There were numerous parts of iron ships of war which requires chemical supervision, as not only should every metallic fitting electro-negative to the iron be insulated, but every piece of timber should be insulated, especially in the bilge; for when wood decayed in contact with iron and sea-water it produced sulphuretted hydrogen. Certain woods, however, were less liable to decay than others when in contact with iron, and among them were teak and stink wood. In conclusion, the author alluded to the statements made respecting the foulness of the Warrior's bottom. He said that after she had been out of dock nine months she had no oxidation whatever on her bottom, although she was coated with the greatest expedition, it being then thought that her presence would be required in American waters."

58. The following is a short but practical paper read before the Glasgow Philosophical Society, by James Robert Napier, on "*Sections of least resistance for ships of limited breadth and limited draft of water.*"

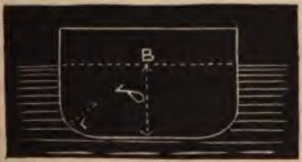
"As the friction of water along the submerged surface of ships forms an important part of the resistance to be overcome it is desirable that this surface be the smallest possible consistent with other conditions.

"The common problem of passing a curve of a given length through two points, so as to enclose the greatest area between the curve and the straight line joining the points, may be applied to the construction of all vessels whose breadth and draft of water are not limited.

"But there are many cases where both the breadth and draft of water are limited, it may be by the width of dock entrances and the depth of rivers. Then the problem becomes to enclose within a rectangle of a given breadth and depth the greatest area with the least wetted boundary that the enclosed area, divided by the wetted boundary, may be a maximum; for then, whatever form it may be considered necessary to give to the water lines, the vessel of this breadth and draft of water, with this midship section, these water lines, and with the narrower sections constructed on the same system, will have the greatest displacement or volume below water with the least surface for friction, and therefore the least resistance. In this sense I have called them sections of least resistance.

"To construct these sections the problem reduces itself to finding the radius of bilge, which, with the given breadth and draft of water, shall complete the section, whose area, divided by the wetted boundary, shall be a maximum.

Fig. 9.



Let B be the breadth of the vessel.
$\mathfrak{d}$ the draft of water.
r the radius of bilge.

$$\frac{\text{Area of Section,}}{\text{Wetted boundary,}} = \frac{B\,\mathfrak{d} - 0{\cdot}429\,r^2}{B + 2\,\mathfrak{d} - 0{\cdot}858\,r} \text{ is to be maximum.}$$

Therefore,

$$\frac{0{\cdot}858\,r\,d\,r \times \text{denominator} - 0{\cdot}858\,d\,r \times \text{numerator}}{(\text{Denominator})^2} = 0$$

$$\therefore r \times \text{denominator} = \text{numerator}$$

$$(B + 2\,\mathfrak{d})\,r - 0{\cdot}858\,r^2 = B\,\mathfrak{d} - 0{\cdot}429\,r^2$$

$$0{\cdot}429\,r^2 - (B + 2\,\mathfrak{d})\,r = -B\,\mathfrak{d}$$

$$r^2 - \frac{(B + 2\,\mathfrak{d})\,r}{0{\cdot}429} = -\frac{B\,\mathfrak{d}}{0{\cdot}429}$$

A quadratic equation from which the radius is found,

$$r = \frac{B + 2\,\mathfrak{d} - \sqrt{B^2 + 4\,\mathfrak{d}^2 + 2{\cdot}284\,B\,\mathfrak{d}}}{0{\cdot}858}$$

Examples.—When $\mathfrak{d} = 4\,B$ $r = 0{\cdot}114\,\mathfrak{d}$ when $\mathfrak{d} = \infty$ $r = \frac{B}{2}$

$$\begin{array}{llll}
\mathfrak{d} = 2\,B & r = 0{\cdot}23\ \mathfrak{d} & \qquad B = \infty & r = \mathfrak{d} \\
\mathfrak{d} = B & r = 0{\cdot}35\ \mathfrak{d} & & \\
\mathfrak{d} = \frac{1}{2}\,B & r = 0{\cdot}54\ \mathfrak{d} & & \\
\mathfrak{d} = \frac{1}{3}\,B & r = 0{\cdot}63\ \mathfrak{d} & & \\
\mathfrak{d} = \frac{1}{4}\,B & r = 0{\cdot}70\ \mathfrak{d} & &
\end{array}$$

By describing sections in a rectangle whose breadth equ twice its depth, it will be found that

$$\frac{\text{Area of rectangle}}{\text{Wetted boundary}} = \frac{2\,\mathfrak{d}^2}{4\,\mathfrak{d}} = 0{\cdot}5\,\mathfrak{d}$$

$$\frac{\text{Area of semicircle}}{\text{Wetted boundary}} = \frac{\frac{1}{2}\,\pi\,\mathfrak{d}^2}{\pi\,\mathfrak{d}} = 0{\cdot}5\,\mathfrak{d}$$

$$\frac{\text{Area of best section}}{\text{Wetted boundary}} = \frac{2\,\mathfrak{d}^2 - 0{\cdot}43 \times (0\ 54\,\mathfrak{d})^2}{4\,\mathfrak{d} - 0{\cdot}86 \times 0{\cdot}54\,\mathfrak{d}} = 0{\cdot}531\,\mathfrak{d}$$

showing that when the radius of bilge is 0·54 times the draft water there is a gain of about 6 per cent. over the semicircu or rectangular section.

"Professor Macquorn Rankine said that he had revised t mathematical investigation in Mr. Napier's paper, and could c roborate its accuracy. Its practical utility arose from the f that the whole, or nearly the whole, of the resistance to the moti of a well-shaped ship arose either directly or indirectly from fi tion. A theory based on that fact had been applied to pract in designing steamships and their engines by Mr. Napier and hi elf, in December, 1857, and subsequently, and in every instance vith success. He had read a paper giving a general account of he theory, and an explanation of the practical formulæ deduced rom it, with tables of comparison between their results and those f experiment, to the British Association, in 1861. That paper vas published entire in the *Civil Engineer and Architect's Journal* for October of that year, and, in part, in other engineering periodicals also. The theory was connected with some researches on the motion of waves, which were read in abstract to the British Association, and in full to the Royal Society in 1862.

"As might be expected in a theory whose practical application was only four years and a half old, various questions still remained to be settled by experiment. A serious obstacle in the way of obtaining exact experimental data as to such questions arose from want of precision in the indicator diagrams of steam-engines, especially in engines of rapid stroke, which was produced partly by the friction of the indicator, but chiefly by the oscillations of its spring. One of the best means of diminishing the extent of these oscillations, and the effect of friction at the same time, was to increase the stiffness of the spring and diminish the mass of the indicator piston. He had seen at the International Exhibition an indicator (that of Mr. Richards) in which that principle had been adopted, and so far as he could judge from having seen it in action two or three times, with very good results, in point of precision.

"A comparison of the diagrams given by a very accurate indicator applied to the engines of such vessels as the Admiral, the Athanasian, the Lancefield, &c., would settle some very important points regarding the comparative advantages of straight and hollow water lines, &c. Unfortunately, when vessels were engaged in trade it was difficult to find opportunities for making scientific experiments upon them.

"The special subject of Mr. Napier's paper, however, was not ne of these problematical points; for there could be no doubt that o diminish a vessel's mean girth, as compared with her sectional rea, was a certain means of diminishing resistance; that princi-le, indeed, had been admitted ever since friction had been recog-ised as one of the causes of resistance; and Mr. Napier's in-estigation showed *how to carry* that sort of diminution as far as possible under the circumstances stated by him, viz., a fixed extreme breadth and draft of water.

"The importance of smallness of girth in diminishing resistance was strikingly shown in the case of the well-known match between the yachts Titania (now called the Themis) and America. The Titania was the smaller vessel of the two, and had the less capacity for carrying sail; and in order to make her speed equal to that of the America, her friction ought to have been less in the same proportion with her capacity for carrying sail. But while the cross-sections of the America were nearly triangular, those of the Titania were formed by ogee curves of great concavity, producing a comparatively large girth relatively to her capacity; and although the Titania had a smaller midship section than the America the quantity called the 'argumented surface,' upon which the friction depends, was almost exactly equal in two vessels, and hence the Titania, having the less power of carrying sail, was beaten in the race."

59. The following article on the "*Science of Ship-building,*" and referring to the above paper, is from the pages of the "Scientific American."

"It has hitherto been the common theory respecting naval architecture, that the speed of a vessel under a given power is mainly dependent upon what are known as her "water-lines," or shape from stem to stern. The main study of ship-builders has, therefore, been to perfect these lines so as to diminish resistance and avoid the formation of eddies while the vessel is in motion. Probably they have reached perfection of model in this respect; but much room was still left for improvement in another important particular. The weight and inertia of the water to be displaced by the vessel, does not constitute the whole of the resistance to be overcome. A large additional amount arises from the friction between the water and the entire submerged surface of the vessel. This is due to the viscidity which water possesses in common with all fluids. A film of water adheres to the entire submerged surface, and when the vessel is moved there is a resistance to be overcome, arising from the cohesion of the particles constituting the film with the particles lying next to them. Of course, this resistance will be overcome in proportion as the submerged surface is diminished. It thus seems highly important to form such transverse sections of a vessel as shall, with the maximum area or contents below the water-line, afford the maximum extent of boundary line or wetted surface. This problem forms the subject of a paper lately read before the Glasgow Philosophical Society by James R. Napier. In the construction of vessels whose breadth and depth of water are not limited, the question reduces itself to the common mathematical problem of passing a curve of given length through two points, so as to enclose the greatest area between the curve and the straight line joining the points. But when the breadth and draft of water are limited, as by the width of dock entrances and the depth of rivers, the problem is far more complicated. The given dimensions of breadth and depth afford a rectangular space within which it is required to enclose the greatest area with the least extent of boundary—wetted surface of the vessel. A transverse section of a vessel thus constructed will afford the greatest displacement or capacity below the water-line, with the least surface for friction. The breadth and draft being thus given, the problem is to find the radius of curvature, or radius of bilge, which will afford the shortest boundary enclosing the greatest area—the line which will secure the greatest carrying capacity with the least frictional surface. As this radius is formed in terms of the breadth and depth, it can be applied to the construction of all the transverse sections from the stem to the stern of a vessel. It does not interfere with the water-lines, and thus these 'sections of least resistance' may be introduced into a vessel having water-lines of any desired model. We can scarcely do more in this article than indicate the general process by which this 'radius of bilge' is found. Such a curve is to be found as will enclose the greatest area with the least boundary, Of course this area, divided by the proposed boundary, must be a maximum. By the methods of analytical geometry we first find this proposed area in terms of the proposed breadth and depth and radius, (the latter as yet being an unknown quantity). In the same manner we find the proposed boundary in the same terms, the unknown radius being likewise involved. Placing the value of the area as a numerator, and the value of the boundary as denominator, we have a fraction of which we have now to find the maximum value. This is readily *done* by the methods of the differential calculus. A quadratic equation appears in which the radius is the unknown quantity. Solving this equation, we find the value of the radius in the known terms of breadth and draft. This is the radius of curvature which will afford a maximum area below the waterline of a vessel with a minimum amount of surface. The following are some values of this radius, for given breadths and depths:—

"1. When D (depth) $=$ 4 B (breadth), then r (radius) $=$ ·114 D. 2. When D $=$ 2 B, then $r =$ ·23 D. 3. When D $=$ B, then $r =$ ·35 D. 4. When D $= \frac{1}{2}$ B, then $r =$ ·54 D. 5. When D $= \frac{1}{3}$ B, then $r =$ ·63 D. 6. When D $= \frac{1}{4}$ B, then $r =$ ·70 D.

"Taking the fourth of these propositions where the depth is one-half of the breadth, and constructing a section with the ascertained radius, the area divided by the boundary gives a result expressed by ·531 D. When we make the section a simple semicircle, the area divided by the boundary gives only ·5 D, showing that in the proportion of surface to area, there is a gain of about six per cent. in the section above described over a semicircular section. The gain is still greater over sections formed by ogee curves of great concavity, such as are sometimes employed on vessels. That cross section which gives the greatest ratio of its area to its boundary is entitled to be called 'the section of least resistance.' It follows from this also that of two steamers, equal in displacement and capacity, with engines of the same power, and equally well modelled as to water-lines, the one will excel in speed whose sections are constructed with the radius of bilge as found according to the method set forth in the paper of Mr. Napier. These results of pure mathematical science are not chimeras, for they have been applied with unprecedented success in the construction of several steamers in Glasgow, and they must ere long come into general application. They furnish another illustration of the value of pure science in promoting the progress of the useful arts. Mechanical ingenuity, however great it may be, cannot dispense with the deductions of science, but must employ them in attaining the highest results."

60. Up to a certain point in the history of the art of modern ship-building, we find that there are two systems, each advocated with uncompromising eagerness, namely, the "wood" and "iron" system, of which the latter may be said to be one in the highest favour, so much so, that iron seems to be gradually superseding

wood. Numerous as are the advantages of iron for ships, it is indisputable that it possesses a very great disadvantage in the readiness with which the bottoms "foul." Attention, therefore, has been drawn of late to the advantage of a compromise of material to be used, by which all the strength of iron could be obtained with all the advantages of wood in the prevention of fouling. Another objection to iron is "local weakness." Under the title of *Composite Ships*, the "Mechanics' Magazine" has an article, in which the leading features of the system are described, of which we give an abstract:—

"Two very excellent specimens of this description of vessel may now be seen, one at the building-yard of Mr. Langley, at Deptford Green, the other at Messrs. Fletcher's, of Limehouse. Both of them are building under the inspection of Lloyd's surveyors, with a view to their classification in the Register book, and both will be classed for a high term of years. So far as the rules of Lloyd's bear upon the construction of composite ships, the vessel at Mr. Langley's establishment is constructed in accordance with the scale given for iron vessels of 1,000 tons burden, but as there are many points of construction upon which no definite rules have as yet been laid down, we propose to give the following few particulars concerning her:—

"Her keel, which is of American elm, is 226 feet long and 16 inches square; her sternpost and stem are of teak, each having more than the ordinary moulding, or breadth, in a fore and aft direction, in order that the wood ends may be well supported and bolted, and properly housed in the double rabbet provided for them. Fore and aft the keel, rising well up the post and stem, and firmly bolted thereto, is wrought a flat keel-plate of iron, 36 inches in breadth and $\frac{3}{4}$ths of an inch in thickness, and this may be said to form the foundation for the iron frames which come upon and are firmly riveted to it. The longitudinal strength would appear to be well provided for, the stringer plates on the iron beams at the sides of the vessel being 32 inches by $\frac{10}{16}$ths of an inch, in addition to which is a gunwale angle iron, 5 inches by 5 inches by $\frac{8}{16}$ths of an inch, a sheerstrake 20 inches by $\frac{8}{16}$ths of an inch, and, of course, the usual longitudinal and diagonal tie-plates on the beams. Both outer skins are composed of 3-inch teak, wrought *longitudinally*; the garboard strakes, however, being $4\frac{1}{2}$ inches in thickness, thus giving a substance of 9 inches at a part of the vessel where such a provision is invaluable. Throughout the entire hull of the ship, the inner skin, or that which is wrought against the iron frames, is double fastened, there being two $\frac{3}{4}$-inch galvanised iron nut and screw bolts in every plank at every frame, their heads being let in flush with the outside surface of the planking. And now we come to speak of a provision which, considering the manifold and varying strains to which a ship is subjected, must be of almost incalculable advantage for securing general strength throughout the hull. This provision consists in two sets of iron straps 5 inches by $\frac{1}{2}$ an inch, extending from the top sides to the bottom, spaced about 4 feet apart, measured on a square, and worked diagonally. The first set are let in flush with the outside surface of the inner or first skin, and the second set are worked to cross the first at opposite angles, thus forming, as it were, a network of iron straps throughout the hull, secured to every frame, and tending to bind the whole of the planking as one whole skin. The outer skin is now brought on, covering the seams of the inner one, and double fastened to it throughout by $\frac{3}{4}$-inch yellow metal bolts, clenched, of course, on the inside of the inner skin.

"Here, then, we have a ship, the entire frame of which, together with the decks, beams, and other internal fittings, possess all the strength of those of an iron ship, the two thicknesses of 3-inch teak, and the two sets of diagonal riders, being substituted for the outside plating, thereby affording the opportunity of coppering the bottom without the slightest disadvantage, and, at the same time, the great evil of local weakness is avoided. We may go on improving the manufacture of our iron, we may get it to bear double the tensile and cross strains it now bears, we may argue that a ship should be built on the 'girder' principle for strength, and we might quote theory to prove us right in all our advances; but stern daily practice brings us back to cope with matters for which theory does not provide, and for which it is not likely it ever can provide. Ships *will* come into disastrous collision, *will* run upon shoals and sands, and *will* occasionally bump themselves upon the tops of sharp-pointed rocks; and recent experiences go to prove that these occurrences are not *by any* means rare exceptions; on the other hand, they are frequent and alarming, and it would not, we think, be saying too much, if we affirmed that every ship constructed might be expected to meet with the casualty of grounding at least two or three times during the term of her natural life. When by any chance an iron vessel lands herself upon the rocks, her chances of escape are few and small. We know, of course, of cases where they have been saved, but it is not well to reason upon exceptional cases, or we might instance the loss of a large, new, strong iron steamer, called the 'Run Her,' which was lost, not under circumstances of perilous weather, she having run into the harbour of Terceira, passed the shipping, and actually brought up to anchor, when she struck upon a rock, and became a total wreck. Concerning wood ships, however, what we know is—and the evidence of the vessels themselves in dry docks confirm, while their logbooks attest the facts—that scores of them have been on the ground and rocks, thumping and chafing for hours under conditions which would have rendered the strongest iron vessel a total and irreclaimable wreck.

"In comparing these vessels with those built entirely of iron the two chief points of superiority, it may be said, consist in the wooden bottom, whereby early fouling and local weakness are avoided; but in comparing them with ships built entirely of wood, they appear to possess several advantages—first, greater capacity for size of hull; second, greater general strength of hull; third, less liability to decay; and, probably, they will prove less costly to repair. At any rate, all the essential parts of such a vessel are always exposed, and to be got at, while the frame timbers of a wood ship are shut up from its birth, and often not opened until dry rot and sap have worked dreadful ravages. Many, very many shipowners know this to their cost, and will, we are sure, endorse this statement.

"There are, however, one or two points in the construction of these composite ships which appear to us to be worthy of further consideration, and which, we think, will commend themselves to the attention of ship-builders. In the first place, we would like to see the flat keel-plate of such a thickness as would warrant us in believing that it would last the vessel her lifetime, because it really forms a most essential feature of her, while its position renders it both difficult and expensive to repair. Then, again, we think that those flanges of the iron frames which receive the fastenings of the planking, might, with prudence, be slightly increased in breadth, seeing that, in a double-fastened vessel, the bolt holes in them are very numerous, and, in many cases, so near their edges as to impair their strength. Next, we look upon it as desirable that the inner of the two outer skins should be at least lightly caulked; and, although we have stated our preference for the employment of the two skins of outside planking, yet we question whether it would not be wiser to stop these at a short distance from the keel, and introduce a few strakes of thick planking, rabbeted edgewise, and the garboard strakes themselves cross-bolted from side to side. All these are only small points in themselves, but we know of no other mechanical structure in which it is so essential to keep always in mind the fact that a perfect whole can only be produced by unremitting attention to matters of detail, for we know of no other structure, of even approaching magnitude, which is subjected to the trials and strains, the vicissitudes and misfortunes, of a heavily laden ship at sea."

DIVISION EIGHTH.

METALS USED IN CONSTRUCTION.

61. The following arrangement of this division will facilitate ready reference to its contents:—*a.* Cast-iron and wrought ditto; *b.* Steel; *c.* Lead and other metals. On the historical points connected with the introduction of iron, Mr. Fairbairn, in a paper read before the Literary and Philosophical Society, Newcastle-upon-Tyne, has the following:—

"It requires no great depth of research to discover the time when iron first came into use in aid of our manufacturing industry. It is almost within the recollection of the present generation, and we may safely date its application to the discoveries of Watt and Arkwright. Its extensive use may date from the commencement of the present century, or, more accurately, from the close of the war, in 1815, when a new era burst upon the country in the arts of peace. From that time up to the present there has

continuous and amazing increase—an increase unparalleled
history of nations, and without example as regards extent,
s varied forms of application to constructive art. It must
the recollection of many persons now living, how very im-
t our machines and mechanical constructions were as late
20. At that time the steam engine had certainly attained
ible shape in being composed entirely of iron, and millwork
ust emerging from the state in which it was left by Smeaton
Rennie. Both of these engineers had introduced improve-
by substituting iron for wood, and the latter, in his con-
ion of the Albion Mills, was the first to supplant the old
n wheels by the more compact and ingenious constructions
t-iron. Smeaton and Rennie may, therefore, be considered
oneers of iron appliances."

A most elaborate paper was read before the Scottish Ship-
rs' Association on "*Iron — Its Molecular Structure and*
etic Distribution," by Mr. Paul Cameron, and was fully re-
l in the "Mechanics' Magazine," of which report we here give
h illustrations—an abstract taking up the principal points
d of. "This subject," says Mr. Cameron, "is attended
many difficulties which stand in the way and break the con-
ng links in the chain of our process of reasoning. I may
ly admit that I have not selected it with the view of clearing
these difficulties. My object is to bring before you an out-
f the various theories that have been proposed, to account
e metalliferous formation, and my endeavour to trace how
e magnetical influence may have induced their structure and
lidation.

Ve have not as yet definite ideas of the molecular forces
induce the magnetic condition, so that on this question we
ee to advance such ideas and principles as will bear the test
periment, and from these deduce the probable results."

ving reviewed the various theories proposed to account
etalliferous formation, and concluding this review by no-
Mr. Hopkins' theory that "all mineral veins have been
d by magnetic currents," Mr. Cameron proceeds :—"By
icity or magnetic influence we possess the power of composing
ecomposing bodies, causing the union of simple substances
m compounds; and it may be also applied to the separation

of compounds into their elementary constituents. Its secret influence is actively engaged in the development of all the varied forms presented throughout nature. The forms which crystalline matters assume have been termed primary and secondary, the latter being derived from the former. The primary forms of the crystals are supposed to be six, as the cube, prism, equilateral, parallelopiped, &c. From these the varied forms of the secondary are induced. . . . .

"Before proceeding with the inquiry as to the relation subsisting between electrical energies and matter, it may be well that we assume a hypothesis, so that in our process of reasoning we may keep the following propositions clearly in view:—

"Energy is a function; and its immediate indications in bodies depend on the atomical structure of the mass; thus, two bodies whose energies are equal, the bodies are then equal to one another.

"When two bodies differ in energy, the one continues to absorb from the other until they become equal. Sensitive energy induces energy in all bodies within its sphere of action.

"When a body is acted upon by energy, a progressive change takes place in the structure of that body, the change being expansion or contraction; so that these bodies may possess active energy without indicating sensitive energy—this depending on the condition of the mass. Energy in equilibrium is latent, when not in equilibrium it is sensitive. The particular molecules of matter arrange themselves in a particular way when expanding, and re-arrange when contracting; and it is the particles so changing their arrangements, if we conceive them to be of a cubic, prismatic, triangular, spheroid, or oblong form, which causes contraction at the beginning and expansion at the end. This is a law indicated by all metals. If we reason as closely as possible on the following definitions—1st, energy; 2d, polarity; 3d, expansion; and, 4th, contraction, these appear to me to form distinct principles of action. In order that we may more clearly understand these definitions, let us suppose that we take a series of small triangular steel plates, and combine them so as to form a parallelogram similar to the diagram A, fig. 10, taking care that the reed or grain of the metal runs in one direction; when they are bound together, magnetize them by any convenient mode, and they wil form a combined magnet, each end indicating polarity. If we now

Fig. 10.

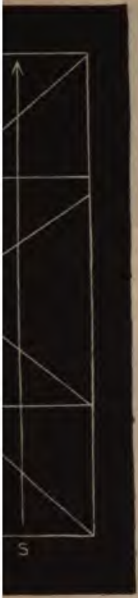


Fig. 11.

the triangles, each will form a distinct magnet of itself. each cube or triangle to represent certain forms of atoms mpose the mass of matter, however different the atomic matter may be, these, at least, convey to our ideas certain rms of arrangement.

eferring to the diagram B, fig. 11, it will be observed polarities of the cube, marked N and S, are so arranged ract each other, this indicating cohesive energy, also rance of solidity.

12 (C) represents a cube and triangle attached. By this ent it will be observed that the solidity is not so com- in the former, the S O poles repelling each other weakly, N S attract each other, this arrangement weakening the f the mass, and making it more brittle or sensitive to the f heat.

Fig. 12.

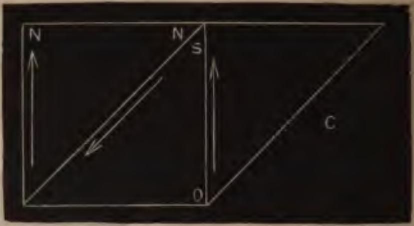
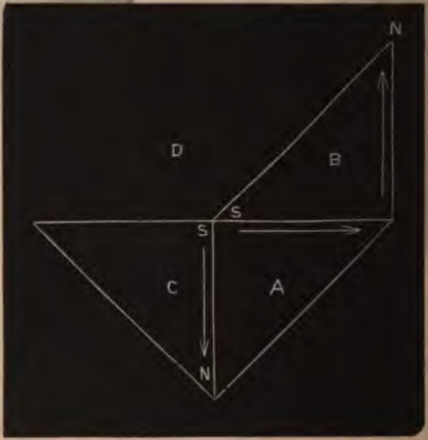


Fig. 13 (D).—The position of the triangles forming C, A, B, the

Fig. 13.



suppose the triangle A to represent an atom of hydrogen, and th triangles B and C proportions of oxygen ; in this arrangement th S S S are repelling each other, and the N S attracting each other This arrangement, so far, represents to us the components of wate and the repulsion of the S S convey an idea of the cause of fluidit and when the energy of heat is applied, vapour or steam is t

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* "I have here referred to fluids simply to show that the same proces *reasoning* can be equally applied to them as metals."

effect. The energies S S S convey to us an idea of the cause of the latent heat of fluids and the light vapour which arises in the absence of sensitive heat.

"By reversing the triangle A, that is, to place the N to N, all the polarities would then be repellant, so that neither solid nor fluid could be formed; hence we can form an idea of the gaseous arrangements; when the energy of heat is applied, their great expansion, and when the energy of force is applied, their great compression, extreme pressure forcing many of them to assume the fluid form.

"The first definitions of magnetism are attraction and repulsion. These clearly imply two distinct and opposite forces. For the evidence of this we are referred to the magnetic bar, the one end attracting and the other repelling. We may naturally inquire, Does the one-half of the bar attract the force and the other repel it? We know of no law which can assist us, by any process of reasoning, to offer an explanation. We know, by the mechanical law of forces, that forces which are equal can only remain in equilibrium, and, for the time, cease to indicate energy or force; but we know that this energy still continues. Then, does one-half of the bar receive one description of force, and the other an opposite. This seems equally absurd. Then, do the forces reside in the bar? We think not; for we know that we can induce it in bars that seemed to be free of it, so far as indicative of energy or power; we also know, when we induce magnetism by physical action or otherwise, that the structure of the mass composing the bar undergoes a change—that of expansion—thus clearly indicating that a certain arrangement within the mass is necessary previous to its indication of the magnetical energy. We may now freely inquire,—Did the mass, in its former arrangement, resist energy, or was the energy in equilibrium with the inertness of matter, waiting for the touch of energy to overcome the equilibrium of the mass, and reconstruct it so as to indicate energy? Then is energy not a property of matter? We think not. Matter seems passive, and is acted upon by impulse or energy, which is co-existent with matter, but independent of it.

"Let us now endeavour to explain why attraction and repulsion are indicated in the magnetic bar. I have often endeavoured to reason the magnetical *indications* on hydrostatical principles—

that of the flow of fluids forming currents. Then let us, by analogy, suppose a current setting in any particular direction, similar to the annexed engraving. Suppose the force of the current setting from north to south. Now let us suppose the force of another current of less power, setting in the opposite direction—that is, from south to north. It will be evident that, if the opposite currents were equal, they would repel each other, and thus induce motion at right angles to that of the others; but the one being weaker than the other, becomes absorbed by the stronger, so that this, so far, represents to us the effects indicated by two magnets; the poles of the weaker would be reversed by the stronger currents.

Fig. 14.

"In reasoning the magnetical indications on hydrostatical principles—that is, the flow of a current—it may be necessary, before proceeding further with the magnetic laws, that I define, as clearly as possible, those terms which we shall require a free use of in the examination of the causes that produce the deviations of the compass in iron ships.

"The polarities of the magnetic needle are the first indications of energy which we may call magnetical force, magnetical energy, or magnetical influence. There is one point that we must endeavour to form as clear a conception of as possible. We have not as yet any clear definition of the terms 'polarity,' 'polarities. These are generally understood to express two opposite forces, as attraction and repulsion. They have been defined by Dr. Whewell as a *contrast of properties corresponding to a contra of positions.* In the first part of this definition we have still difficulty to contend with, as we cannot well define or conceive a contrast of properties. Of the latter we can form some i but we cannot well conceive of energy or motion being a cont *of positions*; and it seems evident that, as long as we reason

gy being a property of matter, we shall still have to contend
those mechanical facts which will at all times stand in the
when we endeavour to reason the magnetical laws on me-
ical principles. There is no good reason why we ought to
rd energy or motion as a property of matter. Let us assume
the mechanical laws are correct, then let us discuss the mag-
cal laws on clearly-defined mechanical principles.

Energy is a function ; and its immediate indications in bodies
end on the atomical structure of the mass : thus two bodies
se energies are equal, the bodies are then equal to one another.
en two bodies differ in energy, the one continues to absorb
the other until they become equal. Sensitive energy induces
gy in all bodies within its sphere of action. When a body
ted upon by energy, a progressive change takes place in the
cture of that body, the change being expansion or contraction ;
hat these bodies may possess active energy without indicating
itive energy—this depending on the condition of the mass :
gy in equilibrium is latent, when not in equilibrium it is
itive.

The term polarity conveys to us an idea of energy of motion.
great question now is, Is energy or motion a property of
ter? We think not, for we cannot well conceive of motion
ing and then giving motion to itself, nor can we have the per-
ion of matter giving motion to itself. It is true we have
y learned papers on the conservation of force into *vis viva*,
still we are without the answer to what is energy. One point
as plain—that is, we can form an idea of matter being passive
acted upon. In this view of the question we can reason all
cation of energy or motion on clear mechanical deductions :
, let us fix in our mind the meaning of the terms polarity
energy, and what we mean by them. Polarity we apply to
ter, and believe it to be a certain condition or arrangement of
atomic mass of matter ; and that matter, when acted upon by
gy, is indicative of its influence—the amount of that influ-
depending on the arrangement or construction of the atomic
. I know that the question may now be asked, What is
gy or motion? Perhaps a blank line might convey as much
his point as any explanation I might offer in words. It is a
tion that seems *for the time to* be veiled ; but I do not know

what I believe it to be. It is the parent of matter; it effect of an eternal and primary intelligent cause; and its on inanimate matter constitute one of the great sources happiness in observing and studying its laws; but the qu may be equally asked, and with as much reason, *What is m* Its ultimate basis or properties we know as little of as we the primary cause of motion. . . . .

"Let us now assume that polarity conveys to us a certai dition of the atomic mass, which mass is pervaded by which continues to act upon it, the atomic arrangement i ing the lines of energy which may either impede or deflec energy. From this we can perceive that, by certain arrange of the atomic mass, matter may be either compressed or re thus giving an idea of gravity, cohesion, and expansion. this view of the question we may have as many conditi force indicated as the atomic form may have sides to refl Assuming this hypothesis of energy acting on matter, all th ditions of force may be indicated as—

Central force is	Gravity.
Resisting force is . . .	Inertia.
Elastic force is	Repellent.
Affinitive force is . . .	Cohesion.

"That we may, by analogy, form some idea of the polar netic indications, let us suppose we have three tubes of any venient length, and that these tubes are so arranged that or gas may flow through them (see fig. 15), A, B, and C. I

Fig. 15.

be evident that, when the current is flowing through each tube the upper ends N, N, are the including or attracting, which also repel that of the fluid which they cannot receive, and the lower ends repel, in consequence of the discharge of the fluid, so that the tubes are in a condition of attracting and repelling. But suppose the current in the tube C to be reverse to the former, the current passing up this tube will then be in the condition of being attracted by B, as it will convey the fluid from S to N, thus equalizing each other's forces by a continuous current being formed. This, then, is similar to the effects of two magnets, the one force equalizing the other, although the magnet A would still maintain its condition of repelling B. Suppose these tubes to be transverse to the indicated current, it will be evident that the current would cease to flow, and that the attractive and repelling forces would cease to be indicated, although the flow might continue without that force being indicated, this so far giving an idea of bars that are magnetized north and south, and those that are not, also of bars east and west.

"I have endeavoured to show that magnetism may be reasoned on principles similar to that of the flow of a current. Then it would seem plain that, when we discover the set or flow of a current, we may use means to equalize that flow or set. We now come to the question, How are the magnetic currents induced? It appears clear that the induced magnetic power depends on the atomic arrangements of the mass, and that the magnetic influence may either bind or loose the atoms of matter. Indeed magnetism may for a time react against the great natural law, but the weaker current must ultimately give way to the stronger. To induce sensitive magnetism in a bar or plate of iron, the bar or plate must be rolled or hammered in a line with the magnetic meridian. By this means we induce a sensitive current of magnetism in the bar or plate. Also, if the bar or plate be suspended in the magnetic meridian, it will acquire magnetism by induction without physical action. Magnetism may also be powerfully induced by the galvanic battery.

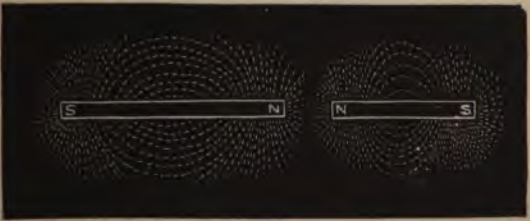
"That we may understand this more clearly, let us suppose that we clip or twist a strip of iron in the magnetic meridian, it immediately forms a magnet. Suppose that we clip or twist a strip of iron in an easterly or westerly direction, its magnetism is indefinite to polarity; thus clearly indicating that there is no current of magnetism from east to west to induce magnetism in iron. From this we observe that bars or plates which may be rolled, hammered, bent, or clipped east and west, will be comparatively free of magnetism, compared with those rolled or twisted north and south. This, then, so far assists us in reasoning on the deviations of the compasses in iron ships. Then let us keep clearly in view these leading facts, that we may draw clear deductions from them. Let us first examine the magnetic condition of the iron previous to its being used in the construction of the ship.

"The rolling of the iron is the finishing process, so far as the manufacturer is concerned; on the direction in which it is rolled and cut depends the strength of its magnetic condition. The direction in which the iron is rolled may be favourable to the arrangement of the atomic mass composing it. Bars or plates rolled in a polar direction will at all times indicate a greater flow of magnetism. From observations I have made in large iron manufactories, I have observed that iron, during the process of rolling, acquired an amount of magnetism, the quantity of that magnetism depending upon the direction in which it had been rolled; and the magnetism so acquired is not, in my opinion, at all times destroyed during the construction of the ship. The experiments of Dr. Scoresby on iron bars and plates, in reversing or changing the magnetism, demonstrate the power we possess by physical means of making the magnetic laws so far subservient to our designs in the construction of our ships; but while we keep strictly in view the utility of these experiments, we must be careful in our deductions when applying them to the building or construction of iron ships." . . . .

"I have stated that the strength of the magnetic condition depends much on the direction in which the iron has been rolled; and I am not altogether inclined to think that iron which readily indicates the flow of magnetism is of an inferior quality. This conclusion I have come to from extensive observation and practical experiments. Keeping first principles in view, it seems to be clearly indicated that the strength or flow of the magnetic current depends on a certain arrangement of the atomic mass composing the bar or plates; and this arrangement of the mass is induced by the bars or plates being rolled in a polar direction, which will at all times induce a free current of magnetism; and I believe that this atomic arrangement of the mass is calculated to improve the quality of the iron. It has been proposed to determine the quality of iron by its magnetic condition—that is, iron which indicates a free flow of magnetism is inferior. This may be doubted, as it will not at all times stand the test of observation and experiment; for we know from the latter that bars of steel which may be hardened near to the magnetic meridian will immediately indicate distinct polarity, and the bar which may be hardened east and west will be indifferent to polarity, and will never indicate a strength of magnetism equal to the former when both are magnetized by the galvanic battery.

"Let us now examine the indications of the magnetic needle, that we may have a clear perception of the magnetic influence, from a steel bar which has been magnetized. Suppose it to be placed under a sheet of paper, and iron filings strewed over it; when the paper is gently tapped these particles form themselves into curves, taking a distinctive elliptical form, as shown in the annexed engraving (fig. 16); but if the magnet be held above the paper the effect is just the reverse. A bar or needle will at all times produce similar effects to the above. The first of these apparent properties are attraction and repulsion. I have previously referred to these properties, and endeavoured to show that those apparent effects are the result of one great simple primary cause—the flow of energy; and it is only by a certain arrangement of the atomic mass that this energy is made apparent. Then it seems clear that this energy, in its indications, flows as a current. The question

Fig. 16.



now is, What are the indications when a current flows? *First,* it sets in a particular direction, as north and south; then it must be evident that if a current were setting from south to north, the two currents must repel each other; if they be equal, an equilibrium is the result, and the energy for the time appears suspended. This, so far, gives us an idea of the principles of repulsion and energy.

"Again, suppose one portion of the matter which energy has acted upon to undergo an atomic arrangement in consequence of the dominancy of one of the currents, it is evident that the flow of the current would be unimpeded, and that which repelled would now attract the former, and the flow of energy would follow the same course; thus attraction and repulsion are only the material atoms impeding the primary flow of energy. On referring to the engraving, the arrangement of the particles, forming distinct elliptical curves, convey to us an idea of lines of energy completing their current, and returning to flow again in the same direction.

"From the engraving (fig. 16) it will be observed that one of the magnets is represented much larger than the other, and the pole of the smaller is repelling; but the dominant power of the larger would ultimately reverse the poles of the smaller, so that their magnetic currents would set in the same direction; thus giving an idea that poles, when dominant, may change the set of the magnetic current to any point of the compass.

"Then, let us inquire what our experience and observations are on board of an iron ship. In the first place, in ships that are built in northern latitudes, the top of each rib or pillar forms a strong south pole, the plating and beams occasionally weakening

Fig 17.

or strengthening the flow of magnetism, so that the current of magnetism on a ship's deck may be likened to a series of winding currents and eddies. The annexed engraving (fig. 17) represents the outline of a ship's deck, and also indicates the position of 1, 2, and 3 compasses; M M, masts; A, cabin skylight; B, a hatch. It will be observed that the darts on each compass represent the direction of the magnetic needle at the different points on the ship's deck, and thus give an idea of the flow or set of the magnetic currents in the different positions. Then it must be evident that if we find the set of the magnetic current, we may equalize that current by a similar power; thus for a time inducing an equilibrium that the compasses may indicate correctly. That the magnetic currents on a ship's deck may be better understood, let us suppose the current setting in any particular direction, as N.E., and that current inducing a deviation equal to one point at north, the other points following in a similar proportion. We know by practical experiment that, when we discover the magnetic set of the current, we can experimentally produce similar deviations by placing a magnet to an isolated compass, and thus induce similar deviations to those indicated by the compass on ship's deck. If we can do this experimentally by one magnet, we must then have the power to correct it by placing a similar magnet parallel with the former, taking care to place the magnet so that the set of its

Fig. 18.

current may run in the reverse direction; the two currents would thus equalize each other, and the compass would indicate freely. This may be better understood by the annexed engraving (fig. 18). The circle represents the outline of a compass; the magnet A, the set of the disturbing current; the correcting magnet B, the set of the magnetic current reverse of A, as indicated by the darts; thus the two forces equalize each other, and the compass indicates freely. This will be evident when we come to examine the compass deviations in the various ships.

"It is now generally admitted that in an iron ship passing from a northern to a southern latitude, what we term the natural deviations undergo a considerable change. The amount of that change depends much on the original deviations—*i. e.*, when the deviations are small, the change will be in proportion; but in ships where the deviations are great, the change will be in a similar proportion.

"If the adjustment of the compass by a single magnet be a fact that we can demonstrate, then it is not necessary that a combination of magnets be used. With the single magnet there are many advantages. If the natural deviations be induced by a magnetic current setting in a particular direction, by placing the correcting magnet so that its current might set in the opposite direction, the two currents meeting would form an equilibrium, and the compass would be free to indicate. With this view of the question the commander would be able to assist himself in passing from a northern to a southern latitude. It will be evident that the principle resolves itself into two contending forces; the commander having the power of one—the magnet—he may use it for counterpoising the other—the magnetism of the ship. By following this principle he has the power to approximate his compass as near to the point of correction as may be possible. This principle cannot be applied where a combination of magnets is used."

63. The following article upon a subject which possesses great scientific and practical interest—namely, *Malleable Cast Iron*,—is from the pages of the "Engineer."

"Among a large majority of those engaged in the arts, malleable cast iron has always been a metallurgical mystery. The mode o *its* production is generally a secret in the few foundries where i is made, and the very ignorance of its true character has prevented its use to anything like the extent it deserves. M. Brüll not long since communicated to the French Society of Civil Engineers a very complete account of the history, mode of production, and properties of malleable cast-iron, which deserves to become widely known. It appears that Réaumur, as early as 1722, read as many as six *memoires* before the Academy upon the 'art of softening cast-iron,' and to quote literally, 'de faire des ouvrages de fer fondu aussi finis que ceux de fer forgé.' According to Réaumur this art was a secret which, even before the eighteenth century, had been lost and recovered several times. Indeed, the art was then practised in Paris, but as a secret which not even Réaumur was permitted to penetrate. He made experiments for himself, however, and, to an extent, accomplished what was desired by enclosing ordinary iron castings in crucibles filled with a mixture of chalk and coal, or bone lime and coal, the crucibles being then exposed to a high and continued heat.

"In 1804 Samuel Lucas, of Sheffield, patented a mode of producing malleable cast-iron, and his specification clearly indicated the theory of conversion. It was that, simply, of partial decarbonisation by exposing the castings to a high heat, when surrounded, in close vessels, with powdered iron ore, or other metallic oxides capable of abstracting a portion of the carbon in the iron. For the most complete results the weight of oxide was to be from one-half to two-thirds that of the castings treated, and the heat was to be kept up for five or six days. Lucas' specification contains, indeed, nearly all that is essential to the production of good malleable castings, and his process is substantially that which has been followed for the purpose ever since the time of his description.

"Taking M. Brüll's account of the converting process as now practised, the castings should be of charcoal iron from Ulverstone —a locality which M. Brüll, by the way, fixes 'en Ecosse." The white iron is preferred for the larger class of castings and the gray for the smaller pieces. The iron, M. Brüll states, is to be melted in crucibles, heated over a steel converter's fire, the weight in each crucible being about 66 lb. The fusion is to be continued from an hour to an hour and a half. The articles to be cast are moulded either *in green or dry* sand as may be preferred, and are to be poured in the ordinary manner. The castings are very brittle, and unless well proportioned and very carefully handled they are apt to crack. They are then ready for treatment in the converting furnace. This is rectangular in form, and opens only at a small door for charging and discharging. The furnace, or more properly speaking, oven, has narrow firegrates beneath extending along its whole length. The castings to be treated are packed, in iron cylinders, in alternate layers of red hematite ore finely powdered. These cylinders are placed in the oven, which is closely sealed, so as to completely exclude the air, and then gradually heated until the contents are brought to a bright red. The time occupied in raising the heat is about twenty-four hours, and this heat is to be continued three, four, or five days afterwards, according to the size of the castings under treatment. At the end of this period the heat is to be gradually let down, another twenty-four hours being properly allotted to this. The annealing operation is one of great delicacy. If any air penetrates to the interior of the oven, or if the heat is raised too high, or if the oxide (hematite ore) employed is not properly mixed with a quantity which has already served before, the castings are certain to be burnt. If the heat is too low, or unequal, the annealing is insufficient, and the castings are liable to break. Care, too, or rather a considerable degree of experience, is requisite to prevent the fusion of lumps of the ore upon the surfaces of the casting. An American mode of rendering iron castings malleable consists in heating them in layers of oxide of zinc, which never forms lumps upon their surfaces. Care, too, is required in packing the castings in the powdered ore. If the thickness is not nearly equal the castings are considerably warped. It is no wonder, with so many contingencies, that the price of malleable iron castings in Paris is from 7½d. to 10d. the lb.

"M. Brüll states that the density of malleable castings is hardly greater than that of ordinary cast-iron. Three samples of the former, selected at random, had a specific gravity of 7·10, 7·25, and 7·35 respectively. The colour, both external and that of the fractured specimens, approaches that of steel. The 'malleableised' metal takes readily a very fine polish, which is not very easily destroyed upon exposure to moisture. Its resistance under cutting tools, or when exposed to friction, is not, however, great. The metal is very porous, as is proved by the gradual diffusion of oil over a considerable surface where only a portion was placed in a reservoir of that liquid. The Ulverstone white iron is very sonorous, and good clock bells are cast from it. The treatment of malleable castings diminishes this property of communicating sound, but of two objects of the same form, that in malleable cast-iron can be distinguished from that in wrought-iron by the superior note given off on striking it. On breaking a malleable casting the converting process appears to have penetrated only to the depth of from $\frac{1}{8}$th to $\frac{1}{6}$th inch, and instead of a gradual transition from one condition to another, there is a well-defined line of demarcation. Yet the core, originally brittle, is found to have become soft and easily workable. Worked under cutting tools the outside of a malleable casting gives long and elastic shavings, while, as the tool enters beneath the surface, the chips, towards the centre of the casting, become more and more brittle. Under twisting and other strains the interior cracks, while the exterior presents its customary appearance of toughness. Malleable cast-iron is easily stamped, drawn, and hammered without heating. It can also be worked well under the hammer at a low heat, and at this stage hammering appears to improve the grain. At a higher heat it breaks into fragments. Very small sections may be, now and then, welded, but on the whole, malleable cast-iron is not weldable. It is, however, readily brazed with copper. It melts only under a very high heat, and, indeed, it stands fire so well that it is employed for foundry ladles, crucibles for the precious metals, and for the tubes of some descriptions of boilers. Malleable cast-iron may be case-hardened more readily and to a greater depth than wrought-iron. The castings are not blistered, scaled, or warped in the process, and the case-hardening may be effected either with bones, hoops, or leather in the ordinary manner, or with prussiate of potash.

"MM. Morin and Tresca have made an extensive series of experiments upon the resistance to rupture, limit of elasticity, &c., of malleable cast-iron, all of which are recorded in the 'Annales du Conservatoire des Arts et Metiérs." The strength per unit of section was found to diminish greatly as the dimensions of the pieces submitted to experiment were increased. The direct resistance to rupture was *found*, in some of the experiments, to be about 50,000 lb. per square inch, or exactly 35 kilogrammes per square millemètre. As to the general results of these experiments, M. Brüll observes that they indicate a general resistance, a co-efficient of elasticity, and a limit of elasticity as great in malleable cast-iron as in good wrought-iron. This was, indeed, to have been expected from the ordinary practical acquaintance which we have of the first-named material. M. Brüll touches upon the prices at which malleable cast-iron is produced in various countries. In Switzerland, for example, it costs upwards of a shilling a pound, while at Liége the cost of castings in this material is not much greater than that of English cast-iron. The whole question of the employment of malleable cast-iron turns really upon that of its cost. If it can be cheaply produced, and we have no doubt that, with simple improvements, it may be, it may be readily substituted in place of many applications of wrought-iron. A Glasgow firm has already done something in this direction, but the subject should be more generally pursued by others."

64. The use of cast-iron, while being lessened in some departments of engineering, as in that of bridges and the like, is being increased in others, as in that of boilers; it is therefore of importance that we should know the best modes of using it. The following paper, on "*The Strengthening of Cast-iron*," by Zerah Colborn, in the pages of the *Engineer*, conveys much that is valuable on the subject. Space only permits us to give an extract here and there from it. The reader will find it *in extenso* in p. 307, under date Nov. 18, 1864, of the *Engineer*:—

"Once melted, there are several modes by which the strength of cast-iron may be increased, assuming that it is not already white iron.

"It would appear that, to a certain extent, it may be strengthened by repeatedly re-melting it, say twelve or fourteen times.

"It may be strengthened by re-melting it two or three times, and maintaining it in fusion for a considerable period, say one or two hours, at each melting.

"It may be strengthened by mixing wrought-iron scrap with the metal, in the manner patented by Mr. Stirling.

"It has been found that cast-iron may be strengthened also by *loying it* with other substances, as with copper and zinc.

"It will be the subject of inquiry, presently, to ascertain if it may not also be strengthened by another mode, much cheaper, if not better, than any of these.

"As for repeated re-melting, say to the thirteenth time, this is commercially out of the question, although the results obtained by Mr. Fairbairn, and reported in 1853 to the British Association, are interesting. . . .

"The next mode of strengthening cast-iron, that of two or three re-meltings with a protracted period of fusion, is practised in the casting of American ordnance, whether in the solid, or upon a cooling core (according to the plan patented by the late General Rodman, as long ago as August 14th, 1847, although it has not been long adopted by the American Government. . .

"A third mode of increasing the strength and hardness of cast-iron, is that patented in October, 1848, by Mr. J. D. Morries Stirling. It consists in adding to cast-iron in the cupola from 15 per cent. to 40 per cent. of its own weight of wrought iron scrap. . . .

"As in the cases of other modes of strengthening cast-iron, however, Stirling's adds something to the cost, and on referring to this, little or nothing appears to have been gained by it. The late Mr. Stephenson, in his evidence before the Iron Commission, expressed himself upon this point as follows:—'If it adds so much to the strength of ordinary cast-iron, it merely amounts to adding so much more to the bulk or dimensions of a beam of cast-iron, unless it gives it more flexibility, and unless it makes the cast-iron, in fact, approach the quality of the wrought iron. The invention of Mr. Morries Stirling becomes purely a commercial question, because, if I can introduce into a girder one ton more of common iron cheaper than he could introduce the admixture of malleable iron, then of course the one ton additional to the girder would beat him out of the market.'

"Of the strengthening of cast-iron by alloying it with copper and zinc, it may be said, that practically a new material is thus made, at a very considerable expense, and which, although it possesses advantages for certain purposes, cannot be considered in connection with the more important applications of cast-iron. Dr. Percy, in his work on 'Iron and Steel,' has given very full accounts of the several alloys, under this head, known as Kier's metal, *Aich metal, and Sterro* metal.

"It now becomes a question whether the whole advantage of the American mode of treatment, and the whole advantage (without the disadvantage, if any, in greatly increased hardness) of Stirling's mixture, may not be secured with scarcely any additional expense beyond the ordinary melting in the cupola. Wherever an even quality of iron is required—and it would be difficult to say where an *uneven* quality is ever required in castings—the metal should be run, not directly into the founder's ladles, but into a receiver of considerable capacity in front of the cupola, and wherein the iron should be stirred to some extent. Where chilled castings are made, as in Messrs. Howard's well-known works at Bedford, and in the American railway wheel foundries, this receiver cannot be dispensed with. In this receiver, then, the melted iron may be operated upon to increase its strength. The only element which can be brought to bear for this purpose is oxygen, and the readiest and cheapest mode of administering it is evidently that employed by Mr. Bessemer. In the blast furnace, a strong blast of air blown into or upon the melted iron, is known to make it 'white.' Overman, writing in 1848, says:—'At many European furnaces where forge metal is manufactured, the desired effect—that is, the production of white, strong metal, with the least expenditure of coal—is obtained by some secret method of twisting and dipping a tuyere. This manœuvre, at the wült's oven and the blue oven is applied to the ores of the primitive and transition formation as spathic and magnetic iron ores.' This 'dipping a tuyere,' although not resorted to for the direct conversion of the cast into wrought iron or steel, involves the very principle of the Bessemer process, and it is evident that with a pillar of blast of $2\frac{1}{2}$ lb., the oxygen could be forced down into, and thus through, a pool of iron nearly 9 inches in depth. But the production of white iron, by a continued blast through a dipped tuyere, may be readily referred to the great proportionate quantity of oxygen administered to a given weight of iron. In perhaps a ton of iron, in a receiver in front of the cupola, the introduction of a regulated quantity of air under pressure would remove a larger or smaller proportion of the silicon and sulphur with only a slight diminution of—not to say an increase in—the contained carbon. Instead of the blowing apparatus employed by Mr. Bessemer, a small air-pump, worked by the en gine, would be constantly forcing air into an accumulator (on the principle of that employed in Sir William Armstrong's hydraulic machinery), and loaded to the pressure required to force the air through the iron in the receiver. When the accumulator was filled, the air-pump would be thrown out of work by self-acting gear, as in water-pressure machinery; or, as the power expended in pumping air would not be great, the surplus might even be allowed to escape through a regulating valve. The accumulator would leak air to some extent, however tight it might be made by ordinary means; but if the leakage was only slight, so would be the waste, while the *pressure* — of chief importance — would be uniformly maintained by the descent of the loaded ram of the accumulator to an extent exactly corresponding to the loss by leakage. If this loss were indeed considerable, from a plate iron reservoir, it would be effectually prevented by making the vessel double, with a surrounding water space, always filled with water.

"The writer has not learned from Mr. Bessemer that he has at any time contemplated the strengthening of foundry iron by this partial application of his process, but it is quite possible that this mode of strengthening is protected by Mr. Bessemer's patents of December 7th, 1855, and March 15th, 1856. In the first, he proposes to partly purify pig iron, preparatory to the puddling process, by dipping a blast pipe into the melted iron, in a receiver in front of the blast furnace, and thus allowing the air—heated, by preference—to bubble up through the iron, removing, not so much (as supposed in the specification of the patent) the *carbon*, but the silicon, and, possibly, the sulphur. The iron is then to be cast into ingots to be broken up and melted for puddling in the ordinary manner. In his patent of March 15th, 1856, Mr. Bessemer proposes to apply the same treatment directly within the hearths of blast and cupola furnaces. But it is evident that it could be better managed in one of his 'converters,' mounted on trunnions, and taking the blast in at the bottom, the vessel being afterwards tilted and emptied.

"Although the proposition, to apply atmospheric air, in jets, through melted cast-iron, for the purpose of strengthening it as foundry iron, may be a novel one, the writer is confident that it requires but to be carried into practice to secure important advantages at an insignificant cost. The proposed treatment is entirely analogous in principle, although incomparably superior in point of cheapness, celerity, and practical convenience, to that by which the strength of gun iron is known to be so greatly increased."

65. It is difficult to over-estimate the value of the services which William Fairbairn (there is noble simplicity in the plain name without any "handle," which is quite in keeping with that of the mind of this eminent engineer) has rendered to the engineers of modern times, in investigating the nature and properties of, and in introducing into practice, new modes of applying iron in construction. This great authority has recently added another to the many services he has done for practical science in the able report, issued under the authority of the Board of Trade, on "*the strength of iron structures*," which we have much pleasure in giving here *in extenso.*

"My Lords,—In the year 1859 a small sum of money was granted by the Treasury for the purpose of ascertaining, by direct experiment, the effects of continued changes of load upon iron structures, and to what extent they could be loaded without danger to their ultimate security. Having completed the experiments, I have now the honour to submit the results.

"The experiments instituted for the purpose of ascertaining the value of wrought-iron riveted plates in the form of tubes, through which a railway train should pass, was a conception which led to a new era in the history of bridges, and ultimately effected the passage of the estuary of the Conway and the Menai Straits. These experiments gave not only the form and strength required for the construction of those colossal structures, but they developed an entirely new system of constructive art, and established the principle on which wrought-iron bridges should be made. Since then some thousands of bridges, many of them of great span, have been made, composed entirely of wrought-iron, and are now in existence, supporting railways and common roads to an extent hitherto unknown in structures, which could not have been accomplished by any other description of material than that of malleable iron.

"The construction of the Britannia and Conway bridges in the tubular form, led to others, such as the tubular girder, the plate and lattice girder, and other forms, all founded on the principle developed in the construction of the large tubes as they now span the Conway and Menai Straits. In the tubular bridges it was first designed that their ultimate strength should be six times the heaviest rolling load that could ever be laid upon them, after deducting half the weight of the tube. This was considered a fair margin of strength, but subsequent considerations, such as generally attend a new principle of construction with an untried metal, induced an increase of strength, and instead of the ultimate powers of resistance being six times, it was increased, in some cases, to eight times the weight of the greatest load.

"The stability and great success of these bridges gave increased confidence to the engineer and the public, and for several years the resistance of six times the heaviest load was considered an amply sufficient margin of strength.

"Owing to the success of these undertakings, there was a general demand for wrought-iron bridges in every direction, and numbers were made without any regard to first principles or to the law of proportion which should be observed in the sectional areas of the top and bottom flanges, so clearly and satisfactorily shown in the early experiments. The result of this was a number of weak bridges, and many of them so disproportioned in the distribution of the material as to be almost at the point of rupture, with little more than double the permanent load. These discrepancies, and the erroneous system of contractors tendering by weight, led not only to defects in the principle of construction, but the introduction of bad iron, and in many cases equally bad workmanship. Now there is no construction which requires greater care and more minute attention to sound principles than wrought-iron girders, whether employed for bridges of large or small span, or for buildings. The lives of the public, in this respect, entirely depend upon the knowledge and skill of the engineer, and the selection of the material which he employs.

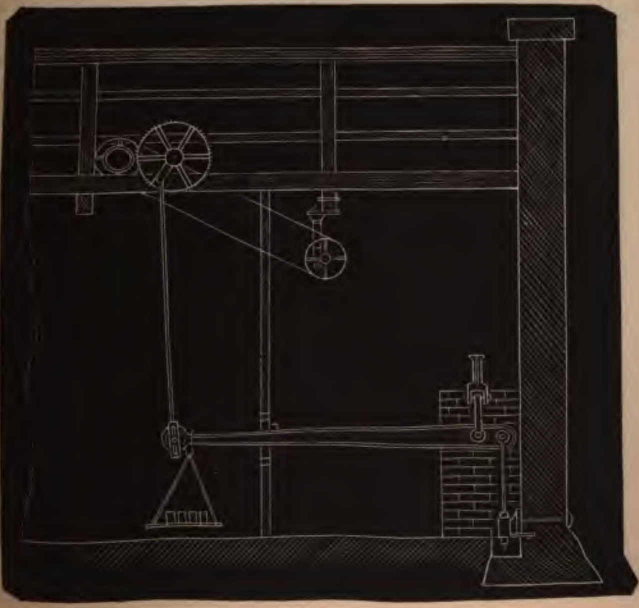
"The defects and break-downs which followed the first successful application of wrought-iron to bridge building, led to doubts and fears on the part of engineers, and many of them contended for eight, and even ten, times the heaviest load as the safe margin of strength. Others, and amongst them the late Mr. Brunel, fixed a lower standard, and I believe that gentleman was prepared in practice to work up to one-third or two-fifths of the ultimate strength of the weight that would break the bridge. Ultimately it was decided by your lordships, but from what data I am unable to determine, that no wrought-iron bridge should, with the heaviest load, exceed a strain of five tons per square inch. Now, on what principle this standard was established does not appear, and, on application to the Board of Trade, the answer is, that 'the Lords Commissioners of Trade require that all future bridges for railway traffic shall not exceed a strain of five tons per square inch.'

"The requirement of five tons per square inch did not appear sufficiently definite to secure, in all cases, the best form of construction. It is well known that the powers of the resistance to strain are widely different with wrought-iron, according as the forces of tension or compression are applied; it is even possible so to disproportion the top and bottom flanges of a wrought-iron girder, calculated to support six times the rolling load, as to cause it to yield with little more than half the ultimate strain, or ten tons on the square inch. For example, in wrought-iron girders with solid tops, it requires the sectional area in the top to be nearly double that of the bottom, to equalize the two forces of tension and compression; and unless these proportions are strictly adhered to in the construction, the five ton strain per square inch is a fallacy which may lead to dangerous errors. Again, it was ascertained from direct experiment that double the quantity of material in the top of a wrought-iron girder was not the most effective form for resisting compression. On the contrary, it was found that little more than half the sectional area of the top, when converted into rectangular cells, was equivalent in its powers of resistance to double the area when formed of a solid plate. This discovery was of great value in the construction of tubes and girders of wide span, as the weight of the structure itself—which increases as the cubes, and the strength only as the squares—forms an important part of the load to which it is subjected. On this question it is evident that the requirements of a strain not exceeding five tons per square inch cannot be applied in both cases, and is therefore ambiguous as regards its application to different forms of structure. In the five ton per square inch strain there is nothing said about the dead weight of the bridge, and we are not informed whether the breaking weight was to be so many times the applied weight, *plus* the multiple of the load, or whether it included or deducted the weight of the bridge itself.

"These data are wanting in the railway instructions, and until some fixed principle of construction is determined upon, accompanied by a standard measure of strength, it is in vain to look for any satisfactory result in the construction of road and railway bridges composed entirely of wrought-iron.

"I have been led to inquire into this subject with more than ordinary care, not only on account of the imperfect state of our knowledge, but from the want of definite instructions. I have in the following experimental researches endeavoured to arrive at the extent to which a bridge or girder of wrought-iron may be strained without injury to its ultimate powers of resistance. And, moreover, I have endeavoured to ascertain the exact amount of load to which a bridge may be subjected without endangering its

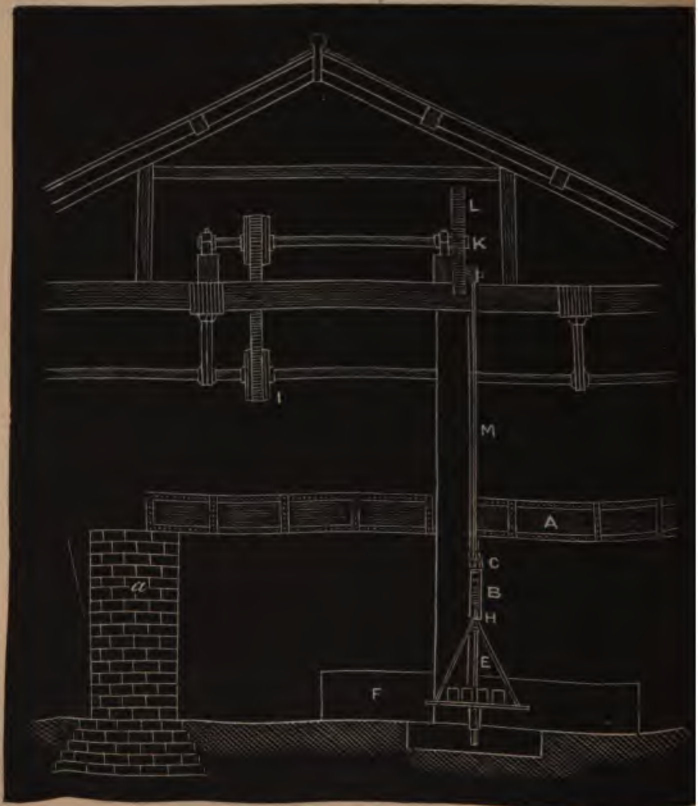
Fig. 19.



safety; or, in other words, to determine the fractional strain of its estimated powers of resistance.

"To arrive at correct results, and to imitate as nearly as possible the strain to which bridges are subjected by the passage of heavy trains, the apparatus specially adapted for that purpose was designed to lower the load quickly upon the beam in the first instance, and subsequently to produce a considerable amount of vibration, as the large lever with its load and shackle was left

Fig. 20.



suspended upon it in the second. The apparatus was sufficiently elastic for that purpose, as may be seen on reference to the attached drawings.

"The beam A, Fig. 20, is composed of an iron plate, riveted with angle irons, 22 ft. long, ⅛ in. thick, and 16 in. deep. It is supported on two brick piers 20 ft. apart (one only, *a*, is shown in the diagram). Beneath the bottom flange is fixed the lever B, which, by means of the link and shackle C, grasps the lower web of the beam close to the fulcrum D. This fulcrum, on which the lever oscillates, is formed of a vertical bar E, which acts as a standard, and has screw nuts to regulate the height from the cast-iron plate F to the fulcrum D. The machinery for lifting the lever and scale at H consists of the shaft and pulley I, driven by a water-wheel, and from this shaft the apparatus for lifting the load is worked by a strap from the pulley on the pinion shaft K, which drives the shaft and spur wheel L, giving motion to the connecting rod M. This rod has an oblong slot at its lower end, in which the pin at the end of the lever works. From this description it will be seen that, in turning the spur wheel L, the weight is not raised until the bottom of the slot comes in contact with the pin of the lever, when the load is taken entirely off the beam. That being accomplished, the connecting rod descends, when the load is again laid on the beam and left suspended, with a vibratory motion, for some seconds, until the remainder of the stroke is completed, when the connecting rod again rises for the succeeding lift. In this way the weights are lifted off and replaced alternately upon the beam at the rate of seven to eight strokes per minute. The apparatus is worked night and day by a water-wheel, and the number of changes are registered by the counter attached to the vertical post at G.

"The girder subjected to vibration in these experiments is a wrought-iron plate beam of 20 ft. clear span, and of the following dimensions:—

	in.	
Area of top—1 plate, 4½ in. × ½ in. . .	2·00	
,, 2 angle irons, 2″ × 2″ × $\frac{5}{16}$″ .	2·30	
		4·30
Area of bottom—1 plate, 4 in. × ¼″ . .	1·00	
,, 2 angle irons, 2″ × 2″ × $\frac{3}{16}$″	1·40	
		2·40
Web—1 plate, 15¼″ × ⅛″		1·90
Total sectional area . . .		8·60

Depth	16 in.
Weight	7 cwt. 3 qrs.
Breaking weight (calculated)	12 tons.

"The beam having been loaded with 6,643 lb., equivalent to one-fourth of the ultimate breaking weight, the experiment commenced as follows :—

EXPERIMENT I.—*Experiment on a wrought-iron beam with a changing load equivalent to one-fourth of the breaking weight.*

Date.	Number of changes of load.	Deflection produced by load.	Remarks.
1860.			
March 21	0	0·17	
,, 23	15,610	0·16	
,, 26	46,100	0·16	Strap found loose on the 24th, and failing to lift the load.
,, 28	72,440	0·17	
,, 31	112,810	0·17	
April 2	144,350	0·16	
,, 7	202,890	0·17	
,, 13	268,328	0·17	
,, 17	321,015	0·16	Strap found broken on the 20th.
,, 27	408,264	0·16	
May 1	449,280	0·16	
,, 6	489,769	0·16	
,, 9	536,355	0·16	
,, 14	596,790	0·16	

"The beam having undergone about half a million changes of load, by working continuously for two months, night and day, at the rate of about eight changes per minute, without producing any visible alteration, the load was increased from one-fourth to two-sevenths of the statical breaking weight, and the experiment proceeded with till the number of changes of load reached a million.

XPERIMENT II.—*Experiment on the same beam with a load equi- alent to two-sevenths of the breaking weight, or nearly 3½ tons.*

Date.	Number of changes of loads.	Deflection in inches.	Remarks.
1860.			In this experiment the number of changes of load are counted from 0, although the beam had already undergone 596,790 changes, as shown in the preceding table.
May 14	0	0·22	
,, 17	36,417	0·22	
,, 22	85,820	0·22	
,, 29	161,500	0·22	
June 4	194,500	0·21	
,, 9	236,460	0·21	
,, 16	292,600	0·22	
,, 26	403,210	0·23	

"The beam had now sustained one million changes of load thout any apparent change, when it was considered necessary increase the load to 10,486 lb., or two-fifths of the breaking ight, when the machinery was again put in motion. With is additional weight the deflections were increased, with a rmanent set of ·05 in., from ·23 in. to ·35 in., and after sus- ning 5,175 changes it broke by tension a short distance from e middle of the beam. It is satisfactory here to observe that ring the whole of the 1,005,175 changes, none of the rivets re loosened or broke.

EXPERIMENT III.—*Beam repaired.*

"The beam broken in the preceding experiment was repaired replacing the broken angle irons on each side, and putting a tch over the broken plate equal in area to the plate itself. hus repaired, a weight of three tons was placed on the beam, uivalent to one-fourth of the breaking weight, when the ex- riments were again continued as before.

Date, 1860.	Number of changes of load.	Deflection in inches.	Permanent set in inches.	Remarks.
1860.				
August 9	158	—	—	The load during th changes was equi lent to 10,500 lb., 4·6875 tons at t centre. With th weight the beam to a large but unme sured set.
,, 11	12,950	—	—	During these chang the load on the bea was 8,025 lb., or 3 tons.
,, 13	25,900	0·22		
,, 13	25,900	0·18	0	Load reduced to 2 tons, or one-four the breaking weigh
,, 24	101,760	0·18	0	
Sept. 1	140,500	0·18	0·01	
,, 15	242,860	0·18	0·01	
Oct. 6	375,000	0·18	0·01	
Nov. 3	577,800	0·18	0·01	
Dec. 1	768,100	0·18	0·01	
1861.				
Jan. 9	1,121,100	0·18	0·01	
Feb. 2	1,342,800	0·18	0·01	
March 2	1,602,000	0·18	0·01	
April 6	1,885,000	0·17	0·01	
May 4	2,110,000	0·17	0·01	
Sept. 4	2,727,754	0·17	0·01	
Oct. 16	3,150,000	0·17	0·01	

"At this point the beam having sustained upwards of 3,000, changes of load without any increase of the permanent set, it assumed that it might have continued to bear alternate cha to any extent with the same tenacity of purpose, as exhib in the foregoing table. It was then concluded to increase load from one-fourth to one-third of the breaking weight, having laid on four tons, which increased the deflection to this experiment was proceeded with in the same order as in previous ones.

EXPERIMENT IV.

Date, 1861.	Changes of load.	Deflection in inches.	Permanent set in inches.	Remarks.
1861.				
October 18	0	0·20		
" 19	4,000	0·20		
November 18	126,000	0·20		
December 18	237,000	0·20		
1862.				
January	313,000	—	—	Broke by tension across the bottom web.

"From these experiments it is evident that wrought-iron girders of ordinary construction are not safe when submitted to violent disturbances equivalent to one-third the weight that would break them. They, however, exhibit wonderful tenacity when subjected to the same treatment with one-fourth the load; and assuming, therefore, that an iron girder bridge will bear, with this load, 12,000,000 changes without injury, it is clear that it would require 328 years, at the rate of 100 changes per day, before its security was affected. It would, however, be dangerous to risk a load of one-third the breaking weight upon bridges of this description, as, according to the last experiment, the beam broke with 313,000 changes, or a period of eight years at the same rate as before would be sufficient to break it. It is more than probable that the beam might have been injured by the previous three million changes to which it had been subjected; and, assuming this to be true, as time is an element in the calculation, it would then follow that the beam was progressing to destruction, and must of necessity, at some time, however remote, have terminated in fracture.

"The experiments, so far as they go, throw considerable light on this very intricate and very important subject. They are probably carried sufficiently far to enable us to state with certainty what is the safe measure of strength; and as much depends upon the quality of the material and the skill with which the girders are put together, it becomes necessary for the public safety that a measure of strength should be established without encumbering the structure with *unnecessary* weight. On this question it must be borne in mind that every additional ton that is not required beyond the limits of safety is an evil that operates as a constant quantity tending to produce rupture; and hence follows the necessity of a careful distribution of the material, in order that the tube or girder shall be duly proportioned to the strains it has to bear, and that every part of the structure shall have its due proportion of work to perform.

"I have assumed, for the sake of illustration, that every description of material, as regards its cohesive properties, follows the same law as that which we have experimented upon, or, in other words, in the ratio of its physical powers of resistance, that is to say, any beam will follow the same law in regard to its ultimate powers of resistance when operated upon by a corresponding load due to that power. If this be true, we have only to follow the same rule as observed in the experiments, by loading cast-iron or wooden beams in the ratio of their cohesive powers of resistance and their breaking weights respectively. This has not been proved experimentally, but I hope at some future time to have an opportunity of extending the experiments, in order to determine to what extent these views are correct.

"Assuming the top of the girder to be sufficiently rigid to prevent buckling by compression, the formula for the strength of the bottom section, derived from my own experiments on the model tube at Millwall, is—

$$W = \frac{adc}{l}$$

c = the constant 80 derived from experiment.

Applying this formula to the beam experimented upon, we have—

a, the area of the bottom = 2·4 in.
d, the depth of the beam = 16 in.
c, the constant deduced from the model tube = 80 in.
l, the span or distance between the supports = 240 in.

Hence $W = \frac{2{\cdot}4 \times 16 \times 80}{240} = 12{\cdot}8$ tons,

the ultimate strength of the beam.

"In order to obtain the strain per square inch from these experiments, formula $S = \frac{lw}{4\,ad}$ may be useful

where S represents the strain per square inch upon the section produced by the greatest load w, laid upon the middle of the girder

"It is necessary to observe, that in a girder properly proportioned, the greatest strain per square inch will take place upon the bottom section, so that if the strain upon the bottom section of such a girder be within your lordships' conditions of safety, the strain upon the top section will necessarily be within this limit also. In a girder, having the cellular structure at its top section, the area should be very nearly $1\frac{1}{4}$ times that of the bottom section, or the areas of their sections should be respectively 5 : 4; and the strain per square inch upon these parts will be respectively inversely as their areas—that is, the strain per square inch upon the top section will be four-fifths of the strain per square inch upon the bottom section. In one of the foregoing experiments, without cells, we have, where l, the length of the girder $=240$ in.

w, the weight laid on the middle $=2\cdot96$ tons.
a, the area of the bottom section $=2\cdot4$ in.
d, the depth of the girder $=16$ in.; then

$$S=\frac{240\times2\cdot96}{4\times2\cdot4\times16}=4\cdot62 \text{ tons},$$

which is the strain per square inch on the bottom section of the girder.

"Applying these formulæ to the whole series of experiments, we obtain the following summary of results:—

SUMMARY OF RESULTS.—*First Series of Experiments.—Beam 20 ft. between the supports.*

No. of experiment.	Date.	Weight on middle of the beam in tons.	Number of changes of load.	Strain per sq. inch on bottom.	Strain per square inch on top.	Deflection in inches.	Remarks.
1	From March 21 to May 14, 1860	2·96	596,790	4·62	2·58	·17	
2	From May 14 to June 26, 1860	3·50	403,210	5·46	3·05	·23	
3	From July 25 to July 28, 1860	4·68	5,175	7·31	4·08	·35	Broke by tension a short distance from the centre of the beam.

"Here it will be observed that the number of 1,005,175 changes was attained before fracture, with varying strains upon the bottom flange of 4·62, 5·46, and 7·31 tons per square inch; and in the

SECOND SERIES OF EXPERIMENTS—*Beam repaired—the following results were obtained:—*

No. of experiment.	Date.	Weight on middle of the beam in tons.	Number of changes of load.	Strain per square inch on bottom.	Strain per square inch on top.	Deflection in inches.	Remarks.
1	Aug. 9, 1860	4·68	158	7·31	4·08	—	The apparatus was accidentally set in motion.
2	Aug. 11, and 12	3·58	25,742	3·59	3·12	·22	
3	From Aug. 13, 1860, to Oct. 16, 1861	2·96	3,124,100	4·62	2·58	·18	
4	From Oct. 18, 1861, to Jan. 9, 1862	4·00	313,000	6·25	3·48	·20	Broke by tension as before, close to the plate riveted over the previous fracture.

"The number 3,463,000 changes was, in this case, attained before fracture ensued.

"From the above it is evident that wrought-iron girders, when subjected to a load equal to a tensile strain of seven tons per square inch, are not safe if that strain is subjected to alternate changes of taking off the load and laying it on again, provided a certain amount of vibration is produced by that process; and what is important to notice is, that from 300,000 to 400,000 changes of this description are sufficient to ensure fracture. It must, however, be borne in mind that the beam from which these conclusions are derived had sustained upwards of 3,000,000 changes, with nearly five tons tensile strain on the square inch, and it must be admitted from the experiments thus recorded that five tons per square inch of tensile strain on the bottom of girders, as fixed by your lordships, is an ample standard of strength.

"As regards compression, we have only to compare for practical purposes the difference between the resisting powers of the material to tension and compression, and we shall require in a girder without cellular top, from one-third to three-fourths more material to resist compression than that of tension; and as wrought-iron, in a state of compression, is, to that of tension, as about 3 to 4·5, the area of the top and bottom will be nearly in that proportion, or in other words, it will require much more material in the top than the bottom to equalise the two forces.

"In the experimental beam, the area of the top was considerably in excess of that of the bottom, having been constructed on data deduced from the experiments on tubes without cells, which required nearly double the area on the top to resist crushing. In the construction of larger girders, where thicker plates are used, this proportion no longer exists, as much greater rigidity is obtained from the thicker plates, which causes a closer approximation to equal area, in the top and bottom of the girder; and from this we deduce that from ½ to ¾, and in some cases ⅓ additional area in the top has been found, according to the size of the girder, sufficient to balance the two forces under strain.

"The foregoing experiments were, however, instituted to determine the safe measure of strength as respects tension, and it will be seen that in no case during the whole of the experiments was there any appearance of the top yielding to compression.

"In all these experiments it will be observed that we have taken the whole area of the bottom flange, without deducting for the rivet-holes in the angle irons and the bottom plate.*—I have the honour to be, your lordships' faithful servant,

WM. FAIRBAIRN."

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* "ADDENDA.—It will be observed that the above summaries exhibit the strains per square inch on the top and bottom flanges without deducting the rivet-holes, and there being four ½-in. diameter in the bottom flange, two in each angle iron, and two in the plate, is equal to ·625 in. This reduces the area for tension from 2·4 to 1·775 in. In the calculations, I have not, however, made these deductions, in order that the experiments might compare with others where they have not been taken into account. Under the conditions of reduced area, it will be found that the strains per square inch upon the bottom flange, with the variable load, according to the formula, will be as follows:—

	Weight on middle of beam in tons.	No. of changes.	Strain per square inch on bottom flange.
1st Experiment, May 14, 1860,	2·96	596,790	6·25
2d Experiment, June 26, 1860,	3·50	403,201	7·39
3d Experiment, July 28, 1860,	4·68	5,175	9·88
Beam Repaired.			
1st Experiment, August 9, 1860,	4·68	158	9·88
2d Experiment, August 12, 1860,	3·58	25,742	7·56
3d Experiment, October 16, 1861,	2·96	3,124,100	6·25
4th Experiment, January 9, 1862,	4·00	313,000	8·45

From the above it will be seen that the actual strain upon the solid plate was considerably increased. And the beam broke in the first series with a strain of nearly ten tons upon the square inch; and in the second, with a strain of 8¼ tons, after sustaining 3,463,000 changes of load. From this it may be inferred that a wrought-iron bridge would be perfectly safe for a long series of years with a strain of six tons per square inch, or one-fourth the statical breaking weight. It is, however, evident from these experiments, that time is an element which enters into the resisting powers of materials of every description when subjected to a continued series of changes. These may be very minute, but assuming them to be of sufficient force to produce molecular disturbance, it then follows that rupture must eventually ensue.—W. F."

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DIVISION NINTH.

MISCELLANEOUS NOTES UPON THE MODES OF WORKING AND USING OF IRON—FORGING—RIVETING—WELDING, &c.

66. In view of the enormous increase of wrought-iron, as used for a wide variety of structures, it is impossible to over-estimate the importance of all plans to secure good riveting of the plates of which they are composed. In the "Mechanics' Magazine" for October 1, 1864, there is a paper on "*Riveted Joints*," which abounds in much that is practically suggestive; we can only find space for brief extracts from it, referring the reader to the article itself for the remaining portion:—

"Not the least important branch of the subject is the relative merit of punched and drilled holes. For years engineers have been content to regard the punched hole as being so far perfect, that any improvement upon it was practically impossible. Recently, however, we find that an idea has got abroad that the operation of the punch seriously injures the iron submitted to it. In the almost absolute dearth of experimental results, it is not easy perhaps, to come to any conclusion upon the subject which can be worth much. The advocates of the drill state that by its use not only is the iron in no way injured, but that a better fit is secured for the rivets, and that the work can be performed so accurately that the use of the drift is altogether done away with. The advocates of the punch, on the other hand, state that the work can be done by it at a price varying from one-third to one-fifth that of the drill, and that practically a joint n every respect as sound and trustworthy can be secured by proper attention and skill. If it can be proved that the iron really does suffer injury and loss of strength by being punched, then it is certain that the drill has so far the best of it. In order to arrive at any decision on this point, it is necessary to comprehend the nature of the injury inflicted."

After making an inquiry into this, the writer proceeds :—

"There are thus, we see, many operating causes at work tending to reduce the strength of the joints which have nothing to do with the punch, and we are disposed to regard them as being quite sufficient to account for the loss of 4 per cent. of the true strength of the plate, if not much more. Brunel's experiments, conducted some years ago, go to confirm this opinion. The repetition of these experiments proved that the results varied very ittle whether the shear of the rivets was 9 per cent. less, or 0 per cent. greater, than that of the plates. The results of variations in workmanship, apparently the best possible, must ccount for the difference; and we think that in the face of such acts it is extremely difficult, if not impossible, to prove that a deterioration of 4 or 5 per cent. must invariably follow on the se of the punch.

"All this is, of course, negative evidence, but we can fortuately go a step further and advance positive proof that the quality f the plate is not affected by the punch. Brunel selected five est Staffordshire plates, and submitted them to a breaking tensile stress. The strength of the worst sample was 19·4 tons per quare inch; that of the best 22 tons. Five other plates from he same piece were then punched and broken through the rivet holes. The worst specimen broke with 20 tons; and through three rows of holes arranged for triple riveting, the plate gave way with 20·4 tons. It is impossible to arrive at any conclusion from these results, other than that the plates were as strong, inch for inch of area, after the punching as they were before, the mean of the experiments giving fully as high a co-efficient in the one case as in the other. It is true that these experiments are not as conclusive as might be wished, simply because they were not sufficiently numerous; but they were carefully conducted, and are very satisfactory as far as they go.

"In the operation of punching, holes are invariably slightly countersunk, and there is little doubt that this countersink adds materially to the efficiency of the work when but two or three plates are to be joined. The contraction of a rivet in cooling exposes the head to very considerable strain—one so great, indeed, that it must militate seriously against the powers of the rivet. If there is a good countersink at each side, the heads of the rivets have little to do, and thus an element of safety is introduced. With the drill a countersink cannot be produced, except at a price which at once precludes its adoption, and in drilled holes, therefore, the rivet heads have to do all the work. When three or more plates have to be put together to make up a given thickness, as in bridge building, however, it is probable that the countersink operates injuriously, as a long rivet cannot be made to fill the holes. The system adopted in the construction of the great Charing-cross railway bridge may then be resorted to with advantage. All the holes were punched ·5 of an inch too small. When the plates were put in place, a small travelling engine bored or reamed them up to the proper size, and the rivets or bolts were then driven home tight by a species of 'dolly' extemporised for the purpose."

67. On the subject of *Rough Forgings*, we take the following from the pages of the "Scientific American."

"We have often remarked, in the course of our professional experience, upon the indifference displayed in some of our large machine-shops toward obtaining good iron forgings. In certain intricate shapes, where the safety of the work would be imperilled by too much elaboration, when often heated, where some heavy parts are in close proximity to some very light portions, it is perhaps advisable to bring the work something near the finished size and leave the rest to be removed by machines intended for such business. Instead, however, of working as closely to the drawing as they might, a great many blacksmiths leave altogether too much iron for the turner and planer to cut off. This practice is to be reprehended, as, in addition to the increased cost of the job, the value of it as material is very much reduced. If a blacksmith leaves from three-fourths to an inch and a quarter of sound iron for the turner to remove from a shaft 5 inches in diameter, he is guilty of a very great waste of time, labour, and material. We do not allude to shafts turned up from rolled iron; any person who had to make a 5-inch shaft, and should deliberately select a 6-inch bar of iron to turn it out of, would be regarded as demented by all sensible persons. If the practice is not to be tolerated in the case of rolled iron, how shall we reconcile the fact of forging a piece of shafting very much larger than there is any occasion for, with mechanical common sense?

"Trip hammers are very useful tools in a blacksmith's shop, for they condense metal into itself and compact the fibres of it firmly together. What shall be said of those persons who leave such an excess of metal that the best of it is all turned off by the machinist at a dead loss to the proprietors? Comparatively a blacksmith can work faster than a machinist; he can heat his iron and dress off a piece of metal that would require four times the labour on the part of the mechanician. So also with heavy hammers, they can draw down an inch and a quarter of iron much sooner than a lathe can turn it off, and the shaft so hammered will be a far better one than another roughly forged.

"In locomotive-shops there are better forgings made than there are in the marine engine-shops in this city. There is more die-work, and a greater attention given to producing smooth, sound, even, and good forgings, than in the large works above mentioned. It seems to us that this subject ought to receive some attention. It is as easy to make a forging somewhere within rifle-cannon range of the finished dimensions as it is to produce a lump of n with scarcely the most remote resemblance to the final line. The scale ought to be removed much oftener than it When iron is over-heated the impurities in it work out to surface; a certain portion of the exterior, a very thin skin of is burnt, this makes a hard vitreous scale that ruins the edge of a tool in a short time. Every blacksmith knows very well how to knock it off, and improve not only the looks of their own work, but lessen materially the time demanded by subsequent operations. These matters are worthy of attention. They are those little details of machine work that are too often lost sight of, but which exercise a very material influence over the profit and loss account. A minute in a factory represents some portion of a dollar, whatever the same may be; it does not require any very brilliant effort of logic to see that many minutes make many fractions of a dollar. The waste of time in doing useless work has a pecuniary value, and it is just as foolish to cut an inch or half an inch off a shaft, when it could be avoided, as it would be folly to throw money into the sea. Let us have no more such waste, but turn out blacksmith work in some degree approximating to the mechanical advancement of the age. We have seen shafts forged (ay, and turned them too) that required to have two inches cut off the ends before they were of the right length. Such carelessness, for it is nothing else, shows a want of consideration for the employer's interest that should be seen to at once by those concerned."

68. On the subject of *welding by pressure*, the "Scientific American" has the following:—"When a machinist drives a dry key into a dry key seat it sticks fast and cannot be got out, oftentimes without drilling it. In this case the surface fibres of the material are interlaced, and are as firmly united as if they were one. The same action takes place in drawing metals, and an English company, working a patent for a peculiar method of drawing metal tubes, have found that where one tube has been forced over another, a perfect union takes place, and no joint can be discovered when they are cut across. When a blacksmith unites two pieces of iron, the heat and the percussion of his hammer effects nothing more than an intimate union of the two parts. If he had sufficient strength, and applied it in the proper way, he might join two pieces of iron quite as well cold as hot.

"It will probably be some time, however, before we have machinery sufficiently powerful to unite masses of metal so that they shall be practically welded, and break at any part rather than at the points of junction. Could such machinery be devised or rendered practical in its results, it is easy to see that an immense saving would be gained in point of time. In some kinds of work this cold welding, so to speak, is already done. Car wheels are pressed on to their axles and remain fast without any key. This is not due to merely pushing a large body into a bore slightly smaller, for if the machinist leaves the axle too large the wheel stretches or splits, and the job is not properly done. The wheels stay on the axles because the two metals, although of different natures, one being cast and the other wrought, have an intimate relation with each other, amounting to an absolute surface weld; very many wheels split before they can be removed.

"Welding by pressure and by heat in connection with pressure has been experimented with abroad. *Galignani's Messenger* speaks of a case, which we here append:—

"'Experiments have lately been made at Paris by M. Duportail, engineer, in the workshops of the Western Railway, to ascertain whether iron might be welded by hydraulic pressure instead of by the sledge hammer. The latter, indeed, has not a sufficient impetus to reach the very core of the metal, while continuous pressure acts indefinitely to any depth. In the experiments alluded to, M. Duportail caused two iron bars, 1½ inch in diameter, and heated to the welding point, to be placed between the piston and the top of an hydraulic press. The bars were welded together by this means with extraordinary ease, the iron being, as it were, kneaded together, and bulged out at the sides under the pressure. The action of the press was suspended when the part welded was brought down to the thickness of the bars. After cooling, the welded part was cut through to examine the inside, which was found perfectly compact. To try it, one of the halves was placed under a forge hammer, weighing 1,800 kil., and it was not until the third stroke that the welding was discovered.'"

"Heavy steamboat shafts are very often hollow at the centre from a want of power in the trip hammer, or through an imperfect manipulation of the 'pile' they are fagotted from. Masses of hot metal drawn between revolving rolls are, indeed, subjected to pressure, but the iron thus made is not of so good quality as hammered metal. It is not in connection with preparing iron for market that these remarks are made, but it would seem not at all impracticable to make a neat and perfect weld by heavy continuous pressure for a short time, rather than by the ordinary method of hammering. Time would be gained both in the smith and finishing shops. That it is perfectly feasible there is no question, and for heavy connecting-rods, rudder-posts, keels of iron vessels, or similar parts, a great economy of time would be apparent, while equal, if not better, workmanship would result."

69. *The Manipulation of Metals.*—"There are many occasions," says the "Scientific American," "where a knowledge of some simple alloy or a peculiar solder would save hundreds, yes, thousands of dollars, just as a life may be saved by merely tying a pocket handkerchief tightly above a bleeding artery. It is only a few years ago that the valve-stem on the engine that runs the *Herald* presses broke in the dead of night, when but half the edition was run off. This was a dilemma, indeed, for a valve-stem is not made in half-an-hour, neither can it be bought at a hardware store like a pound of nails. The engine was injured in a vital part, and unless it was mended the entire edition would be stopped, and incalculable loss sustained. Fortunately for the proprietors there was one of the *employés* present who understood the manipulation of metals, and he informed the bystanders that if they would collect their spare silver he would restore the broken part to a condition of usefulness.

"It was done.

"The stem was brazed with silver solder, and the engine performed until morning, so that the whole edition was successfully run off. But for the presence of the adept referred to, and his knowledge of this simple process, very great loss would have been incurred.

"Some of our readers may be caught in just such a predicament, and we therefore append a formula for a solder which will braze steel. It is as follows:—Silver, 19 parts; copper, 1 part; brass, 2 parts; if practicable, charcoal dust should be strewed over the melted metal in the crucible.

"A good article of yellow brass is extremely desirable for fine work in telescopes and optical instruments generally. A metal that works free and soft under the tool, and is capable of receiving a fair lustre from the burnisher, is always in request. A good yellow brass can be made from the following metals:—That denominated 'watchmaker's brass" is made of one part copper and two parts zinc. German brass is equal parts of copper and zinc;

the addition of a little lead makes the metal work easier, and less liable to tear under the tool.

"In all these mixtures the zinc must be added last, as it is a volatile metal, and fuses at a much lower heat than the copper, the melting point of which is 4587°, while that of zinc is only 700°.

"Iron and brass must be united by spelter, which is equal parts of brass and zinc. When the joints are cleaned and wired together, fine powdered borax is applied to them as a flux. The solder is then dusted on in the form of a powder, or fine filings, and melted in, either with a blow-pipe or by being placed in a charcoal fire. Care must be taken not to melt the brass to be brazed. The solder, of course, has a much lower fusion point than the metals to be joined, else they would both run at the same time.

"A simple method of case-hardening small cast-iron work is to make a mixture of equal parts of pulverized prussiate of potash, saltpetre, and sal ammoniac. The articles must be heated to a dull red, then rolled in this powder, and afterwards plunged into a bath of 4 ounces of sal ammoniac and 2 ounces of the prussiate of potash dissolved in a gallon of water.

"These simple rules are practical, and will give good results with good workmanship. If the cast-iron is overheated and burned, the unskilful workman must not blame the formula for his failure; or if he put on such a blast as to blow the solder out of the joints when brazing, and instead of making a joint spoils the job, he must not charge it upon us, but keep a brighter look out in future. Good rules are useless unless put in force and practised with skill and intelligence."

70. *Prevention of Rust in Iron.*—"Many a valuable hint," says a correspondent of the "Builder"—Mr. C. H. Smith—"is to be obtained from an intelligent practical labouring man, which may lead the philosopher into a train of ideas that may, perhaps, result in discoveries or inventions of great importance. When bricklayers leave off work for a day or two, as from Saturday to Monday, they push their trowel in and out of the moist mortar, so that the bright steel may be smeared all over with a film of it, and find this plan an effectual remedy against rust. In Wren's 'Parentalia' there is a passage bearing upon this sub-

ject:—‘In taking out iron cramps and ties from stonework, at least 400 years old, which were so bedded in mortar that all air was perfectly excluded, the iron appeared as fresh as from the forge.’ In the victualling department at Plymouth, some years ago, I observed a man lime-whiting the inside of some iron tanks, previously to their being filled with water for the service of the crew and passengers during a voyage; this was to prevent the iron rust affecting the water. In London I have also recently seen men, with a tub of lime-whiting and a mop, smearing the inside of large water-pipes, as security against rust. Oxygen, which is the main cause of rust, is abundant in the composition of both water and the atmosphere; and that quicklime has an astonishing affinity for it, is evinced in the homely practice of preserving polished steel or iron goods, such as fire-irons, fenders, and the fronts of ‘bright stoves,’ when not in use, a little powdered lime beaten upon them out of a muslin bag being found sufficient to prevent their rusting. Another instance, very different and far more delicate, bearing upon the same principles—the manufacturers of needles, watch-springs, cutlery, &c., generally introduce a small packet of quicklime in the same box or parcel with polished steel goods, as security from rust, before sending it to a distant customer, or stowing it away for future use. These cases are extremely curious, because, as a general rule, bright steel or iron has a most powerful affinity for oxygen, consequently it is very readily acted upon by damp, and is rusted in a short time, either by decomposing the water and obtaining oxygen from that source, or direct from the atmosphere. It is not absolutely essential that the quicklime should be in actual contact with the metal, but if somewhere near, as in the case of the parcel of lime packed up with the needles or watch-springs, the bright metal will remain a long while without the least alteration in its appearance; the lime (which is already an oxide of calcium) either receiving an additional dose of oxygen, or being converted into a carbonate of lime.”

DIVISION TENTH.

BUILDING MATERIALS—TIMBER—STONE—MORTAR—CEMENTS.

71. In the volume for 1863 will be found, in Division VIII., p. 351, reports of some papers on the subject of *Timber* as used for building purposes, which abound in much that is interesting to the practical man. To these papers we refer the reader for points not touched upon here, proceeding to give some of the matter which, during the past year, has appeared in the various professional papers. Compared with what we have given in the first volume, this is not much in amount, although it is not wanting in practical value. The *preservation of timber*, more especially for railway purposes, has been a subject to which the attention of practical men has been much given of late years, and their researches, and the experience founded upon these, have done much to advance the practical solution of the points involved in the question. The following abstract of an article, which appeared in the pages of the "Practical Mechanics' Journal," on the experiments which have been instituted at Ostend, in Belgium, by M. Crepin, to test the value of the application of *Bethell's process of Creosoting to Baltic Timber*, will be useful here.

"The experiments undertaken by me in 1857, at Ostend, to ascertain the relative preservation of timber prepared with sulphate of copper, and timber prepared with creosote oil, when placed in the sea, and the relative resistance of such differently prepared timber to the attacks of the Teredo worm, have been previously given to the scientific world.

"I have proceeded with these experiments, and having again minutely inspected the creosoted wood, I am able to say that it presents no trace of the Teredo, and is in a perfect state of preservation. The experiments, I believe, may be now taken as decisive, and we may conclude that well creosoted fir timber, prepared with creosote oil of good quality, is proof against the attacks of the Teredo, and is certain to last for a long time."

After describing the trial, the author proceeds:—

"This trial of creosoted fir, for marine purposes, appears to me conclusive, both as regards the preservation of the wood, and as regards its resistance to the Teredo. Experiments made in England, and recently in France and Holland, tend to the same conclusion. I cannot too strongly recommend the use of creosoted fir-wood, in Hydraulic engineering, in preference to oak (the price of which, especially for the larger pieces, has become excessive), since, in addition to its being cheaper, there is no doubt of the creosoted fir lasting longer. The Government Public Works Department has cordially adopted this most beneficial process, and constructed part of the dyke, and the whole of the American foot-passengers' bridge, in the new works at Ostend, of creosoted red fir.

"At Nieuport, a visitors' pier, 600 met. (660 feet), has been built of creosoted fir, upon the left bank of the channel; and the new pier, which is to be carried out from the end of it into the sea, will doubtless likewise be made of creosoted fir. Moreover, various sluice-gates at Ostend have recently been ordered to be renewed, and creosoted Baltic fir and pitch pine to be used for that purpose.

"The only things about which, to my mind, we need be solicitous, are, *the proper creosoting of the timber with proper creosote oil, and the use of the proper kinds of timber*, viz., those best suited to the process of creosoting.

"It has been observed that the resinous descriptions of wood become most thoroughly injected, and that the use of white fir should be discountenanced.

"I also think it right to mention that, in the case of the sluice-gates recently ordered, no limit has been fixed to the quantity of creosote which may be injected into the wood; also, that it is required that the wood be first subjected to a vacuum of 20 per cent. of the barometer for an hour; and immediately after this, have creosote oil forced into it at a pressure of 8 atmospheres during at least two hours."

72. The following brief "notes" exhaust all that we have this year to record upon the subject of timber.

a, The age of Trees.—"It *was* (I should rather say *is*)," says Mr. J. Blenkarn in the "Builder," "a generally received opinion that in order to ascertain the age of any tree, when felled, it is *only* necessary to take a transverse section and count the number of (*annual*) rings. When writing my work on 'British Timber Trees,' which was published in 1859, I had examined so many trees, whose ages were pretty accurately determined, that I knew no reliance, in most cases, could be placed on the method of counting the rings to ascertain the age. And, although in opposition to men older and better acquainted with the subject than myself, I could not, altogether, pass over the matter in silence, and at page 4 (first edition) is the following observation on the subject:—' By counting the number of these so-called annual rings, which are very distinct in some species, it is supposed the age of the tree can be ascertained; but we are inclined to doubt this hypothesis, when we consider the immense number of these rings in some trees which bear no comparison to the time they may be supposed to have been growing.' As corroborative of the accuracy of this statement, I read the following in the *Times,* in the review of Mr. Wm. Menzies's great work, 'The History of Windsor Great Park and Windsor Forest:'—' Having obtained permission to fell two or three trees in each plantation, about which he entertained a doubt, he planed the stems smooth and counted the rings. When, however, he came to test this method of cutting down trees in plantations, whose age was ascertained, he found that, between trees whose ages varied one or two centuries, there was perceptible only a difference of four or five years.' "

b, From the same Journal we take the following note:—

" *Preservation of Building Materials by the Residuum of Coal-tar.*—In France the residuum obtained by the distillation of tar, for the purpose of extracting the oils and hydrocarbons, is called *brai* (coal-tar pitch in English). Upon immersing bricks in this resin, melted at 200 degrees, they become fit to use, with success, in the construction of chlorine chambers, also for condensers for chlorhydric acid. Plaster acquires a strong consistency, and does not crack as it does after being dipped in silicate of potash or soluble glass; by virtue of its porosity, it is thoroughly penetrated by the resin, and becomes permeable to all other substances; while objects moulded in plaster retain their form without the least alteration. This is so true, that crystals of gypsum (natural hydrated sulphate of lime) become, in the resin, of a shining black colour, the crystalline form not being changed, but the water of hydration being replaced by the resin: it is a pseudomorph. Alabaster acts in the same way.

"Stones covered with coal-tar, or even with greasy or resinous coating, resist the action of wind bringing salt-spray from the sea better than do bare stones. Mr. Kuhlman, according to *Silliman's Journal*, has discovered, that resins, greasy matter, and various other substances, act in the same way, and that it is also the case with all liquids and bodies in fusion, when they *wet* the body which is to be penetrated. In the case of plaster it is not a simple effect of permeability, but rather of displacement of the water; the plaster becoming anhydrous, is thoroughly penetrated by the tarry matter, and its consistence increases, but the form of the object moulded is preserved unaltered, even when the bath of resin is raised to the temperature of 400 degrees C. At from 150 degrees to 200 degrees C., stearic acid acts like resin; the plaster becomes impregnated with it, and at the same time loses its water of hydration."

c, The following is from the "Building News:"—

"*Preserving Railway Timber.*—There are several modes in use for chemically preserving timber. One recently adopted with success in America, consists of Burnetizing, or using a solution of chloride of zinc, one pound of chloride to about eight and one-half gallons of water. The liquid is forced into the pores of the wood under heavy pressures, and by this process, the wood is not only preserved from decay, but in a degree rendered incombustible. The stronger the solution, the less danger from fire. The wood is treated when newly cut, and as the salt does not injuriously affect iron, and it is a powerful deodorizer and disinfectant, it has some positive merits. The cost of this process, per sleeper, in ordinary times, is about seven cents. The annual report of the Philadelphia, Wilmington, and Baltimore Railway, says:—'From every appearance, this mode of preparing cross-ties and timber, will result in the end in great savings, as it promises to greatly increase the durability of all kinds of lumber, and greatly diminish the expense of labour in removing defective materials. As a case in point, we may mention that about two-and-a-half years since we caused to be placed in the track, side by side, two cross-ties of gum, a wood the most perishable, when ced in exposed positions. One was Burnetized, and the other was in its natural state. A few days since, both were examined; the one that was Burnetized was found to be as sound as when put in, and the fibre of the wood had become hardened in the meantime. The one that was not Burnetized was found to be entirely rotten and useless.' The time occupied in the process for completely saturating sleepers, is about seven and one-half hours, so that two charges per diem, of the solution, can easily be prepared."

73. In March 1863, the Royal Institute of British Architects appointed a Committee to investigate into, and make experiments upon, the subject of "*Artificial Stones*," to which, of late, very considerable prominence has been given, from a variety of circumstances not necessary here to specify. The committee, in carrying out the experiments, "deemed it advisable to institute experiments upon other materials, as a means of comparison,"—these being—1. *Portland and other varieties of Stone;* 2. *Slate;* 3. *Bricks;* 4. *Concrete;* 5. *Martin's Cement;* 6. *Wood;* so that the report has a much wider interest to the practical man than its more special title, as given above, would lead one to suppose.

"The Committee met on the 11th of March 1863, and at once issued notices, and advertised in the public journals, that it was desirous of receiving prospectuses or other information connected with the manufacture of artificial stone; and resolved,—

> That each patentee be informed that this committee proposes to report merely on the actual facts which may appear in the investigation;
> That, so far as possible, the various materials used in the investigations be supplied under the immediate supervision of this committee;
> That Mr. C. H. Smith, Honorary Member, be added to this committee;
> That some eminent chemist be associated with this committee, in order to assist it in the investigation of the processes [Mr. Alfred White was thereon added]; and,
> That each patentee be requested to inform this committee of the proceedings he would propose to adopt with regard to the investigation of his process.

"It received responses from Messrs. Coignet, Ransome, Bodmer,* and Wheeble.†

"Mr. Charles M. Westmacott put forward his patent cement and plaster; and they, although perhaps beyond the scope of the committee, were received by it, on account of the interest that

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* Patent Stone Bricks. † Reading Abbey Stone.

had been shown in the patent, at the meeting of the Institute, on the 23d of February 1863." . . . .

As already stated, "the committee deemed it advisable, for the better understanding of the results obtained, to institute experiments upon other materials as a means of comparison, the results of which are appended in Tables . . ; and it would particularly direct attention to Table D (given at the end of this paragraph), showing a series of experiments suggested by Mr. John W. Papworth, on cubes of Portland stone, 2″, 4″, and 6″ in height, by their respective beds, cut from a carefully selected block 2′ cube. The deductions to be drawn from this table appear to be that the results obtained from crushing small cubes of 2″ and under on the side, as usually given in accepted tables, must be received with considerable caution, inasmuch as while 2″ Prisms 2′×2″ bore 1·5 of a ton put on the square inch, and 2″ Prisms 4″×4″, and 2″ Prisms 6″×6″, nearly 2·5 tons, yet 6″ Prisms 6″×6″ and 4″ Prisms 4″×4″, only bore 1·9 of a ton on the square inch, showing that the strength certainly increased with the size of the area, but apparently not in any definite proportion; while it was observed in these experiments that the height had considerable influence upon the ultimate resistance, a result not expected, and in contradiction of the usual neglect of the height, until that element exceeds six times the diameter.

"From Table F (not here given) it appears that the cohesive power of cements may be classed in the following order:—Martin's Portland and Roman; but it must be borne in mind that none of these had been exposed to atmospheric influences; yet the very remarkable differences without any appreciable cause in the results of the various experiments show that the strength of cements is a subject upon which no satisfactory theory has yet been definitely propounded.

"The committee trusts that the time required for preparing and testing, at given intervals, so many and various materials, will be sufficient reason for not laying the Report earlier before you; and it will be seen from the extreme variation in the results given by the experiments, that the committee is justified in repeating the experience of all zealous investigators—viz., that, without regard to the well-known inapplicability of general formulas to particular works, the council must not be surprised at finding that the committee will not draw peremptory deductions from even the experiments made, considering that the least number, to arrive at anything like a perfect conclusion, should be more than twenty of each size of every material: the committee felt that it had no right to exact so much time and expense as thereby would be required from the professional gentlemen of your committee, or from Mr. Dines, who personally superintended the details of each experiment; and, moreover, it had no funds placed in its hands by the Council for that purpose." . . . .

The following are the "general statements of results" as given in the Report:—

"Mons. Coignet's process is admitted to be highly successful on a large scale in Paris; but the majority of the cubes prepared by him do not appear to be much stronger under pressure than ordinary concrete, and inferior to Bath stone, although they improve by age; and this weakness is impugned by him as a result on the ground that the samples were made out of his factory, and that he had not all the appliances requisite at command. A step-landing, and bas-relief, made, in April 1863, from the sweepings of refuse used for making blocks for experiments, are still at Mr. Dines', and having been exposed to the weather, as well as to wear and tear, appear to stand as well as Portland cement."

Of Mr. Ransome's process the committee express a favourable opinion as to its being founded upon "scientific principles," but state that "there is an important difference between these and Mons. Coignet's examples, that Mr. Ransome is not able to declare that his process is highly successful on a large scale, but represents that he has not yet completed the appliances to put it into operation. In some of his specimens there appears an improvement as they advance in age; but so irregular is this that no reliance can be placed upon that feature. But it would seem that, if the process of penetration is complete, the ultimate strength is attained in a short period, and that the external influences of weather had little effect upon them in that respect. The committee feels that if Mr. Ransome can insure the perfection of his entire process, restrict himself to the production of work for each occasion, as it may arise, and (for the sake of artistic excellence) avoid becoming a manufacturer of casts from a certain number of moulds, it is possible that for external decorative purposes there is a large field open to him; but they are of opinion that, as yet, Mr. Ransome has not rendered his material suitable for the chisel of the carver or the tool of the modeller.

"Mr. Wheeble (Reading Abbey Concrete Stone) sent moulded bricks, made at Reading, from the works to the committee, and they seem to have an ultimate strength, apparently produced by the use of stone lime from Bridgwater, equal to that of common stocks; the latter, however, possess the advantage of not yielding until the instant of disintegration. The 4″ cubes made in moulds supplied by the committee, and in its presence, never attained the strength of concrete except in a case where large gravel or flint was the chief ingredient.

"Messrs. Bodmer (Patent Compressed Stone Bricks) expressed their inability to comply with the requisitions of the committee as to 4″ cubes, as the moulds of their press were of ordinary brick size; and if their materials were pressed by manual labour into 4″ cube moulds it would not represent the artificial stone which they were in the habit of producing. The committee accepted accordingly bricks supplied from their works, which show a steady progressive increase in strength as they advance in age; and the results justify the statement made by Messrs. Bodmer, that after six weeks to two months the bricks are fit for use. The committee regrets the unfortunate inability of Mr. Charles Westmacott to put himself satisfactorily in connection with persons having at their disposal the premises and materials which he required for the display of the qualities of his processes. These chiefly depend upon the mixture of natural materials before adding water. The committee has been able, however, to test one or two experiments, which result in giving it a favourable opinion of the system adopted by him both for ceilings and for composition applied internally or externally. These may still be seen in Mr. Dines's yard, having been exposed through last autumn and winter. The quick stucco, for rendering ceilings, was tried in the month of May 1863, consisting of unslacked lime, chalk, and sand, mixed pure, before adding water; it occupied in making and setting twenty minutes, was followed within an hour by ordinary gauged stuff, and stood without cracking. Messrs. Francis, of Nine Elms, have recently made arrangements with Mr. Westmacott to apply his processes practically; from their operations, on a more extended scale than was possible to be carried on before the committee, the valuable character of his invention may be more decidedly proved.

"Had the results of the experiments now laid before you been more consistent with each other, and had they resulted in conclusions highly favourable to the various processes, the committee would still have felt bound to impress upon the members of the profession who have the opportunity of trying novelties, that future experiments for testing the strength of materials should be made on cubes of larger dimensions than have been heretofore employed; and they would suggest that cubes of 6″ sides would perhaps be the simplest and best adapted for the purpose: with regard to time, years instead of months are necessary to enable any one to arrive at practical conclusions as to the durability of any artificial material put forth in lieu of natural ones." The following is the table referred to in page 318:—

Table showing the results under pressure of Cubes 2″, 4″, and 6″ in height, by their Base.

PORTLAND STONE (*Brown Bed*).

HEIGHT.	Base.	Cracked.	Crushed.	On sq. inch.	REMARKS.
	″ ″	Tons.	Tons.	Tons.	
2″	2 × 2	...	3·2	0·8	At once.
,,	2 × 2	4·0	6·0	1·5	
,,	4 × 2	...	20·2	2·5	At once.
,,	2 × 6	21·0	23·5	1·70	Across the bed.
,,	4 × 4	8·0	41·0	2·5	
,,	6 × 6	64·0	86·0	2·4	
4″	2 × 2	...	3·0	0·75	
,,	4 × 2	...	17·0	2·12	
,,	4 × 4	25·75	29·25	1·82	
,,	4 × 4	24·25	28·75	1·85	
,,	4 × 6	31·0	45·0	1·87	*a* Very slight external.
,,	6 × 6	48·0 *a*	82·0 *b*	2·27	*b* Not crushed.
6″	2 × 2	2·8	3·4	0·85	
,,	6 × 2	...	10·0	0·83	
,,	4 × 4	18·0	20·45	1·27	∟ to bed.
,,	6 × 4	28·0	32·0	1·33	
,,	6 × 6	64·0 *c*	70·0	1·94	*c* Very slight.
,,	6 × 6	55·0	68·75	1·90	

74. It is by no means flattering to the modern practice of building to compare some of its "slop works" with those of former centuries, which were destined to last for ages, and in which mortar of a quality rarely seen now-a-days was used by the ancient builders. In an exceedingly valuable paper in the "Building News"—under the title of "*On the English Style of Making Mortar*"—the whole subject is gone into, and from which much that is thoroughly practical can be derived. "The philosophy of using a mortar," says the writer of this able article—of which we can only give an abstract—"consists in presenting to the materials that are employed in masonry a body that should set or harden in such a manner as to constitute, in conjunction with those materials, a solid, homogeneous mass. This is generally effected by means of the varieties of the carbonates of lime that are reduced by burning to the state of the caustic lime; which then, by the mixture of a certain proportion of water, crystallize in a rude, imperfect manner around the matrices that are presented to them, and gradually harden by the absorption of the carbonic acid gas from the atmosphere. The ancient theory was that this absorption of the carbonic acid gas was the immediate cause of the hardening of all limes; but modern chemists have found that there were insuperable difficulties in the way of the lime meeting with a sufficient quantity of the gas to ensure the conversion of it, within the usual time of setting, into the carbonate of lime, or into its original state. The present opinion is, that the caustic lime passes into the state of the hydrate of lime. In this state it converts the water necessary for its crystallization, and it gradually absorbs the carbonic acid gas necessary for its reconversion into the carbonate of lime. The differences that are observed to take place in the rates of setting of the different qualities of lime are accounted for by the greater or less affinity that they possess for the combination with the water; and as the silicate of lime and alumina, in certain proportions, has a notable facility for forming this combination in the caustic state, the great object of the constructors is to present such proportions of lime and alumina as shall have the necessary conditions. Thus, the grey stone lime, the blue lias lime, the Portland cement, and the Roman cement, in their various degrees, offer the conditions esenting the silicate of alumina in the requisite proportions

for the gradual hardening of the mixtures; but they are, it must be observed, very different in their modes of setting, owing to the different proportions of their ingredients, and also, it may be suspected, to the state in which those ingredients are found, as the state of combination of the silica and alumina has been found to materially affect the nature and the conditions of the compound thus formed. . . .

"From what has thus been said with respect to the setting of limes, it will be easy to see that the practice of London builders in using that material 'hot,' as they call it, is a mistaken and dangerous one, both theoretically and practically; and the attention of professional men cannot be called to this abuse of materials too forcibly. The lime, in these cases, is rarely completely slaked, at least in the ordinary methods of making the mortar by the use of the pugmill or by hand; and there are, consequently, large portions of the lime that are exposed to derive their water from the atmosphere, or from the surrounding bodies with which they are in contact. But if the lime be, on the whole, well slaked, and there be only a few lumps that have escaped the notice of the person charged with the preparation of the lime, still there must be the danger of employing the lime before it has completed the action of hydration; that always takes from one to two days, with the exception of the cements. There can be no doubt but the lime ought to be used as fresh from the kiln as possible, so as to ensure the process of hydration taking effect in the best way possible, without the limes having had time to become partially and irregularly slaked.

"Whilst thus alluding to a bad custom, that owes its origin to the ignorance of the workmen of the conditions that ought to prevail in the hydration of limes, it may be as well to revert to another custom, which appears to be owing to the same cause —we mean the use of grouting, as the thin lime is called, that the London builders deluge their work with. It may be necessary thus to introduce it in the brickwork executed with *hot* bricks, and thus have a degree of absorption that would infallibly subtract all the moisture necessary for the hydration of the lime from the mortar; but this is a very bad way to supply the water that the bricks would require, and it amounts to just so much lime wasted as enters into the composition of the grout. The proper principle of all masonry is that of executing it with wet materials, and dry, or rather stiff, mortar: instead of this, it would appear that what the London builders aim at is the use of dry materials and wet mortar, so that they provide for the absorption by the proportions of the moisture they hold in solution in the cementing ingredients. Vicat, and all the French authorities who have written on the subject of limes, have always protested against the use of grout; and no doubt the continuance of the practice is only owing to the ignorance of the workmen employed in the execution of the brickwork. There is, however, for them some shadow of an excuse, in the excoriation of their fingers attending the use of wet bricks and stiff mortar; but that consideration ought not to weigh with the architects or civil engineers, who are bound to see that the various materials are employed in the best conditions. The arguments by which this practice is defended only prove the carelessness with which London bricklayers execute their work, and their ignorance of the laws affecting the class of materials they employ.

"There appear to be many things connected with the degree of calcination at present involved in mystery. Thus, it is known that with the moderately hydraulic limes, the portions that are *under-burnt* acquire the property of setting in water to a much greater degree than those portions that would be considered well-burnt; and the portions that are *over-burnt* also seem to have the same power. The core of the furnaces, as the under and over-burnt parts are called, has thus been frequently used for hydraulic works with tolerable success, so long as the selection remained in the hands of those who were capable of using it. Again, the introduction of the artificial pozzuolanas, or of broken tiles, slack-burnt bricks, and other ingredients, into the moderately hydraulic limes, with the view of presenting to them the silicate of alumina in a peculiar state, has been found to succeed so long as the mixture was not exposed to the action of the salts contained in sea water. But directly the sea water acts upon the compounds they have always gone to pieces. In the case of Portland cement, the mixture of 80 per cent. of lime, and 20 per cent. of clay, has, under the influence of the extra degree of burning it is exposed to, yielded an ingredient that has stood the effects of sea water for now more than fifteen years; nor does there appear to be any reason to apprehend its ultimate yielding to the attacks of this most insidious cause of decay. The theory of the pyrogenic compounds of lime and the silicate of alumina is just now in a very unsatisfactory state, and it would well repay any person who would devote the necessary time and attention to its study; it is in this direction that any new discoveries in the preparation of limes and cements must be realized.

"What has thus been said with respect to the mixture of some substances with the moderately hydraulic limes, for the purpose of giving them the powers of setting under certain conditions, would naturally lead to the inquiry of how the qualities of the substances that are generally mixed with limes can influence their rate of setting. This is a matter of far greater moment than builders seem to think; for the limes they use are all eminently of this description—that is to say, they are all moderately hydraulic—and builders are therefore driven to the use of cements where they have to execute works that require the rapid setting of their mortars. The road sand, and the river sand, that are generally used for mixing with lime, are composed of pure silica, mixed with vegetable and animal matter, that do not communicate to the mixture any properties that would harden it, but they only serve to render it poorer, or they only dilute the lime. Pit sand is better than either of these, especially if it contains the silicate of alumina in the soluble form, which all the pit sand of the Bagshot Heath formation does; but London builders appear to have found out, by some rule-of-thumb process, that the presence of the silicate of alumina in old brick rubbish is the best thing for presenting an ingredient to the lime that should contribute to its setting; and the care with which the ruins of old buildings are worked up with very moderately hydraulic lime used in London, under the name of stone lime, must be a subject of surprise to those who know how little science builders bring to bear upon their profession. The mixture of blue lias lime with burnt clay under edge rollers, that allow the hydration of the whole mass to be effected in a substantial manner, must be referred to the same class of phenomena; and the custom of using blue ash mortar, which is prevalent in London wherever pointing is required, may be explained on the same ground. Coal cinders are said to contain about 44 parts of *silica*, 17 of alumina, 5 of lime, and 34 of oxide of iron; and the reasons for their mixture with the moderately hydraulic lime is therefore apparent; but they must be used with care, for they are remarkably absorbent of water, and are very likely to reduce the mortar to the state that the workmen designate by the term 'short.' Pozzuolana and trass, or Dutch erras, was formerly much used in London for the execution of foundations and water-works; and could the mixture be depended on, there seems no reason why it should not now be occasionally resorted to. The composition of the pozzuolana of Civita Vecchia, and of the trass of Andemach, was said by Berthier to be composed of about 57 to 44 of silica, and 12 to 15 of alumina; the remaining ingredients being lime, magnesia, oxide of iron, potash, and soda, in insignificant proportions. But the ingredients had, in this case, been assembled together in nature's laboratory, under the influence, too, of great heat, and the effect of them was always remarkable. Smeaton used the blue lias lime mixed with certain proportions of the pozzuolanas for the Eddystone lighthouse. Vitruvius recommends the introduction of the ingredient in all foundation works; nor can there be any reason to doubt that its mixture with the moderately hydraulic limes, *properly hydrated*, would produce an excellent mortar. Whilst upon the subject of the influence of the materials that enter into the composition of lime mixtures, it may be as well to add that in concrete there is little done, other than to provide a kind of nucleus, round which the lime may crystallize; and the presence of the Kentish rag in small volume, or the refuse of broken limestone, seems therefore to be desirable as presenting a form which the lime itself would affect in crystallizing. The only condition, with respect to this introduction, is, that it should not be allowed to diminish the resistance to crushing of the mass."

DIVISION ELEVENTH.

BRIDGES — ROOFS — RESERVOIRS.

75. As introductory to what we have to give, and, indeed, comprising much that can be said upon the subject of Bridg

we give an abstract of an able paper in the "*Engineer*," under the title of *Railway and other Bridges*. After giving the meaning of the word, and a notice of some of the earliest forms of bridges, the writer proceeds to point out that "all bridges must be constructed on one of two principles, compression and tension, and most involve the two principles together. Bridges of stone, brick, concrete, cast-iron, and some of timber, involve the compression principle or thrust, as in arched forms, and cast-iron is the best as far as regards strength, for it is practically incompressible, and probably the cast-iron bridge called the Southwark is the strongest bridge in the world as regards superstructure. It is subject to rust or oxydize, but so are some kinds of granite; and then, again, granite is more brittle and apt to chip at the edges, for which reason 2 inches in thickness are wasted in chipping away the edges regularly to prevent them from chipping irregularly.

"But there is a disadvantage in the compression principle, the great weight of material which presses hard upon the piers is an unfavourable condition to the marshy beds of rivers; and we cannot conceive anything more unmechanical than a huge stack of wooden piles driven into the bed of a river, and a massive stone pier built thereon, to support ponderous stone arches, the smallest settlement causing the arches to crack—a disadvantage avoided by the use of cast-iron. We have long been accustomed to consider stone as the most chemically durable material; but it is, in truth, as uncertain as the different kinds of timber, and though some kinds of granite are durable, there are other kinds inferior to good brick. Upon the whole, artificial stone, whether prepared by fire, as bricks, or by chemical mixture, will, as they go on improving, be found to be the best chemically; but it is not probable that they will attain the solidity of metal, which, from its first introduction by Thomas Paine or others, has gone on increasing in use from the time the Sunderland bridge was first erected; and since the advent of railways goes far to abolish the use of stone altogether, at least for railway structures. The vibration caused by heavy rolling masses disintegrates stone; and there is not a doubt that, if iron does not displace it, concrete will, for the same reason that steel displaces iron—it is homogeneous. Brick and mortar, or brick and cement, are not good, unless they are of equal mechanical hardness and toughness; and when stone is used, it is sought to make a mechanical fit of the surfaces without cement, unless in structures similar to what is called Kentish rag, or flint walls, in which the walls are really formed with mortar, in which the stone does not serve for strength, but for filling in—and, we may add, for falling out also.

"The weight of cast-iron has given rise to the use of wrought-iron in the structure of railway bridges. It is generally assumed that cast-iron is most fitted for compression, and wrought-iron for tension; but in truth, wrought-iron is well enough adapted for thrust, if it be in sufficient thickness, and it has the advantage of not being brittle—a very serious defect in railway bridges in case of concussion—but whether for railway bridges or for ordinary traffic we have probably seen the last of stone bridges over the river Thames. . . .

"In the construction of iron bridges, not the least important point is the rapidity with which they can be erected, and especially as regards the piers. The atrocious old cofferdams, laying bare the bed of the river, and breaking it up with piles, have departed, and the caisson has assumed another form in the hollow cast-iron cylinders. But these have still their defect. There is no existing means of spreading their foundation. They are still samples of want of 'footing,' and are deficient in bearing surface. . . . .

"The question is, would rust affect the cast-iron mischievously internally? We do not think it would, for in the process of building the cast-iron might be heated with fires and solidly pitched over. Smeaton, in the Eddystone, heated his iron and dipped it in linseed oil. We look forward to this mode of structure as a great probability—combining ample strength with great lightness and abundant bearing area, analogous to the screw pile in principle, but of a diameter it would not be possible to attain with a manageable screw. Pitched inside, and on a heated surface, and with the outer side close rammed in the earth, it would take some generations to convert that cast-iron into an oxide.

"Preservation from rust is a very important element in iron, and more especially in wrought-iron structures, and this is gradually forcing itself on public notice. At the time of the erection of the Conway and Britannia bridges, a preference was pointed out in a quarterly periodical for the high-level bridge at Newcastle-on-Tyne instead of the Britannia, the one being a permanent and the other an ephemeral structure, having 7 miles of cellular tubing rough with angle iron, 21 inches in height, and 18 inches wide, which no engineer could possibly inspect without being drawn through on a truck, first on his right side, then on his left, then on his back, and lastly on his stomach, making 28 miles in all. Where is the engineer who would do this, with the dust dripping into his eyes, and condensed water following? And, if painting be contemplated, who is to supervise the boys at work when, with the sun shining, the draught of air is so strong that, unless closed at one end, each cellular tube becomes not a pea, but a boy shooter. The papers have lately been rife with an account of 40 tons of rust and scales taken out of the tubes, and we remember that very soon after the erection of the Conway 4 tons were taken out. We had predicted this result, and that the time would come when the papers would be full of notices of 'the unaccountable subsidence of the Britannia Bridge.' The rust has come, and of a surety the subsidence has to follow in due time. It has long been roofed with asphalted paper to mitigate external rust."

76. On the subject of (*a*) *Short-span Railway Bridges*, we give part of an article taken from the "Mechanics' Magazine," supplementing it by (*b*) *The Strength of Small-span Railway Bridges* taken from the "Building News." After describing the brick or stone arches which characterised the practice of railway engineering in the first period of its history, the writer proceeds to say that the days for the employment of these materials, for the construction of railway bridges of moderate span, are numbered.

"The wrought-iron girder acts so safely, cheaply, and conveniently as a substitute, that its employment has become almost a matter of necessity. With the first cost, paid to the ironmaster or engineering firm who undertake its manufacture, the outlay for a girder bridge may be said to begin and end. The expenses of erection are usually very moderate indeed as compared with the cost of a bridge of either brick or stone; while in many cases, where headway is valuable, an immense amount of indirect expenditure is avoided in the lowering of the road crossed, or in the elevation of the railway. The girder bridge, too, will sustain its load well, under conditions where a built arch would give way at once. We may cite as an instance—one among many—a case where an accommodation-bridge is carried across a branch railway line in a crowded mining district in South Staffordshire. The bridge accommodates a double line of narrow-gauge tramway, on which trucks, loaded with from two to three tons of coal or iron-stone, are conveyed from the pits to the blast-furnaces, and a wide Macadamized road as well. The workings of an old mine run right beneath the abutments of this bridge, which is of about 28 feet span, composed of four wrought-iron girders. A few years ago the ground began to give way, and the abutments to sink. A strong timber frame was then erected at each side against the face of the brick-work, a top sill sustaining the ends of the girders. This is supported in turn by heavy uprights, resting at their lower ends on double oak wedges, opposed to each other, which rest on large balks well ballasted. As the ballast sinks, the wedges are driven in from time to time, by an arrangement of screws, and the girders are thus lifted again through the space they have descended. The vacuity between them and the abutment is made good from time to time in this way; four courses of brick have been put in at one side and three at the other without any interruption to the traffic on the road above, or the railway beneath the structure. Had this been a brick or stone arch, instead of an iron girder bridge, it would have tumbled into fragments long since. The great strides recently made in the iron manufacture enable the modern engineer to avail himself of wrought-iron as a constructive material, to an extent which was hardly hoped for ten or a dozen years ago. One firm already undertakes to supply girders rolled in one piece, top and bottom flange included, of a length sufficient for all moderate spans, at a price little greater than that which cast-iron girders of equal strength would cost. For greater spans, box and built-up girders are turned out with the greatest ease and rapidity, by the combined aid of improved punching and riveting machinery. The rules for calculating the strength of these beams are simple in the extreme; and, once completed, we know that bridges composed of them are thoroughly reliable for very many years. Probably the cheapest bridge that can be erected is one with a wrought-iron girder placed directly beneath each rail, a longitudinal sleeper being interposed. All the expense for cross girders—often a very considerable sum—is thus saved, and the load is at once transferred, in the most direct manner, to the point of support. In rural districts, headway is seldom much of an object within certain limits, and this mode of construction is thus peculiarly suited to such situations. The following formula shows, almost at a glance, the dimensions which should be given to each girder:—

$D =$ Depth of girder in inches.
$A =$ Area of bottom flange in inches.
$S =$ Span in inches.
$W =$ Breaking weight in tons.

$$\frac{80\,A.D}{S} = W \text{ for girders loaded at centre.}$$

$$\frac{160\,A.D}{S} = W \text{ for girders with distributed load.}$$

The depth should equal 1-12th or 1-10th of the span, although the rule is often departed from both ways.

The principles involved in the construction of wide-span bridges are far more complicated and abstruse than anything which applies to the plain girder, acting, so to speak, as a joist of the simplest kind. The varieties of bridge are all but infinite; almost every engineer regarding some particular system with favour, and employing it to the exclusion of all others. The number of wide-spans is comparatively small, however, while those of 10 ft. to 30 ft. can be counted by the thousand. The means of carrying railways across the roads and streams, which traverse the face of the country in all directions, thus becomes a matter worthy of careful consideration, as on it an outlay of very large sums indeed, almost wholly depends. Great improvements may yet be looked for in the manufacture of one-piece girders; and their invariable adoption, to the exclusion of brick, stone, and cast-iron, is far from unlikely. A certain limit, it is true, exists, which it is very improbable we will ever exceed, in the dimensions of rolled-iron bars. What that limit is, however, no one now alive can determine. Once arrived at in iron, there can be no difficulty in ttaining it in steel as well; and a few years will, we have no oubt, see spans crossed by girders of that material, which are ow got over by very costly and complicated structures, in a less fficient or convenient *manner.*"

b "*Strength of Small-span Railway Bridges.*—In calculating the strength of small-span railway bridges, it must always be borne in mind that they will have a greater load, per foot lineal to support, than a large span bridge; and we must not simply take the usual allowance of 1·5 tons per foot lineal (for a single line of rails) as the greatest moving load. For instance—place a locomotive on a bridge of, say, 7 ft. span, with the driving wheels in the centre, having a load of 14 tons on them, this will be equal to a distributed load of 28 tons, and, therefore, equal to 4 tons per foot lineal. We must consider the span to be the distance from centre to centre of the bearing surface of the ends of the girders on the abutments. In the following calculated loads per foot lineal, the weight of the bridge itself is not included; it must, therefore, be added to the moving or accidental load in making the calculation of the strength of the girders.

"A bridge of 32 ft. span, having a locomotive placed in a position to give the greatest strain, thus—

Fig. 21.

will be equal to a load, in the centre, of 24 tons very nearly, and equal to 1·5 ton per foot lineal. No other position of the locomotive will give a greater load, per foot lineal, on this span. If the span is increased, the load, per foot, will decrease slightly; therefore, we may take 1·5 ton, per foot lineal, as the greatest moving load that can ever come on bridges of 32 ft. span and upwards, for a single line of railway, on which locomotives run of the above dimensions and weights on the wheels. Decrease the above span to 30 ft., and we shall have a load on the bridge equal to 1·55 ton, per foot lineal, with the locomotive in the same position. With 28 ft. span, under the same conditions, the load will be equal to 1·6 ton, per foot lineal, the moving load per foot lineal increasing rapidly as the lengths of the spans decrease, as the following tables will show:—

Greatest moving load on 32 feet span = 1·50 tons per foot lineal.
" " 30 " = 1·55 " "
" " 28 " = 1·60 " "
" " 26 " = 1·66 " "
" " 24 " = 1·73 " "
" " 22 " = 1·79 " "
" " 20 " = 1·83 " "
" " 18 " = 1·85 " "

With a 16 ft. span bridge, single line, the position of the comotive must be altered to give the greatest strain, thus—

Fig. 22.

The wheels with the heaviest weight must be placed in the ntre of the span, as this position will now give the greatest eight per foot lineal:—

Greatest moving load on 16 feet span = 1·94 tons per foot lineal.
" " 14 " = 2·00 " "
" " 12 " = 2·25 " "
" " 11 " = 2·55 " "
" " 10 " = 2·80 " "
" " 9 " = 3·11 " "
" " 8 " = 3·50 " "
" " 7 " = 4·00 " "
" " 6 " = 4·66 " "
" " 5 " = 5·60 " "
" " 4 " = 7·00 " "

"If the locomotives vary in size and weight, the load per foot neal will also vary accordingly. Therefore, in making bridges ' small spans, the locomotives must be taken into account in aking the calculations of the strengths. This is not often done y many engineers, who often simply take the usual 1·5 ton for idges of any span.

"The following formula, for calculating the strengths of built rought-iron-plate girders, is very simple:—

Let w = distributed moving load.
,, w' = ,, weight of bridge.
,, l = length of girder, or distance between centres of bearings, in feet.
,, d = depth of girder, in feet.
,, x = number of square inches, sectional area of bottom flange; the strain on the metal to be 5 tons per square inch, which is a safe load.

$$\frac{(w+w')\,l}{8} = d \times 5\,x$$

$$= \frac{(w+w')\,l}{8\,d \times 5} = x = \text{number of square inches in the bottom flange.}$$

77. The following is an abstract from a paper on *Light Roofs* in the "Building News:"—"A proper distinction must be drawn between roofs which are really, and those which are only apparently, light. In the present article we use the word in its absolute sense, and not as a mere technical or æsthetical term. It is quite possible to construct one roof from timber beams which shall look exceedingly heavy, and yet weigh many pounds less per superficial foot covered in, than another formed of iron of the most aerial proportions.

"Iron alone is wholly inapplicable to roofs of a minimum weight, while it is obvious that wide spans cannot be treated successfully with wood alone unless it is either employed in masses—excluded by the conditions given—or else arranged according to some system which will impart the necessary strength and stiffness.

"By the use of wood in combination with iron, considerable spans may be occasionally dealt with to great advantage. Trussed timber girders, as employed in bressummers, purlins, temporary bridges, &c., are so well known that they scarcely require notice; but a cheap and very excellent light rafter, which has not yet received the attention it deserves, may be constructed after much the same fashion. Rafters have two duties to perform. They must transmit to the walls a strain in the direction of their length, which is strictly compressive in as far as it affects their own powers of endurance, and they must also sustain a transverse stress tending to break them, and, in fact, precisely similar in its effects to a uniformly-distributed load upon a beam supported at both ends. Bodies at rest upon inclined planes, such as the slates upon the slope of a roof, act upon them in a direction precisely at right angles with the plane, and thus we have the transverse breaking force. Now, a very small scantling will suffice to resist a strain in the direction of the length of the timber. The transverse strain is not so easily dealt with, and in ordinary roofs we find that either collar beams or purlins, or both, must be introduced to render the structure strong enough to sustain its load. In very flat roofs neither of these expedients can do much good, collar beams especially becoming absolutely inapplicable. In such cases it is perhaps better to abandon the use of all extraneous aid, and enable each rafter to sustain its own burden. This can easily be accomplished by applying a strap of common hoop iron from end to end of the rafter. The strap must be put on slackly, and strongly screwed to the rafter at each end. Two small bolts and nuts will answer better than wood screws. Struts composed of small blocks of hard wood must then be interposed between the iron band and the under side of the rafter. These will not require to be very deep, and so head room may be saved. The blocks, by being forced into their places, will, if properly fitted, camber up the rafter, or impart to it a curve, the amount of which may be easily regulated at the will of the architect. Such a curve would prove very troublesome if slates were used to cover in the roof; but for exceedingly light structures slates cannot be employed, and with felt, or very thin sheet metal, this camber is rather useful than hurtful. Excellent hoop iron can be obtained everywhere at moderate prices, and it is so easily applied, weighs so little, and answers such an excellent purpose, that it is somewhat remarkable that it is not more freely used in modern architecture. By its aid it is certainly possible to reduce timber roofs to the extreme limit of weight, while the ease with which it can be handled, and the non-necessity for heavy tools or skilled labour in its manipulation, render its use extremely inexpensive."

78. Among other details on the construction of buildings we find the following practical article on *roofs and arches* by a correspondent of the *Building News*:—

"*The Parallelogram of Forces.*—You will admit, Mr. Editor, that sound practice is based upon correct theory—that the former must suffer if the latter be false. I wish, with your permission, to submit a few remarks upon the commonly received theory of the 'parallelogram of forces' as applied to measuring the resistances, strains, and degree of stability of the parts of a building, showing the results obtained by it to be very incorrect; and to give, instead, a simple rule which can be used equally well for roofs, cantilevers, trusses, arches of every form, stability of walls and piers, suspension chains, &c., measuring correctly the various forces of each; the rule being deduced from experiments in each class.

"My attention was drawn to the subject by a letter in the *Mechanics' Magazine*, Feb. 13th. 1863, upon 'Funicular Action'—as the writer styled it—in which he brought forward instances of the marked failure of arches, wires or chains in suspension, and construction of a triangular outline generally, and said that there must have been something wrong in the principle upon which they had been constructed, or the failures would never have occurred.

Fig. 23.

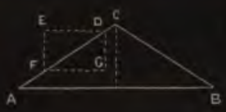
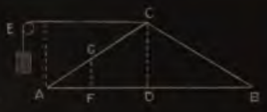


Fig. 24.



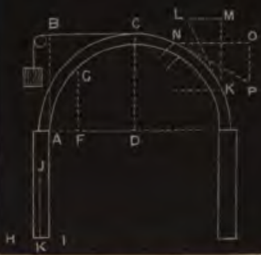


Fig. 25.

Fig. 26.

"(1.) Roofs.—Fig. 23.—It is said that as the principals AC, CB support the roof, the whole weight of the roof is transmitted in the direction CA, CB, the diagonals of a parallelogram, and is resolved into DE the horizontal, and DG the vertical pressure, each of which takes a portion of the whole weight. Thus, let DF be 10, FG 8, DG 6; if the roof weigh 20 cwt., the pressure on AC, CB is 10 cwt. each, and the strain on the tie or the pressure on each wall is represented by FG, 8 cwt. It is very evident that FG is always less than FD; and, therefore (if the theory be true), the horizontal strain is always less than the dead weight of the roof; whereas, by experiment with a model for testing the strains of a roof at different inclinations, a horizontal strain much greater than the actual weight of the roof was obtained at low pitches. Let any one who may be sceptical on this point fix a weight to the centre of a stick, tie a string to one end, and, placing the other end of the stick on some convenient part of his body (making his body the fulcrum), let him by pulling horizontally at the string, keep the stick first at a high pitch, and afterwards at a low one, and he will note the much greater pressure on his body, and the much greater force with which he has to pull the string, at low pitches.

"Fig. 24.—We may suppose the roof ACB to act as a double lever, A and B being the fulcra upon which the levers AC, BC have a tendency to turn, the pressure of one inwards counterbalanced by that of the other. Now supposing half of the roof CDB taken away, a line fixed at C, and a horizontal strain applied at E sufficient to keep the half-roof AC in its original position, this strain will be equal to the horizontal pressure of CB at C, it will be carried down CA, and be counterbalanced by the resistance of the tie-rod or wall (as the case may be) in the opposite direction.

"The horizontal effect of AG is represented by AF, and the vertical effect of AC by AE, so that it resolves itself into the angular lever EAF, with the weight at F, and the power at E.

$$\begin{aligned}
&\text{Let } t = \text{horizontal thrust,}\\
&W = \text{weight of roof,}\\
&\frac{W}{2} = \text{weight of half-roof,}\\
&AD = 2 \times AF, \text{ and } EA = CD;\\
&\text{then } t \times EA = \frac{W}{2} \times AF = \frac{W}{4} \times AD,\\
&\text{the thrust } t = \frac{W}{4} \times \frac{AD}{AE} = \frac{W}{4} \times \frac{AD}{CD},\\
&\text{compression in the direction of } AC = \frac{W}{4} \times \frac{AD}{CD} \times \frac{AC}{AD},\\
&= \frac{W}{4} \times \frac{AC}{CD};
\end{aligned}$$

That is, the horizontal thrust of a roof is equal to one-fourth its weight multiplied by half the span, divided by the height.

"The formula was tested with every variety of pitch from 70 deg., a rise of 1 vertical in $\frac{4}{10}$ horizontal, to 4 deg., a rise of 1 in 14, and it gave results in each case approximating very closely to the calculations.

"Taking four roofs of equal span and different pitches, and allowing for diminished weight of roof as the height is lessened, the following table gives the comparative thrusts :—

Pitch.	Thrust.	Thrust (allowing for diminished weight of roof).
1 in 1½	75	75
1 in 2	100	93
1 in 3	150	129
1 in 5	250	209

So that the actual weights being the same, the strength of a truss having a pitch of 1 in 2, is one-fourth less than that of 1 in 1½; the strength of 1 in 3 is two-fifths less than 1 in 1½; that of 1 in 5 is two-thirds less than 1 in 1½, the trusses having the same scantlings in each case. It will thus be seen that, below an angle of 35 deg., a pitch of 1 vertical in 1½ horizontal, the thrust increases and the strength diminishes in a far greater ratio than the weight of the roof diminishes.

"The inducement for using low pitches is greater in roofs of large span on account of the apparent difficulty of strutting, though this expedient would hardly be resorted to, were the great consequent reduction of strength known.

"(2.) In cantilevers for galleries and balconies the same principle holds good. Example—In a gallery 5 ft. wide, and 8 ft. from centre to centre of cantilevers which are 1 ft. deep; required the strain upon the wall at 1½ cwt. per foot superficial. Here the centre of gravity would be 2½ ft. from the wall (supposing the weight equally distributed), and the dead weight 60 cwt.

$$\text{Horizontal strain on wall} = \frac{60 \times 2\frac{1}{2}}{1} = 150 \text{ cwt.} = 7 \text{ tons } 10 \text{ cwt.}$$

"The horizontal strain would be only one-fourth this, or 37½ cwt., if the cantilever were 4 ft. deep; thus increasing the strength *four times.*

"(3.) Fig. 25.—In arches the same course of reasoning holds good. The voussoirs perform the duty of carrying the weight from the crown to the springing without failure at any point, and, as we are only at present to take notice of the crown and springing, we may consider the half-arch as one solid block, in giving a rule for finding the horizontal thrust. As in the roof, the thrust of one half the arch counterbalances that of the other half at the apex; if we fix a line at C, the horizontal strain along CE necessary to keep the arch in its place will be equal to the opposing force of the other half, will be carried down CA to the springing, and be equal to the horizontal resistance of the pier in the opposite direction.

"The weight of the half-arch is concentrated at the centre of gravity G, and acts vertically with the leverage AF, the thrust diminishing as the height EA increases; so that EAF represents an angular lever, the fulcrum being at A, power applied at E, and weight at F.

Let $t =$ horizontal thrust,

$\frac{W}{2} =$ weight of half the arch;

$$\text{then } t \times EA = \frac{W}{2} \times AF,$$

$$\text{thrust} \qquad t = \frac{W}{2} \times \frac{AF}{AE};$$

That is, the thrust of the arch upon each pier is equal to half the weight of the arch, multiplied by the projection of the centre of gravity beyond the springing, divided by the height of the extrados above the springing.

"This thrust is resisted by the pier HIA.

Let $x =$ width of pier necessary,

$\frac{x}{2} = HK =$ the distance of centre of gravity J from the outer edge H,

$w =$ weight of the pier,

$IA =$ its height;

then $\frac{w \times \frac{x}{2}}{IA} =$ resistance of the pier opposed to the thrust of the arch,

$$\text{and } \frac{W}{2} \times \frac{AF}{AE} = \frac{w \times \frac{x}{2}}{IA},$$

$$\frac{W \times AF \times IA}{2 \times AE} = \frac{w\,x}{2},$$

$$\frac{W \times AF \times IA}{w \times AE} = x \text{ width of pier.}$$

"The following table shows the results of experiments given in Gwilt's 'Encyclopædia,' compared with the results of calculations by the formula just given:—

Gwilt's	Description of arch.	Width of piers. Experiment.	Width of piers. Calculation.
Page 404	Flat skewback	44	53·3
,, 407	Semicircular	6·25	6·95
,, 407	Ditto	28·2	27·2
,, 408	Elliptic (surmounted)	17·0	17·7
,, 410	Ditto (surbased)	26·0	24·2

The rule applies equally to arches of every description of curve, the centre of gravity being determined by the shape of the arch.

"(4) Fig. 26.—To calculate the effect of a superincumbent weight in increasing the thrust of the arch,

Let $\frac{W}{2}$ = weight of wall-space AHIJK,

and G be its centre of gravity,

AF = horizontal effect of its weight at centre of gravity;

$$\text{then thrust} = \frac{W}{2} \times \frac{AF}{DC}.$$

Or let $\frac{W'}{2}$ = weight of wall-space IHLN,

and O = its centre of gravity,

$$\text{then thrust} = \frac{W'}{2} \times \frac{LM}{DC}.$$

In both cases, the weight of the remaining wall-space is added to the pier to help to resist the thrust.

"As the thrust varies inversely as the height DC, it is evident that the higher the extrados of the arch is carried up the wall, the less will be the thrust, the weight and intrados remaining the same; especially if the horizontal courses are jointed vertically (bonded in) with the voussoirs.

"Fig. 25.—Also, the thrust being proportional to the lowness of the pitch CD, an arch of one-quarter the height will have four times the thrust, other things being equal.

"With regard to the compression on each voussoir, in any arch with a vertical springing, the lowest voussoir bears the whole weight of the arch, the compression being diminished at the crown to a force equal to the horizontal thrust at the springing (when not a pointed arch).

"In a segmental arch, the compression at the springing is represented by LK, when MK represents the actual weight of the arch

"In a pointed arch, NP represents the compression at the apex, when NO represents the horizontal thrust.

"Now, as the compression at the springing is always greater than that at the crown, in order to get the greatest strength with the least waste of material (as in iron arches), the arch should be stronger at the springing than at the crown.

"In cross-vaulting, there is far greater thrust than in coving, because the centre of gravity projects much farther from the springing.

"In vaulting, if the arches are filled up to the haunches, they are made stronger, while there is no extra thrust from the increased weight, as the centre of gravity is thus brought nearer to the springing.

"Experiments on suspension-chains of different spans and depths supply an additional verification of the rule; but this part of the subject can be very safely left with the civil engineer.

"To bring this subject to a close:—It will be seen that, throughout, there has been one guiding principle. Gwilt says, p. 385, 'Encyclopædia'—'An acquaintance with the method of finding the centres of gravity is indispensable in estimating the resistances, strains, and degree of stability of any part of an edifice.' Yet, in no case has he acted upon the principle, but, in arches and vaults, for instance, has given a formula (based upon the parallelogram of forces) which is far too complicated for one ever to think of using.

"How simple, however, the whole question becomes by using the centre of gravity as a basis for estimating the various forces."

"Resuming the subject of roofs, a most unexpected loss of strength is manifested by experiment when the tie-rod is cambered to any great extent. It is quite legitimate to obviate the appearance of sagging by cambering the tie to a slight extent; but when it is cambered half the height of the truss—as in some shedding, published in Laxton's 'Working Details,' which has thus only half the strength which it would have with a horizontal tie—the extra headway hardly compensates for the extra amount of material necessary.

"Fig. 27.—It has been proved that the strain on the horizontal tie-rod of a roof is equal to one-fourth the weight multiplied by AD divided by DC. Let the tie-rod be cambered as AKB;

the strain upon AKB will be just the same as if it were AI
Let G be the centre of AC, draw GHF and AI vertically,
perpendicular to AK, and EC parallel to AK. Reasonin
before, let a line be fixed at C and a strain applied at E in
rection parallel to AK, this strain will be carried down CA,
counterbalance that on AK in an opposite direction. The we
of the half-roof being concentrated at the centre of gravity G,

Fig. 27. Fig. 28.

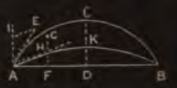


Fig. 29. Fig. 30.

horizontal effect of AG is represented by AF, and the effort
the direction CE by AE; EAF is an angular lever with the po
applied at E and weight at F.

Let S = strain on AK,

$$\frac{W}{2} = \text{weight of half-roof};$$

$$\text{then } S \times EA = \frac{W}{2} \times AF.$$

$$S = \frac{W}{2} \times \frac{AF}{AE}$$

Now, it could easily be proved the triangle EAI is similar to
triangle AHF, and that

$$\frac{AF}{AE} = \frac{AH}{AI};$$

$$\text{and therefore } S = \frac{W}{2} \times \frac{AH}{AI} = \frac{W}{4} \times \frac{AK}{CK},$$

$$\text{compression on AC at } A = \frac{W}{2} \times \frac{AC}{CK},$$

$$\text{compression on AC at } C = \frac{W}{4} \times \frac{AC}{CK}.$$

So that the strain upon the tie-rod is equal to one-fourth the weight, multiplied by AK, divided by CK. It is very evident that the higher K is the longer AK becomes, and the shorter CK, both thus tending to weaken the roof.

"The following are a few of the experiments made:—

Half-span AD.	Height CD.	Length of AK.	Length of CK.	Horizontal strains.		Strains on cambered tie.	
				Calculation.	Experiment.	Calculation.	Experiment.
				oz.	oz.	oz.	oz.
1 191	183	197	134	8·6	—	11·8	12·0
191	183	215	84	8·6	—	20·5	20·7
2 180	193	200	107	7·4	—	15·0	14·0
179	196	—	—	7·3	8·0	—	—
3 206	167	214	110	9·9	—	15·5	15·5
203	170	231	60	9·5	—	30·8	30·0
4 238	111	—	—	18·0	17·5	—	—
235	118	243	58	16·0	—	33·4	31·5

"The weight of roof in each case was 2 lb.

"It will be seen, on comparing the strain on the cambered tie with the horizontal strain in the same bracket, that the former is twice, or even three times the latter, when the span and height and weight of roof were the same. It has also been proved that the strain on AK is determined simply and solely by the proportions of the sides of the triangle ACK, and not by the side of the angle CAK or its tangent; so that (fig. 28) the tie-rods of the four trusses bear the same strain, when the ties and king-posts are of the same length—in the first, the king-post being in tension; in the third and fourth, in compression.

"Fig. 29.—In a truss with a curved rib and curved tie-rod—as in the London, Chatham, and Dover Railway at Victoria Station—make AE, AH, tangents to the curves at A, and IE parallel to AH.

$$\text{Then strain on curved tie at } A = \frac{W}{2} \times \frac{AH}{CK},$$

$$\text{compression on rib at springing} = \frac{W}{2} \times \frac{AE}{AI};$$

when DK is one-fourth the height DC, there is nearly one-third more strain, and nearly one-fourth more compression, than with a horizontal tie-rod.

"With regard to the compression on the principal of a roof, it is not uniform, as might at first be supposed; and the formula given in the preceding article for the compression is not correct. In a beam placed upright, it is evident that the bottom bears the whole weight of the beam, and the top nothing, so that, to bear its own weight in the best way, the bottom should be of greater sectional area than the top. Similarly, in a truss, the weight is uniformly distributed over the principal, and (fig. 30) the compression on A is represented by the weight of half the roof, with an additional weight due to the triangulation of forces; while the compression is reduced at C to a certain proportion of the horizontal strain only.

$$\text{Horizontal strain on AB} = \frac{W}{4} \times \frac{AL}{LC},$$

$$\text{compression on AC at A} = \frac{W}{2} \times \frac{AC}{LC},$$

$$\text{compression on AC at C} = \frac{W}{4} \times \frac{AC}{LC},$$

so that there being a greater weight pressing at A than at C, the principal should have a considerably greater sectional area at the wall-plate than at the ridge.

"The truss ADMB, fig. 30, has the same strength as the truss ACB, both being contained in the same triangle, and proved by experiment; while, in the former, less material is used.

"The parallelogram of forces, *if put in the proper position*—viz., at the ridge, is applicable in measuring the strain upon a horizontal tie only. If a person fix a line to some convenient object, and pull with a force of 10 lb., there must be a force of 10 lb. at the other end to maintain the equilibrium; just as if there were a person at each end pulling with a force of 10 lb. The same holds good with compression.

Fig. 30.—Now, let CIHK represent the parallelogram of forces properly placed. The load at C is equal to half the weight of the roof, represented by CH; one-half of this half is carried down CI, and the other half down CK. There being a pressure of one-fourth the weight at each end of CI, CK, and the pressure on the ends at C counterbalancing each other, there remains an initial force of one-fourth the weight at I and K, giving a total *initial* strain of $\frac{W}{4}$ to calculate the horizontal strain.

which is $\frac{W}{4} \times \frac{IK}{CH} = \frac{W}{4} \times \frac{AL}{LC}$, the correct formula.

"Very different results are given by taking DEFG as the parallelogram; for, in this case, the horizontal strain is represented by $\frac{W}{2} \times \frac{FG}{FD}$; and as FG is nearly equal to FD at low pitches, this would intimate that the horizontal strains vary little at low pitches; experiment showing the very reverse of this—viz., that the strain increases in the same proportion as the pitch is diminished.

"Though the parallelogram of forces may be correctly introduced when there is a horizontal tie, it is not possible so to do when there is a cambered tie as AKB, fig. 27, where there is no alternative but to use the triangle of forces ACK as a basis for the calculations, the vertical line CK always representing the unit."

79. The practical engineer is frequently called upon to carry out erections involving the application of the best modes of securing firm foundations. In the following paper, entitled, *On Foundations for Chimneys, Blast Furnaces, Heavy Machinery, &c.*, by Mr. Jeremiah Head, Engineer, Stockton-on-Tees, will be found much that is practically valuable on the subject. We are indebted for it to the pages of the "Practical Mechanics' Journal:"—

"Large works, such as blast furnaces, rolling mills, &c., are generally sought to be erected, other things being equal, on the banks of a navigable river. The advantage of a private wharf is the reason for preference given to such sites.

"The Clyde, Tyne, Wear, Tees, Humber, Thames, Avon, and Mersey, have each of them their banks studded more or less with manufactories. Most of these works have erections requiring sound and immovable foundations, as, for instance, tall chimneys, furnaces, and heavy machinery, and it frequently happens that the banks of rivers afford only the very worst of foundations.

"Take the Tees, for instance, the heart of the Cleveland district, and the banks of which are becoming rapidly disposed of as sites for various ironworks. The south bank consists mostly of an extensive flat marsh, in many parts as much as 4 feet below the level of spring tides, which are kept in check by an artificial bank. A section of the strata gives usually a crust of

4 or 5 feet of alluvial clay, in all probability gradually deposit
by floods from the river. Below the clay we have from 5 f
upwards of peat, containing trunks of trees which have know
other days. Below that again, down to from 20 to 30 feet,

Fig. 31.

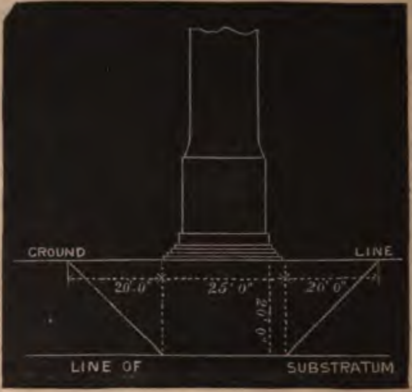
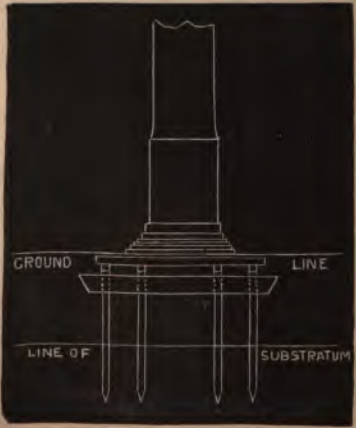


Fig. 32.



find a soft bluish silt, incapable of affording a foundation. At 20 to 30 feet there is often either good clay or a hard sand, either of which are sufficient to satisfy the most fastidious engineer.

"It is, then, from this depth, of from 20 to 30 feet, that we must support our fabric.

"There are two ways commonly in vogue for obtaining a foundation from this substratum. The one is to excavate down to it, and fill up entirely or partly with solid concrete (see fig. 31), the other is to pile (see fig. 32).

"Both these methods are attended with disadvantages. In the former, the ground in the above-named locality is, as vulgarly termed, 'rotten' to such a degree, that a batter of one to one is necessary to prevent land slips, and should it be in the winter season, even this is insufficient. This is supposing that a foundation of, say, not less than 25 feet diameter upon the substratum as for a chimney is necessary. If that substratum be 20 feet below the surface, the excavation must be 20 + 20 + 25, or 65 feet diameter at the top, which gives about 3½ times the solid content of what would be necessary if we could make the excavation 25 feet at the top, and dig perpendicularly down without batter.

"If the excavation is filled up with solid concrete, there is the drawback of the expense of 3½ times as much as is actually necessary, as the overhanging parts, A A, fig. 31, take a bearing only on the 'rotten' soil, which we suppose at starting is not to be trusted.

"And if we build a solid cylinder of concrete, equal in area to the bottom of the excavation, and with perpendicular sides, then soil must be filled in all round, doubling the account for excavation of the parts A A, or in figures making it 3½ less, $1 = 2\frac{1}{2} \times 2 = 5$ times the content of the solid cylinder B, *i.e.*, five times more than is necessary.

"And yet we cannot get the 25 feet circle upon the solid substratum without all this extra labour upon this system. Another objection is the form of this kind of foundation. According to all mechanical principles the base of any structure should be the broadest part, the work gradually narrowing as it ascends, like a basin with its open side downwards.

"But on this *plan*, from the difficulty in excavating in any other way, the foundation has to assume the form of a basin with its open side upwards, and hence should there be any irregularity of weight, or position of the superstructure, there could hardly be a worse form to resist a tendency to roll. Piling, which is the method of securing a good foundation, generally preferred in such cases, is liable to the following objections, viz.:—

"1st—It is very expensive, and if the piles are required of a greater length than about 35 feet, they are often difficult to obtain at any price.

"2d—If the pile-heads project above the surface they are liable to decay at the surface line. If the concrete, usually placed about their heads and crowntrees to keep them in position, be upon rotten ground, as in the case assumed, it frequently subsides, tearing itself away from the crowntrees, and leaving the pile-heads liable to decay.

"If flues, kilns, or stoves pass near them, the crowntrees are apt to get charred or burned, letting down the superstructures. A case of several air-stoves, for blast-furnaces, being rebuilt from this cause, has lately come under the writer's notice.

"To obviate these difficulties, the writer would submit a plan which he has patented, and believes to be new, having never seen or heard of it before.

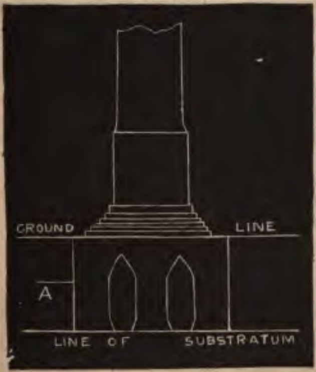
"Although it is not practicable to dig down 20 feet in 'rotten' ground, to obtain a circle of 25 feet diameter, and upwards, without allowing so much batter as to increase the cost of excavation most materially; it has been found by experiment perfectly possible to sink a well of, say 6 to 8 feet diameter, perpendicularly down to that depth, without any fear of land slips.

"The circle is so small that the surrounding strata, pressing together, feel the resistance of the arch form, and neutralize one another.

"It is proposed, then, to take advantage of this fact, to make the foundations of a series of wells, dug one by one, in order to keep the work perfectly under control, and filled up with concrete or slag walling, *i.e.*, rough rubble walling, formed with lumps of blast-furnace slag, a material greatly abounding in the above locality. If a greater depth than 24 feet, or if the nature of the stratum renders it necessary at a less depth, it is recommended to make the wells square, with two planks at each corner, placed ally, each taking a side of the corner; these planks to be ed at intervals in the depth; they are to be hammered down e work proceeds, and drawn out as the concrete rises. An diate stage, with an extra hand upon it, will lift all the soil to a depth of, say 12 feet, below which a jack-roll and ets will be necessary. Near the bottom it is recommended den the base of the excavation slightly, in order to increase ooting of the concrete pillar. It is obvious, that by this instead of the foundation being firmest under the centre of himney, or other structure, forming a pivot upon which it t tend to work, the concrete pillars may be disposed more at orners, forming a spreading base, which is the desired end tain.

he platform on which to commence building would, on this m, be formed also of concrete or slag walling, say five feet , and moulded in the following manner:—The wells having filled up to A, fig. 33, within, say 6 or 8 feet of the base of the structure, they would then be widened out, working a round section into a square one, if a round section has adopted. The intermediate soil must then be cut into the of the soffit of a ground arch, and the concrete made up to round line in the form shown in fig. 33.

Fig. 33.



This foundation, besides the advantages of easy execution, wide-spread base, and minimum cost, possesses the very great one of being formed only of imperishable materials.

"We will now compare the costs of foundations on the three different plans for a chimney, say 500 tons in weight, where the substratum was 20 feet deep.

1st—SOLID CONCRETE FOUNDATION, 25 feet diameter at bottom, 65 feet at top, and 20 feet deep—(fig. 31.)

Excavation, 1,272 cubic yards, at 7½d.,	£39 15 0
Cylinder of concrete, 25 feet diameter and 20 feet deep, 363 cubic yards, at 3s. 6d.,	63 10 6
1,272—363=909 cubic yards, at 7½d., for filling up round concrete,	28 0 0
Pumping, say,	20 0 0
	£151 5 6

2d—PILE FOUNDATION—(fig. 32.)

16 piles, 30 feet long, at 6s. each driver,	£48 0 0
Crowntrees, 260 feet long, at 2s.,	26 0 0
3 planking overtops, 1,056 feet, at 4d.,	17 12 0
Excavation, 274 yards, at 7½d.,	8 11 3
Concrete, 182 yards, at 3s. 6d.,	31 17 0
Spikes,	0 10 0
Use of pile driver, say,	3 0 0
	£135 10 3

"If the under crowntrees alone were whole timbers, and the upper ones half timbers, 6 inches apart, thus forming the platform, and doing away with three inches planking, a better job would be made, but the cost, £144.

3d—ARCHED FOUNDATION—(fig. 33.)

9 wells, 6 feet diameter, each 21 cubic yards, platform 30 feet square and 5 feet deep, say 300 yards of excavation, at 7½d.,	£9 7 6
300 yards of concrete or slag walling,	52 10 0
Pumping, say at 3s. 6d.,	18 0 0
Labour for jack-roll, say,	5 0 0
	£84 17 6

"It thus appears that the arched system, besides the advantages of better mechanical form and imperishability, would cost, in the case assumed, little more than half as much as either of the usual methods.

"In some cases it may be advisable to carry out the same principle by excavating in deep trenches, either in straight lines or in circles, and filling up and arching over, as explained above. An annular excavation, with, perhaps, a single massive pillar in the middle, is particularly recommended where there is not room for an extended base on pillars, as, for instance, two or more blast-furnaces close together. The excavation while in progress is strutted from side to side to prevent it falling in, and is filled up with concrete or slag walling as it advances."

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DIVISION TWELFTH.

AGRICULTURAL MACHINERY.

80. It is difficult to over-estimate the importance of agriculture viewed as one of the sources of a nation's wealth and well-being. It has been well called the "nursing mother of all the arts," and there is probably no better standard by which to judge of the rank of any nation in the scale of civilization than the point to which its practice has been reached by its people and the estimate in which it is held among them. Claiming, as we thus do, so high a position for the art or science, it may be conceived by some that we claim too much for it; but when we consider that it is in truth the mainstay of a people, the means by which they are supported in the happy times of peace, or by which they can successfully wear out the dreary ones of war; when we see, that of all other sciences it is that which brings a man nearest the Divine Author of his being, and shows him the wonders of his working and the evidences of his care, we perceive such a worth and dignity in it that we think we have not claimed enough. If, then, the position which we have above stated is in some measure, if not wholly, correct, we think that a glance at the present position which agriculture occupies amongst us speaks favourably for us as a nation. Contrasting it with that which it occupied at the beginning of the present century, we have much reason to be abundantly satisfied with it. Groping in the dark, unaided by the lights of science, farmers of that period groped slowly and

unsuccessfully, proving in almost all they did that, away from the guidance of correct principles, there is always a greater tendency to go in the wrong than to keep in the right way. Stumbling along in their uncertain path they, figuratively speaking, fell ofttimes into the ditch, not, like the philosopher of old, because they were looking upwards or onwards for the guiding star, but rather because they believed that there was no guiding star needed by them at all. In the power of their prejudice and with their preconceived notions they stood, and standing still was their lot for long time. But the times of movement came, and partly by a stirring of a right principle from within and partly from a pressure of circumstances from without, the movement onward was as rapid as it was fortunately in the right direction. Chemistry began to offer its aid to farming, and wresting from Nature some of her rarest secrets applied them with marvellous results to its every-day practice. The science of mechanics and engineering laid also its richest treasures at its feet, and helped its progress mightily; and now, in place of the valley of dry bones which the prophet of half a century ago might have witnessed with woe, we now gaze with gladness around us on an exceeding great army of living men animated with an ardent desire to claim new victories and to win fresh laurels in the wide and ever-widening field of agricultural progress.

It would be easy, if it were necessary, to descant upon the important part *mechanism* has played in that sure and rapid furthering of agricultural progress which we have just glanced at; but this is not necessary, so abundant are the evidences of it everywhere surrounding us. But we may be permitted to allude to the significant suggestiveness of the circumstance, that if twenty or thirty years ago a course of papers on agricultural machines had been written, two or three might have exhausted their notice, so few were they in number, while so rapidly have they increased of late years, and to such an importance have they attained, that it would take a large volume to contain even brief notices of their leading features and details merely. To the rudimentary implements—if we may so term them—of the spade, the plough, and the harrow, a great number of others have been added, and machines of complicated structure are aiming at, and we may truly say succeeding, in many instances, in securing high efficiency in important processes, are now daily claiming the notice and aiding in the labours of the farmer. Steam, too, has lent her mighty aid, and from cutting the roots, grinding the corn, or preparing it for market, she has recently, and with her usual power and her usual success, dragged the plough, and bids fair to revolutionize the practice of the field as she has already done that of the barn and of the fold.

81. From what has been said, then, it is obvious that our space prevents us from giving anything like a systematic arrangement of subjects under this Division; nor is this necessary, our duty being simply to glance at the leading features of the experience of the year we are recording. The great, nay, the principal feature of each succeeding year, so far as the progress of agricultural machinery is concerned, is the *Show of the Royal Agricultural Society of England.* This calls forth the best efforts of our agricultural machinists, and it is at the exhibitions of this most important Society that the novelties of the year are displayed, as well as those improvements which have been made in older and esteemed forms of machines or implements. The following is an extract from the *Times*, giving the leading features of the show held at Newcastle-on-Tyne in 1864:—

"A glance at the array of coughing engines and gliding implements tells us that the old notion of a locomotive dragging a plough at its tail is completely exploded, and we perceive no longer any attempt to embody in mechanical parts that other and more philosophical idea of a locomotive delving the soil by revolving blades. Locomotives, to be sure, are to be seen pacing along the farm roads, uphill and downhill, and turning through awkward gateways; but these are either the steam-plough engines when travelling from one plot of work to another, with their apparatus and implements forming a train behind, or else portable thrashing machines, like those of Mr. Aveling & Co., of Rochester, which dispense with horses in shifting from one farmyard to another. By-the-by, this now important class of agricultural locomotives has been hitherto excluded from the prize-sheets of the Society; but if there be value in one machine that displaces a portion of the farmer's teams, there must be reason in offering a trial and a prize to another which might accomplish a farther saving of horses and horse-keep.

"Steam tillage at present consists in a steam-engine (or two of them), either stationary at one side or corner of the field, or else moving at intervals along the headland, hauling an implement by means of a wire rope, or a substitute for it. For the two prizes of £100 and £50 offered for the 'best application of steam power to the cultivation of the soil,' there are five sets of apparatus in competition, and the opening trial of Wednesday tested their performances in ordinary turn-over ploughing upon a piece of two-year-old seeds. Mr. Fowler's 14-horse engine, with clip-drum under the boiler, a travelling anchorage pulley at the opposite headland, and a four-furrow balance plough (the old form of apparatus that has been so often described), made some good work at a depth of six inches, the rate of performance being about five acres per day of ten hours, and the coal burnt, 214 lb. per acre. The hands engaged were three men and two lads.

"It will be remembered that last year both Mr. Fowler and Messrs. Savory introduced the system of two engines, one at each end of the furrow, in place of a single engine and anchored pulley, and these engines hauled the implement and rested alternately, coiling the rope upon drums, and so requiring only a single length of rope out at once. The novelty at the present meeting is the employment of 'turn' engines—that is, two engines placed as before, one at each end of the work, but both simultaneously hauling the implement. It is evident that if this plan succeeds it will reduce the power, weight, and prime cost of the engines something like one-half—that is, if a couple of light 7-horse engines will accomplish the same breadth of work per day as two heavy 14-horse engines did, or if a couple of still lighter 5-horse engines will execute as much work as two 10-horse engines did, we shall save a great outlay, while amazingly facilitating the transport of our machinery over a soft and sticky country; and those employers of the steam-plough who have had experience of apparatus requiring to be taken up and again set down at every time of removal from one field to another, will appreciate the advantages of machinery which will steam out of a field within a few minutes after finishing work, and thrust its shares into the next field in an equally short time after arriving at the spot. Accordingly, Mr. Fowler's second set of apparatus consists of two 7-horse engines (with locomotive action and steerage for travelling from place to place), weighing about seven tons each, placed upon opposite headlands, with an endless rope passing one-half turn round each of the clip drums attached in the ordinary manner below the engine-boilers. Thus, both engines grip and pull the rope simultaneously, always exerting their power in haulage, while alternately serving as anchored pulleys to each other. Though the engines have but single cylinders, there appears to be no difficulty in starting, stopping, and working both together, the reversing being instantaneously accomplished by the link-motion expansion gear. The peculiarity in their construction is that the cylinder (steam-jacketed) is attached to a high steam dome towards the smokebox end of the ordinary tubular boiler, thus, without a steam pipe, taking the steam 'dry.' This, with the working pressure of 95 to 100 or more lbs. the square inch, and a high number of revolutions per minute, will account for the surprising performance of these engines, having single cylinders of only 8½ inch diameter and 12 inches stroke. Driving four furrows at once, 6½ inches deep in a strong loam, these engines ploughed at the rate of nearly eight acres per day of 10 hours, with a consumption of only 188 lb. of coal per acre. The hands engaged were three men and two lads, as in the other set of apparatus.

"Messrs. Savory's 12-horse engine is of very peculiar construction. Two coiling-drums of large diameter and ring-shaped, without radial arms or centres, encompass the boiler, each being hung upon three pairs of friction-wheels. The engine crank-shaft is placed horizontally along the boiler-side, passing through both drums, and driving each by means of a pinion gearing with internal teeth inside the drum periphery. The two steam cylinders are attached to the fire-box, one above, the other underneath the boiler, and so inclined at right angles to each other that their connecting-rods lay hold of a single crank upon the crank-shaft before mentioned. As the drums alternately wind up and pay out the rope (which makes two or more layers of coil upon the drum), a peculiar to-and-fro motion of guide-rollers is employed for regulating the proper wrapping of the coils; and this is effected by an arrangement of levers, endless worms, and slowly-rotating heart-shaped grooves or cams. On the opposite headland Messrs. Savory pass the rope round an anchorage pulley on Mr. Fowler's plan. The plough used is that of Messrs. Howard. The two sets of ploughs (facing each other point to point) are not balanced upon a single frame, as in Mr. Fowler's implement, but are upon two separate lever frames, which are supported when out of work by coiled springs, and when in work are held down to the main carriage frame by a catch recently introduced. By this improvement the tendency of the springs and of the weight of one set of ploughs to lift the other set out of work is overcome. Where water furrows exist the four wheels of this plough enable it to pass over without jumping out of work, as ploughs upon a single pair of wheels are apt to do. But one merit of steam culture is that it levels ridge and furrow even on the wettest soils where it is adopted—four furrows at once, 7 inches deep, were exceedingly well cut, turned, and laid, the rate of work being 5¾ acres per day of 10 hours, and the consumption of coal 320 lb. per acre. The hands engaged were two men and two lads.

"In another field of old lea were two other competitors, Mr. Steevens and Messrs. Garrett. Mr. Steevens uses two 12-horse power engines, one on each headland, alternately winding and paying out a single length of rope. The implement has two sets of ploughs upon separate lever frames, raised or lowered by a parallel motion, the carriage frame having a large pair of wheels in the middle, and two smaller wheels at the side. The work done on this occasion was broken, and inferior to former performances of the implement—in some degree owing to the too rapid pace at which it was driven.

"Messrs. Garrett used the same engines, which are of their manufacture, upon Messrs. Savory's principle. Each boiler is surrounded by a very broad shell drum, mounted upon three pairs of friction-wheels, the drum being of 7 feet diameter, and holding 500 yards length of rope with only a single layer of coils. The two steam cylinders are placed at right angles, one above the other below the boiler, as in Messrs. Savory's other engine already alluded to, and they have only one crank and one pair of eccentrics. The weight of the engine is 10 or 11 tons. Messrs. Howard's four-furrow plough was used, making excellent work, though the pace—3½ miles per hour, and sometimes much more—was far too rapid. The rate of work was about 9 acres per day of 10 hours, and the consumption of coal 254 lbs. per acre. The hands engaged were three men and one lad.

"Messrs. Howard do not enter the lists in this class, not having quite completed their new engines and hauling gear; and Mr. Collinson Hall has withdrawn his apparatus, owing to an imperfection in the mechanism, the engines having been finished too late for admitting of trial before the show. This is to be regretted, seeing that a new principle is involved in this apparatus. Twin engines are employed of only 5-horse power each, but worked up to 100 lbs. or 120 lbs. pressure, the weight less than four tons each, and the front wheels so placed that the engine can turn round in a space of double its own length. Instead of a wire rope, Mr. Hall uses a steel chain, made of ½-inch round bars, connected by plates and rivets, this passing half a turn round a polygonal drum under each boiler. It appears that every difficulty in the working of this chain has been overcome, and the inventor maintains that in the point of durability it is immensely superior to the wire rope.

"In the class of steam cultivating machinery, 'adapted for small occupations,' the competition has virtually lain between three sets of apparatus. Messrs. Richardson's engine, with steel boiler, and Allen's patent cylinder (which promises to be a great improvement in portable engines), did not enter into trial; and Messrs. Coleman and Morton have been very unfortunate with their system of working two implements simultaneously by one headland engine. Messrs. Howard use a 10-horse power double cylinder engine, stationed at one corner of the field, and driving a windlass by a connecting-shaft with universal joints; the drums of the windlass alternately wind up and pay out their respective ropes, which pass round the field, the anchored pulleys being shifted as required by manual labour. The compensating pulley used last year maintains a degree of tension in the outgoing rope without sacrificing motive power. On Thursday the four-furrow plough made splendid work at a depth of 7 inches, the rate being 8½ acres per day of 10 hours, and the consumption of coal 270 lbs. per acre. The hands engaged were five men and two boys. Yesterday the same apparatus worked a to-and-fro cultivator with four broadshared tires, thoroughly well smashing up a stiff, loamy, lea ground, 8 or 9 inches deep, at the rate of 14½ acres per day of 10 hours, with a consumption of 194 lbs. of coal per acre. Mr. Fowler's common portable 10-horse engine, driving a separate windlass, on the same plan exhibited last year, ploughed at the rate of about 10 acres per day of 10 hours; but the most surprising performance has been that of his single 7-horse engine, with anchorage and three-furrow implement, which made exceedingly fine ploughing 7 inches deep, at the rate of 8½ acres per day of 10 hours, consuming only 135 lbs. of coal per acre. And yesterday, this little engine, working up to 100 lbs. pressure, broke up and lightly tossed about soil, to the depth of 8 or 9 inches, at the rate of 14·4 acres per day of 10 hours, burning only 95 lbs. of coal per acre.

"Further testings of the several machines are in progress, but the general conclusion appears to be that great improvement has been made in the construction of details, that the work done far surpasses that of last year, while the power and capabilities of the smaller and cheaper sets of tackle rival those of the heavier and more costly. All this is good news for the farmer.

"The old battle between the wheel and swing ploughs has been fought again; the wheel plough has maintained its superior place, and, of course, the great contest has been between Ipswich and Bedford—whether Messrs. Ransome and Sims shall win the laurels from Messrs. Howard, whose plough was the crack implement at the Newcastle meeting 18 years ago."

82. As our readers are aware, the subject attracting the chief attention of agricultural engineers at present is *steam culture.* A fair *resumé* of all, or, if not all, certainly the most important forms of apparatus introduced to effect this economically, will be found in pp. 396 to 404, vol. of Facts and Figures for 1863, to which we refer the reader. Did space permit, we could give some general remarks as to these various plans, and a *resumé* of the principles upon which culture of the soil should be carried out, and which have of necessity a close bearing upon the progress of machinery designed for this purpose—ignored, however, as this too often is; but we content ourselves with here giving (from the "Mark Lane Express") a note on the present condition and the future prospects of steam culture, from the pen of a well-known authority:—

"We apprehend that for some years to come the chief demand from *farmers* will be for the small sets of steam cultivating apparatus. Granted that for a few very large occupations, for public companies, for letting out, and for extensive landowners, the large and more perfect tackle may be required; still, the great body of tenant farmers, who have common steam engines at their command, will, we fancy, be content with the smaller sets. If, therefore, it be asked how much progress has been made in this class since Leeds, we are sorry to say that we have but little to record. A great number of details have been simplified, and many minor improvements introduced; but as to any rapid stride, none whatever has been taken. Fowler's great success was with his two engines at Newcastle, which, of course, required too great an outlay for him to compete with them for the 'small occupations.' So for that prize he showed one of his new 7-horse engines with clip-drum and travelling anchor. Now, beyond the fact that this new engine is a most admirable locomotive, and consumes so little fuel, we have, speaking generally, nothing more than we had at Worcester and Leeds. In fact, the *engine* rather than the *tackle* carried Fowler to the front in the 'small occupations;' Smith was absent, and Howard was pretty much the same as in the year 1861. It is necessary, however, to qualify this by adding, that, by the introduction of *malleable cast-iron* into every available part of the steam cultivating implements, greater strength and durability have been secured, and the scarifier being furnished with extra prongs for more thoroughly disturbing the surface of the soil, makes much better work; yet these improvements involve no new principle, or tend materially to lessen the cost of steam culture; so those agriculturists who have been waiting and watching for something that should supersede all that has yet appeared, will probably go on waiting and watching for at least another three years before their caution will be rewarded with any discovery that will make tillage by steam very different to what it is, or what it has been during the last ten years.

"The *giant power* of steam can only be shown in real perfection on a large scale. A 10-horse thrashing-machine could empty a small farmer's rickyard in a few hours, and it is only on a large holding that such an engine could find scope for its energies. And so, in steam ploughing, it is not wonderful that the grand development of this new application should be found in greater perfection in the large system than the small. Any one who thoroughly watched the Newcastle trials must have seen that it was in the great class only that the real strength and perfect development of steam power was to be found. In the smaller tackle it seemed cramped and confined, as if the motive power wished to impress on us that it 'was born for greater things.' We therefore look to the larger tackle for the most perfect, the cheapest, and the most rapid cultivation; and it is only by combining together, or hiring, that the great body of farmers can take advantage of such grand and expensive machinery. We venture to predict that in very many districts a travelling steam plough will become almost as common as a portable thrashing-machine; and it is where the owner intends to let out his apparatus that these large traction-engines will be specially serviceable. Without the aid of any horse they move from farm to farm, and get into position in a few minutes. On the other hand, the moderate-sized farmer who wishes for his own tackle, so that he can have it *when he most wants it*—which may not always be the case if he hire one—must be content with the old roundabout, and remain satisfied for a while with Howard's or Smith's tackle. Of course, if a man have no engine, he would do well to buy one of Fowler's new 7-horse locomotives, with its clip-drum, moveable anchor, and slack-gear; but we do not see how this system can be applied to a common engine with any advantage over the cheaper sets.

"The conclusion that we come to, from these Newcastle trials, is, that anyhow the advance in steam cultivation is not so great as some sanguine enthusiasts would have us believe, and that it will yet be a very distant day before the steam-engine thoroughly routs and drives from the fields our common horse-ploughs."

83. Another of the problems of the day yet to be solved, and which is engrossing the attention of some of our mechanicians who have made it their special study, is a universally applicable and thoroughly efficient *Reaping Machine*. It may seem to some of our readers to be taking a rather degrading or backward view of the progress of agricultural mechanism to say, that this is still a problem to be solved. But although we are by no means ungrateful for what has been done in the direction of giving the farmer a good cutting machine, we cannot ignore the fact that a reaping machine capable of performing more than mere cutting

and of being applied under all circumstances, has yet to be invented. We could say much on this topic, for it certainly is the fact, that considerable ignorance prevails as to what really is the office of a reaping machine; but we find an article in the "Mechanics' Magazine" so appropriate, and containing so much that is suggestive on the subject of "*Reaping Machinery*," that we give an abstract of it here.

"One of the most difficult problems which the agricultural engineer is required to solve, is involved in the construction of thoroughly efficient reaping machinery. The operation of cutting standing corn appears at first sight simple enough, provided the soil on which it grows is level and clear of stones, roots, and obstructions. But a reaping machine, to answer its purpose properly, must do more than cut standing corn; it must be capable of clearing a field of grain, beaten hither and thither by wind and rain; it must perform its functions over ridge and furrow, be moderate in draught, not easily put out of order, not so wide as to render the extraction of gate-posts requisite to get it into an enclosure, not too dear—and farmers do not like to invest very much money in a machine of the sort; and last, and most important of all, it must so deliver the cut corn that the subsequent operation of binding into sheaves can be effected with facility and dispatch. Any one who has watched a reaper, sickle in hand, bending over his toil, will see at once how numerous and complicated are the evolutions which his hands, wrists, and body perform while cutting materials for a single sheaf. The grand principle governing all he does, is to secure the positation of all the heads or ears in one direction, and the root ends of the straws in the other. The more tangled and 'laid' the crop, the greater the difficulty encountered in securing this end; now and then it cannot be secured at all, except at a vast expense of corn shelled and wasted; each handful, as it is cut, having to be dragged forcibly from among that which is still uncut, and with which it is, as it were, felted into one inseparable whole. In such cases, the scythe or 'cradle,' largely used on the Continent, performs better than the hook or sickle; but the process of drying the straw and preparing it for thrashing, then partakes more of that employed for making hay than is compatible with good harvesting.

"The reaping machine has yet to be invented which will cut corn and place it in position as well as skilled manual labour of the best kind. Such a machine might be an acquisition, but it is certainly not a necessity.

"We do not suppose there are six persons who will read this article, who will not already understand the general mode of construction adopted in the cutting apparatus of the modern reaper. All the makers of machines, with whose practical working we are acquainted, have tacitly agreed to adopt the indented knife, reciprocating at the back of fixed teeth or tines—first introduced by M'Cormick—which hold the corn steadily up to the cutting action of the blade. Many attempts have been made to cut corn with a serrated edge, moved continuously in one direction—something like a band-saw for example—without any success. The only advantage to be derived by the adoption of such a principle, would be the supression of that reciprocating motion which operates injuriously on the working parts of the machine, it is true promoting wear and tear, creating a very disagreeable noise, and rendering rather complex gearing necessary to carry out the various motions; but this very reciprocation, and the partial jar or concussion which takes place at each change in the motion of the knife, is the very element on which the success of the implement indirectly depends. Grass, stubble, weeds, even lumps of earth, collect from time to time within the teeth of the knife-guard, and no expedient can be devised which so effectually removes every foreign substance as the jar of the machinery. Without it, the corn is pushed before the implement, and can scarcely come into contact with the cutting-bar at all; while the draught on the horses is increased, and the worst possible work done. It is very unlikely that anything better than the M'Cormick knife will ever be brought out; the path of invention having thus far led to perfect success.

"We have already stated that cutting the crop alone is not all that is necessary; it must be laid in position convenient for binding as well. In doing this well, lies the great problem; and the means proposed or employed for effecting it are many, and some of them ingenious in the extreme. In Burgess and Key's archimedian reaper—one of the first, if not the first, which ever accomplished a self-acting side delivery which met with favour—the corn falls, as it is cut, on rollers fitted with thin sheet-iron spirals, which carry the corn to the side of the machine. The rollers furthest from the knife rotate much faster than those nearest to it. In consequence, the cut corn describes one-fourth of a circle, of which the straw is the radius, and is, or at least ought to be, deposited on the field in a ribbon or 'ledge,' as it is sometimes called, with ears all pointing away from the machine, and the butts towards it. This is effected tolerably well when the crop stands very erect, and the machine is carefully managed. More commonly, the upper straws lie diagonally across those beneath, rendering much care necessary in binding. The work done is, however, very fair as a rule.

"In Wood's machine, which may be taken as a fair specimen of that class of reapers from which the corn is delivered by manual labour, a platform receives the straw as it is cut, a man seated at the side delivering it in bundles from time to time by means of a rake, each large enough to make three or four sheaves. Where the crop is only moderately heavy, first-rate work may be done in this way; otherwise, the work, which must of necessity be performed by the 'raker off,' is very severe. Dray employs a tilting platform, from which the corn slides when it is lifted by the foot of the driver. Messrs. Kemp and Murray have employed the same arrangement; and Bamlett has taken a prize ere now for a machine in which the board is supported by an elastic band, in such a way, that when loaded sufficiently it yields, and suffers the deposit of its burthen on the ground.

"The different systems of delivery may be thus enumerated:— Continuous delivery by power, as in Burgess and Key's, and several other machines; sheaf delivery by manual labour, as in Wood's reaper; and sheaf delivery by power, as in Samuelson's Victoria reaper, Ransome's, and M'Cormick's. A good sheaf delivery by power is by no means easily effected. The corn as it is cut is continuously falling on the platform, and however quickly the operation of raking off is effected, there is a risk incurred of dragging away the last-cut straws as well, which thus get scattered over the field, and entail much waste and subsequent labour. The bundle, when formed, should be delivered all at once on the ground. The machine travels at about 3½ miles per hour, and any tardiness in the delivery will scatter the cut corn instead of delivering it neatly and compactly. The apparatus employed should not be too heavy, and the simpler the better. It would be out of the question to attempt even a passing allusion to the various ingenious schemes which have from time to time been patented, all intended to effect this grand desideratum—sheaf delivery in a thoroughly perfect way. One, M'Cormick's, generally regarded as the best yet produced, we illustrate this week. The principle involved in the combination of the sweep-rake with the gathering-reel is good, because it secures the delivery of the last-cut particle of corn before the succeeding vane of the reel throws the next cutting on the platform. The mechanical details are very ingeniously carried out; and although the implement looks very complicated on paper, it is not more so in reality than many others not half so efficient. We have preferred to take this machine for illustration rather than any other of the self-acting sheaf deliverers, because it is the best yet brought out. The Victoria reaper bears a good name, and is simple in all its arrangements; but we have had no practical experience in its working."

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DIVISION THIRTEENTH.

MISCELLANEOUS—MACHINERY IN GENERAL—MACHINE CONSTRUCTION.

84. In the possession of a ready capability to notice the weak points of a machine, of a facility to grasp quickly at details, which, from their minuteness, are apt in general to be overlooked, but which yet often lie at the very root of success or non-success, and in a quickness in accepting hints from all diversities of practice—no matter how unpromising these may be in aspect—lies the difference between the engineer whose practice is a success, and he who ignoring these, and careless to possess them, has a practice burdened with blunders. The power of little things is often alluded to, often overlooked; but not, we need scarcely say, by the wise engineer. All who have made a reputation as successful machinists, know well enough that in many cases the first conception of a machine, the bringing of its prin-

ciple into practical shape, is comparatively easy; but that it is in the minutiæ of details, the nice adaptability of one part to another, in the difference there is between the form or shape given to certain parts, and the mode of connection between them, that the difficulties exist. How often are practical men reminded of this truth, in the existence of a defect so minute as to have been again and again overlooked, but, which once attended to, secured success, and in those happy hits of chance which relieve him often from difficulties at one time insuperable to all appearance. The wise engineer then is always alive to the importance of attending to details, and sure that the main and more obvious matters will be attended to, he may delegate the care of them to others; but in the thoughtful attention to the little things, he makes that his own particular care. . And it is surprising how valuable an idea may come from a most unpromising source, and how often a thoroughly practical point works itself out from a hint or a vague suggestion, uttered by a passing stranger, or gathered from the pages of a paper or a book taken up and glanced at at random. Hence, indeed, the value of such a work as that on which we are now engaged; for not only giving the laboured and exact details of precise practice, it, in its numerous subjects, often affords hints which, in the heads, or rather passing through the minds of some readers, yield much that is of high value. For it is true enough that some men have minds so powerful that, like the fabled philosopher's stone, they turn into gold the meaner metals which are looked upon as worthless—and are in consequence so—by others. In the present division we throw together a number of papers, with no pretension to regularity of classification, many of which are of great value as bearing upon matters of precise detail; others which may be looked upon as suggestive merely, and as likely to afford, often unexpectedly, those hints, to the value of which we have just alluded.

85. On the subject of *Bearings*, a correspondent of the "Engineer"—signing himself a Sea-going Engineer—has the following:—

"Perhaps no subject in connection with marine engineering is of more importance than that of bearings, the causes of their heating, and the remedies to be applied. One very obvious reason of bearings being so troublesome—namely, that of their dimensions not being adequate to the work imposed on them—is now pretty generally known and acted on, though there is room for farther progress in that direction also.

"In the case of the smaller class of bearings, such as slide-gear and air-pump levers, for which joints are too often used, the great advantage of size for reducing wear is apt to be lost sight of. True, these joints may be, and no doubt are, amply sufficient in strength; but the wearing surface is often so small that, before the end of a long voyage, the jangling noise caused by their slackness, in otherwise well-constructed engines, is annoying in the extreme. And all the more so, that nothing can be done to remedy the evil while under weigh. The use of conical brasses, which could be tightened up from time to time, while the engines are going, and making the wearing surfaces much larger than is required for strength alone, would tend to cure this evil.

"Nothing is more essential, especially with heavy shafts, than having them properly bottomed. This is a point which cannot be too much insisted on, and the neglect of which has ruined many a bearing. One instance, in particular, occurs to my mind, where a crank shaft for a geared screw was lowered into its place in a great hurry, and instead of being easily turned round in its bearings, as it should have been, even with the weight of the large driving-wheel on it, tackle had to be used for that purpose. Naturally, when the engines came to be started, the crank shaft bearings became smoking hot in the first few revolutions. If a little more time was taken in such cases (and no time could be better employed, as the opportunity never offers again), the shaft lifted two or three times, turned round in its bearings to mark the hard places, and above all, to make sure that the shaft was bedded all along the bottom of the brass, although it should be a little easy at the sides, many a heated and troublesome bearing, and, doubtless, many a flaw in the shaft, would be avoided. And I need not tell my seafaring brethren, mostly, but too well aware of the painful truth, that it is the work of moments to spoil a bearing, but the work of days to get it right again. With heavy shafts, whatever you may do with the top brasses, the bottom ones must be left to their fate. Good fitting, and the precautions here mentioned, are quite as necessary in the case of bearings lined with white metal, as with those made of brass. White metal bearings certainly appear to have a wonderful immunity from heating, though the consequences are rather awkward when such a thing does occur. The fear, however unfounded it may be, of their heating and running out, has prevented their use, in many cases, especially in the great mail companies. One other objection there is to the use of white metal—at least to some that have come under my notice—and that is, that it wears away the iron of the bearings, shafts, or crank-pins, as the case may be, to an appreciable, if not considerable, extent.

"In one case, the difference in diameter, of the part of the bearing running in the white metal, and the part running in the brass at the ends used to contain the metal, was as much as $\frac{3}{16}$ in. Still, the use of white metal, for marine purposes, appears to be daily extending, and it is largely employed by Maudslays and Penn—pretty safe guides in these matters. There is certainly less expectation and anxiety about heated bearings in starting new engines where white metal is employed, than where brass is used; and this leads me to remark (in corroboration of the soundness of the advice as to seeing that shafts are properly bottomed, and a little easy, if anything, at the sides), that, after engines fitted with brasses have been running some time, and given themselves the ease and looseness perhaps denied them at first, they cease to give trouble, and can be quite depended on.

"No one can have been long at sea without observing how much better bearings keep that have a little end play, compared with those that are cribbed, cabined, and confined between their collars. A little end-working prevents the formation of ridges, and puts a polish on the bearing; and it has often occurred, in the case of connecting-rods being thought to travel too much from side to side, and where washers have been fitted to keep them more steady, that the bearings gave no peace till restored to their former freedom, and a very great proportion of heated bearings have their origin at the collars. In paddle engines, the collars are always a source of anxiety when the ship is listed over, and they are scarcely ever made large enough for the great weight that comes on them in such a case. Some makers leave a very large fillet at the collars of paddle and intermediate shaft-bearings, but this, though intended to increase the strength of the shaft, has the great disadvantage, when the ship has a heavy list, of acting as a wedge or cone to force the brasses asunder, and causing the bearing to heat.

"The preferable plan is to have the collar cut in quite square, with the exception of a small fillet in the corner, so as to let the collar bear fairly on the flange. In direct-acting screw-engines, with solid crank-shafts and good collar thrust-blocks, collars on the crank-shaft bearings are being dispensed with altogether, and with the best results.

"In new engines a little heating, after all precautions being taken, is to be looked for till the beautiful working skin polish of the iron is established. In getting up bearings in the lathe the use of a file on them should be forbidden. It seems only reasonable that a clean cut with a sharp, hard, finishing tool must leave a surface more suitable for the work of a bearing than the irregular work of a file, however polished up afterwards.

"I now wish to draw attention to a cause of bearings heating, which I can only point out as a fact that has come under my notice, but cannot profess to explain. This is the clinging or collapsing of the brasses to the shafts. In the long bearings now so prevalent and beneficial the brasses retain their original shape at the ends only (if stiffened by flanges); but from the ends to the middle (and the thinner they are made the worse they are) they cling or collapse to the shaft to the extent of one-eighth, three-sixteenths, and in some cases even more—of course leaving the pillow block to that distance. The same thing has long been noticed with thin brasses fitted into straps used for crank pins, side rods, &c., and it has often been remarked that connecting rods fitted with T heads and bolts give much less trouble than those fitted with straps, owing, no doubt, to the greater stiffness produced by the form of the brass, and the caps and bolts in the former case.

"In thinking of this clinging or collapsing propensity in long and thin brasses, a plan of fitting brasses has suggested itself, which would effectually remedy this great evil, be cheaper of first cost, and more easily renewed than the present system. This plan is to cast dovetail grooves in the pillow blocks or frames, with the taper alternating in each groove, strips of brass to be tightly fitted and driven into the grooves, the spaces between the strips to be filled up with white metal or lignum vitæ, and the whole bored out to the size required; the heads of the strips or keys to have the flanges formed on them, so as to take the collars, if any, and as much brass to be left for retaining the white metal or lignum vitæ as may be deemed necessary. . . . . The grooves might be very cheaply made by leaving steel patterns in the mould, to be afterwards driven out of the casting when cold.

"The bottom strip or key should be the broadest, and made of the hardest brass, or aluminium bronze, so as to take the principal part of the work. Brasses built in this fashion could not possibly cling or collapse, whatever else they might do, and the process of fitting new brasses at any time would be much simpler than at present. That this plan of construction would give great satisfaction, when once tried, appears to be self-evident. The good performance of some tunnel shaft bearings that I have seen confirms this view. These, instead of being fitted with brasses, have merely the pillow blocks bored out to the size, and some white metal dispersed over the surface in thin flat holes of 2 in. diameter. These bearings, which, from their construction, could not possibly collapse, have never been known to warm, as they would most likely have done had they been fitted with thin brasses in the legitimate mode.

"Nothing makes a better bush than cast-iron when a good skin is once attained; and in many cases where brass would not stand, as in the trunnion bearings of oscillating engines where superheated steam is employed, cast-iron has answered perfectly; and if the quality of the iron is good, pretty hard, the casting sound, with care taken in fitting the bushes properly at first, and well attended to when started, such bearings are very durable, and take a beautiful polish.

"It is to be hoped that aluminium bronze will soon come within the engineer's reach in the matter of cost, as it appears to be an admirable material for wear; and while alluding to it for use, it can well be imagined how beautifully it would answer for the smaller details of the ornamental work of an engine-room.

"In all cases where it can possibly be done, and especially with crank shaft bearings and the crank pin ends of connecting rods, the brasses should be worked close together, and screwed hard up. In the case of connecting rod T heads, when fitted, as they sometimes are, with four bolts, it is difficult, and practically impossible, to proportion the strain equally among the bolts in any other way. And even when two bolts only, which appears to be the preferable plan, are employed, working with the brasses hard screwed together, tends, in a great measure, to prevent their slacking, the consequences of which are apt to be very serious if not noticed in time. And when connecting rod brasses are run parted, though it may be more convenient for tightening up from time to time, still there are three sources of wear to contend with instead of one. These are, the head of the bolts working itself into the connecting rod, the nut also bedding itself into the cap or connecting rod, as the case may be, and the wear of the brasses. When screwed hard together, two of these sources of wear and play are done away with, and nothing is left but the wear of the brasses. With large bearings it is surprising how long they will run before it becomes necessary to let them together. The steadiness and rigidity imparted to crank shaft brasses by this method is its great recommendation, and indeed it is now almost universally practised.

"Bearings ought to be most carefully guarded against the attacks of sand, or, what is even much worse, the black dust from the funnel, which, in calm weather, falls profusely about the decks. This substance, which, in its cutting properties, closely resembles the diamond, is most injurious in its action if allowed to touch any bearing.

"With regard to the various mixtures in use for cooling hot bearings, the object of these notes is rather to point out the radical causes of prevention from the first than the means of cure when they do occur. And that they are almost wholly preventable by good construction and fitting we need only look at the every-day performance of locomotives, where, if anywhere, we should expect such things, and yet they are almost unknown.

"Of course, after being made of the most ample dimensions, the best materials, and fitted in the most workmanlike manner, bearings will get hot if not looked after and properly lubricated; but this is, happily, of rare occurrence. It is marvellous with what rapidity a bearing will get hot, though in the case of large bearings it may be detected even before the outside of the brass gets warm. Generally speaking—for no fixed rules can be given for all cases—the best plan to adopt is at once to stop and slack the bolts. If this be promptly done, before the immense friction has begun to tear the shaft, the bearing will most likely be all right again in a short time. Some bearings get rapidly cool, while others take days.

"Great advantage has been experienced in cases where hot bearings have become almost chronic, by allowing a little water, only a drop at a time, to mix with the oil, or rather to go down the same tube. This produces a sort of white lather on the bearing, and ships have been enabled to go on with great comfort by these means which had been previously miserable.

"And who can describe the anguish endured by the too-sensitive engineer, troubled and tormented by hot bearings? Especially is he to be pitied if they are so situated as to be fully exposed to the eager gaze of passengers and crew. While his mind is on the rack as to what is his best plan of remedying the evil, and his olfactory nerves disgusted with the too-well known smells, he is supposed to answer civilly the queries of a hundred voices as to what is the matter. But let us drop the curtain over such scenes, too painful even to write about, and if these notes should tend in any degree to lessen in the future the miseries too awful for thought, they will not have been written in vain."

86. *Chucking Work in Lathes.*—"One of the most indispensable adjuncts of a lathe," says the "Scientific American," "is a chuck for holding work that cannot be turned between the centres, or requires to be bored out. Very great ingenuity has been displayed in constructing chucks so that the piece held, if round, should run perfectly true without any further adjustment. To this class of chuck belongs the scroll, the worm and spiral gear chuck, and others; their utility is very great, and on some work they are indispensable.

"Ordinary chucks have four jaws, which slide in grooves in the face-plate, and are set up by screws running through them. Such a chuck-plate can be altered to take an irregular form, or one that has a hole out of the centre, as an eccentric, but the scroll-chuck cannot. The jaws in this move arbitrarily, or toward the centre, and are therefore unchangeable, although, we believe, there is one variety of scroll-chuck in the market that can be shifted so as to take an irregular form. It is surprising to see what clumsy work some men make in chucking a job. To set a simple pulley takes them half-an-hour, and at the end of that time the face is so covered with chalk marks that it looks as if it were whitewashed; hammer marks indent the work, and the workman loses his patience and gets out of temper for nothing. It is the simplest thing in the world to set a round job true in a few minutes, and without chalk, sticks, or any other aid. When a pulley is to be bored, the centre should be put in the spindle, and the size measured off to the chucks; one of them should be drawn out a little to let the work in, and when it is in place, setting this slack jaw up will bring the pulley fair. One or two revolutions of the lathe will show in a moment if the outside is true. It is unnecessary to tell the mechanic that no work must be turned from the hole cored out rough. Many unthinking persons have done this to their own and the proprietor's sorrow; the cores not unfrequently get pushed on one side in casting, which makes the work all wrong if they be taken as the centre.

"Scroll chucks, in fact, chucks of any kind, are costly tools, and not within the reach of every mechanic. To such, a common block of wood is by no means a useless thing. It is astonishing how much can be done in a wooden chuck when properly made. Very large sizes can be employed, and for very small work it is unequalled as a substitute for the metal chucks. Very frequently cements, such as gum-shellac, &c., are used in connection with the wooden chuck to hold small flat pieces that have no flange or other point to catch. An eccentric may be bored for the shaft, and turned outside in a wooden chuck, or on a face-plate, without the use of a chuck at all.

"In cases of irregularly-shaped jobs, where it is at all practicable, the chuck-plate should be taken off and laid on the bench, and the work set true upon it in that position; by the aid of the lines which are struck, or should be, on every plate, this can be done much more quickly than when the work is hanging by one or more bolts. In all cases the plate should be carefully used, and cleaned when done with, not left to knock about on the floor under the lathe, or to get filled with grease, dirt, and chips."

In connection with the above, the following, from the same journal, may be taken. It is entitled *A Common Fault*:—

"No piece of work can be properly turned on a bad centre. It is a very common thing to see jobs in large shops centred for turning by the use of a centre punch, and in some cases a very stubbed, blunt-ended, triangular-pointed one at that. Some slovenly workmen think that a centre punch, which is not fit for anything else, is good enough to use for turning, and a most extraordinary collection may at times be seen on lathes.

"We have repeatedly advocated the use of the drill for centring work, and we here reiterate this advice—no job, however trivial, should ever be turned without it. Even screw bolts, which, after they leave the shop, may never come within a thousand miles of it again, should be carefully centred. Principle is the point aimed at, for when a workman gets in the habit of doing work properly it will be almost second nature to him; when he gets careless he uses a centre punch on all kinds of work indiscriminately. When work is centred with a drill there is no possibility of its becoming untrue unless chipped with a round-nosed chisel on purpose; but with a centre punch there is no likelihood of its *ever* being true, especially if a punch with an end like a carrot is employed, as is sometimes the case. It often occurs that work is turned in a lathe which has centres worn off at the point. When the drill is not used, the centre in the work turned wears just the shape of that in the spindle of the tail-stock; now, if the work so turned be put in a lathe which has sharp, true centres, it cannot be turned at all unless it is re-centred, which, in all likelihood, makes it run like an eccentric. Have good drills, and drill the centres deep, so that the end may be cut off even, and the body will remain true; with these precautions there is no possibility of doing bad work, so far as the centring is concerned."

87. On the important subject of *Packing for Pistons of Steam Engines and Pumps*, the following paper, descriptive of a new form, was read before the "Institution of Mechanical Engineers" by Mr. G. M. Miller of Dublin:—

"This packing consists of two rings, pressed outwards against the cylinder by the pressure of the steam as it acts on the alternate faces of the piston, without the use of springs. This piston has been used by the writer in the locomotive engines on the Great Southern and Western Railway of Ireland. The piston is of cast-iron, 2 inches in thickness and 15 inches diameter. Two square grooves are turned in the edge of the piston, $\frac{3}{8}$ths of an inch in width and $\frac{3}{8}$ths of an inch apart, and a corresponding steel ring is fitted into each groove, the rings being divided at one part with a plain butt joint, and sprung over the piston into their places. Two small holes, $\frac{1}{8}$th of an inch diameter, open from each face of the piston to the bottom of the nearest groove, whereby the steam is admitted behind the packing ring, and presses it out against the cylinder so long as the steam is acting upon that face of the piston. The alternate action of the two rings is continued as long as the steam is acting on the piston, one of them being always pressed steam-tight against the cylinder.

"Another form of the piston has been used in cases where the piston is desired to be flush on both faces, or to fit a cylinder with flat covers; in this a circular flat head, forged upon the piston-rod, is fitted between the turned faces of the two halves of a cast-iron piston, which are held together by turned pins riveted over, forming a hollow piston flush on both faces, fast upon the piston-rod, and without any loose part besides the two packing rings.

"The ends of the rings, where divided, are made with a butt joint or with a lapped joint. The piston body is turned to pass through the cylinder easily; and the joints of the rings have been found to be practically steam-tight. In some cases the joints have been tongued, but in the writer's experience this has not been found requisite; the butt joint has invariably worked well, whilst it has the advantage of perfect simplicity of construction. In pistons where the packing ring travels over the opening of the cylinder port, a small stop is fixed in the bottom of the groove, entering a short slot in the packing ring, to prevent the ends of the ring coming opposite the cylinder port, but still leaving the ring free to travel round a little in the piston grooves; but it is preferred for the packing rings not to travel over the cylinder ports.

"Another form of joint for the packing ring is intended to be used in a stationary engine with cylinder 16 inches diameter. A brass top-piece, 1 inch thick and 4 inches long, is placed in a recess at the back of the joint, serving as a cover to the joint at the top and bottom by projecting $\frac{1}{8}$th of an inch in thickness on each side of the ring.

"These steam-packed pistons have been used more than seven years in the locomotives of the Great Southern and Western Railway, and have proved so satisfactory and advantageous, that their use has been extended to all the 94 locomotives working upon that line. The following are the results of the working in the engines running from Dublin, as regards the durability of one set of rings, the period of their wear, and the mileage of the engines whilst wearing them out. Nineteen engines working with one set of steel rings averaged 33,020 miles and 16$\frac{1}{2}$ months' running, one engine having worked for 3 years and run as much as 98,073 miles with one set of packing rings. Five engines working with one set of brass rings under the same circumstances averaged 30,986 miles and 19 months' running, the greatest work amongst them being 2$\frac{1}{4}$ years and 43,197 miles. Twenty other engines with steel rings which are still in use have also averaged 40,444 miles and 21 months' work, one of these having worked for 3$\frac{1}{4}$ years and run 94,399 miles with the original set of rings.

"The general result of the above is that one set of steel packing rings have lasted 37,000 miles and 19 months' work, and one set of brass rings 31,000 miles and 19 months' work, the difference in durability being about 16 per cent. in favour of the steel rings. In some of the individual cases of the pistons with steel rings, a very considerable variation from the average result of 37,000 miles is found in the durability of the packing rings, some of them having lasted 2$\frac{3}{4}$ times the average, and some only as much below the average. In the case of the brass rings the variation is not so great, amounting to 1$\frac{3}{4}$ times the average in the highest, and about as much below the average in the lowest. This variation in wear has not been fully accounted for: it may have occurred from a different character of metal in the cylinders, from priming of the boiler, and from the presence of grit in the water; but the writer has reason to believe that the rings have been frequently put to work and set with a pressure upon the cylinder from their own elasticity, thus causing a source of wear. It is found the best plan to turn the rings to the exact diameter of the cylinder, and to put them in without any spring upon them, so that they are not subjected to any wear except when the steam is acting on them. The steel rings are now slightly tempered, to admit of their being sprung into the grooves without altering their form. In all these pistons the steel packing rings were $\frac{3}{8}$ inch thick originally and $\frac{3}{8}$ inch wide, and they were worn down to about $\frac{1}{8}$ inch thick in the thinnest part before being removed. The brass rings are worn down from $\frac{7}{16}$ inch until they are $\frac{1}{8}$ inch thick. Specimens are exhibited of steel rings from four engines, that have worked 38,000, 61,000, 84,000, and 96,000 miles respectively since first put into the pistons. It must be remarked that when opportunities occur, as when engines are under repair, the rings are taken out and reset to the size of the cylinder.

"It is found in practice that two steam ports of $\frac{1}{8}$ inch diameter are quite sufficient for each of the steel packing rings. The rings must be made to fit easily in their grooves, so as to move freely, with a clearance of $\frac{1}{16}$ inch at the bottom of the grooves for the steam to pass round behind the rings. No difficulty has been experienced from the steam passages becoming stopped up with a moderate use of tallow in the cylinders.

"The use of this piston packing in locomotive engines has been productive of economy by reducing the friction and by prolonging the wear of both pistons and cylinders. It will be observed that only one ring is in action at the same time, and that when the steam is shut off, as in descending inclines and approaching stations, the piston is free to move without any friction. The cylinders of the four engines from which the specimen rings exhibited have been taken show a highly polished surface, are very little worn, and are nearly parallel throughout. The operation of putting in these rings so as simply to fit the cylinder is extremely easy, whilst great care and skill are required in giving springs the requisite degree of elasticity and in making them maintain it.

"A set of brass packing rings is also exhibited, taken out of the pistons of a pair of vertical stationary engine cylinders at the Dublin railway station, in which they have been in constant work for the last four years, with a pressure of 50 lbs. steam. The diameter of the cylinders is $19\frac{1}{2}$ inches, and the rings were originally $\frac{5}{8}$ inch thick and $\frac{3}{4}$ inch wide; they are now worn down to $\frac{5}{16}$ inch thick.

"A number of stationary engine pistons are working with these packing rings, and they have proved very durable and thoroughly satisfactory, giving an advantage in reduction of friction, and in preserving the cylinder face in perfect condition. In one case of the engine of the Oldbawn Mill, near Dublin, with vertical cylinder 18 inches diameter and 2½ feet stroke, working with 50 lbs. steam, the cylinder had previously been worn considerably out of truth and much grooved, and one of these pistons was put in having two steel rings of ¾ inch width and ⅜ inch thickness, and was in constant work for four years without the packing rings requiring renewal. They have lately been taken out for examination, and were found to be still ¼ inch thick: and the cylinder from its previous defective condition has been brought completely to truth throughout, with a highly polished surface.

"These packing rings have also been used for four years for pump buckets, and have proved very satisfactory. In one case of a double-acting pump 8 inches diameter, the two packing rings are of brass, ⅜ inch wide and $\frac{5}{16}$ inch thick, and are pressed out by the pressure of the water acting at the alternate faces of the bucket through two ports, ⅛ inch diameter, similar to those in the steam pistons. This pump had two years' constant work at quarries and bridge foundations upon the Great Southern and Western Railway, before the packing rings required nenewal.

"In the case of single-acting pumps the bucket has only a single packing ring, with ports opening from the upper side. A pump bucket 5 inches diameter so arranged has been working constantly for 2½ years at a station on the railway near Dublin. The packing ring in this instance was originally ½ inch wide and ¼ inch thick, and has worn less than $\frac{1}{16}$ inch in the 2½ years that it has been working up to the present time. As the diameter in this case is too small to allow of the ring being sprung over the body of the bucket into its place, it is put in by means of a junk ring screwed on at the under side of the bucket.

"An application of the same construction of packing has also been made to the gland packing of a 9-inch pump-plunger, in which two brass packing rings are used, ½ inch wide and ⅜ inch thick, just like the piston packing rings, except that they act in the opposite direction, being pressed inwards upon the plunger by the pressure of the water through the ports."

88. The three following paragraphs are taken from the "Scientific American."

(*a*) "*Sizes for Key-seats.*—Mr. William Edward Davies, Jersey City, N. J., sends us a diagram of a convenient plan f the sizes of key-seats. It should be engraved on a brass pla and kept by the foreman or tool-keeper so that the workme may have access to it. Our mechanical readers will understan

Fig. 34.

the diagram without any explanation from us. The lines from *a* to *a* represent the depth of the key-seat for wrought-iron, which, in the largest size shown in the diagram, is $\frac{1}{2}$ inch in depth for $1\frac{1}{4}$ inch in width for wrought-iron, and $\frac{9}{16}$ by $1\frac{1}{4}$ for cast-iron. These latter sizes are shown at *b b*. The dimensions of the shafts are shown by the figures at the left. We are always pleased to receive suggestions and plans for expediting work ; if our readers would only impress upon the minds of every one interested in the subject the great need which exists for a standard pitch for different sizes of screw-bolts and their nuts, they would do a great deal towards inaugurating a reform in the matter."

(*b*) "*Formulas for determining the dimensions of Small Gears* *by diametral pitch.*—We are indebted to Messrs. J. R. Brown & Sharpe, the well-known machinists of Providence, R. I., for the following valuable tables. They were originally made especially for this firm :—

Let P denote the *diametral pitch*, or the number of teeth to one inch of diameter of pitch circle.

D′ the diameter of pitch circle.	Larger Wheel.	These wheels run together.
D the whole diameter.		
N the number of teeth.		
V the velocity.		
d′ the diameter of pitch circle.	Smaller Wheel.	
d the whole diameter.		
n the number of teeth.		
v the velocity.		

a the distance between the centres of the two wheels.
b the number of teeth in both wheels.
t the thickness of tooth or cutter on pitch circle.
D″ the depth of tooth.

" The examples placed opposite the formulas below are for a *ingle* wheel of 12 pitch, 6·166 inches or $6\frac{2}{12}$ inches diameter, etc. ; and in the case of the *two* wheels, the larger has the same dimensions. The velocities are respectively 1 and 2.

FOR A SINGLE WHEEL.

Formulas. *Examples.*

$$P=\frac{N+2}{D}=\frac{72+2}{6{\cdot}166}\text{ or }\frac{72+2}{6\frac{2}{12}}=12 \qquad 1.$$

$$P\,\frac{N}{D'}=\frac{72}{6}=12. \qquad 2.$$

$$D'=\frac{N}{P}=\frac{72}{12}=6 \qquad 3.$$

$$N=P\,D'=12\times6=72. \qquad 4.$$

$$N=PD-2=12\times6{\cdot}166-2,\text{ or }12\times6\tfrac{2}{12}-2=72. \qquad 5.$$

$$D=\frac{N+2}{P}=\frac{72+2}{12}=6{\cdot}166,\text{ or }6\tfrac{2}{12}. \qquad 6.$$

$$D=D'+\frac{2}{P}=6+\tfrac{2}{12},\text{ or }6+{\cdot}166=6{\cdot}166. \qquad 7.$$

$$t=\frac{1{\cdot}57}{P}=\frac{1{\cdot}57}{12}={\cdot}130. \qquad 8.$$

$$D''=\frac{2}{P}=\frac{2}{12}={\cdot}166,\text{ or }\tfrac{2}{12}. \qquad 9.$$

FOR A PAIR OF WHEELS.

Formulas. *Examples.*

$$b = 2a\,P = 2 \times 4{\cdot}5 \times 12 = 108. \tag*{10.}$$

$$n = \frac{b\,V}{v+V} = \frac{108 \times 1}{3} = 36. \tag*{11.}$$

$$N = \frac{n\,v}{V} = \frac{36 \times 2}{1} = 72. \tag*{12.}$$

$$n = \frac{N\,V}{v} = \frac{72 \times 1}{2} = 36. \tag*{13.}$$

$$N = \frac{b\,v}{v+V} = \frac{108 \times 2}{3} = 72 \tag*{14.}$$

$$n = \frac{P\,D'V}{v} = \frac{12 \times 6 \times 1}{2} = 36. \tag*{15.}$$

$$V = \frac{n\,v}{N} = \frac{36 \times 2}{72} = 1. \tag*{16.}$$

$$v = \frac{N\,V}{n} = \frac{72 \times 1}{36} = 2. \tag*{17.}$$

$$v = \frac{P\,D'V}{n} = \frac{12 \times 6 \times 1}{36} = 2. \tag*{18.}$$

$$D = \frac{2a\,(N+2)}{b} = \frac{2 \times 4{\cdot}5 \times (72+2)}{108} = 6{\cdot}166. \tag*{19.}$$

$$d = \frac{2a\,(n+2)}{b} = \frac{2 \times 4{\cdot}5 \times (36+2)}{108} = 3{\cdot}166. \tag*{20.}$$

$$a = \frac{b}{2\,P} = \frac{108}{2 \times 12} = 4{\cdot}5. \tag*{21.}$$

(*c*) "*The Pitches of Screw-threads.*—Reason and expedience both demand the early introduction of some fixed system for the pitches of machine screws. At present there is no standard whatever, and the inconvenience, delay, and expense resulting, is felt every day. Repeatedly, engines are stopped, presses stand idle, and pumps deliver no water, for the reason that some bolt has broken, and another has to be made before operations can be resumed. But these delays, although vexatious and costly, are trifles, compared to the want of mechanical system shown in this subject by the trade in general, it is a standing reproach to our machine-makers. None know the truth of this assertion better than they, and it is because no one moves earnestly in *the matter* that so little interest is manifested about it.

"If all the foot-rules varied, or the standard of inches and fractions of it were at the mercy of any person, what confusion there would be, and yet a derangement similar in character exists at this moment in the subject of pitches for screw-threads. It is safe to say, that scarcely two shops use the same standard. One superintendent thinks twelve threads too coarse for half-inch bolts, another thinks it too fine; so, between them, they split the difference and make one of eleven and a half or eleven and three-quarters to the inch; or what is still worse, an almost infinitessimal fraction less than any regular number, as, for instance, thirty-three or thirty-four threads in three inches. It is almost impossible to measure such threads on a single inch, and no true mechanic would ever make one for standard use. Such threads are made, however, and used daily; we have had positive demonstration of this fact.

"The Whitworth standard is very generally used in England; so much so, that it may be called the standard there; but with us there is no fixed idea, although there is great need for one. If the bolts of commerce, or those sold in hardware and ship-chandlery stores, were all of one pitch, for the relative diameters, it would be a convenience that many machine-shops would avail themselves of, and extensive works, even, could purchase sets of bolts, certified of the best iron, at less prices than they could manufacture them for in their own works. The advantages to be derived from some standard pitch seem to be worth working for."

89. On the subject of "*Torsion*," its principles, and their application to the practice of shafting, we find an excellent paper in the "Mechanics' Magazine," which, in giving here, we do our readers a service.

"Any one looking along a line of shafting when an engine is being started, will notice that the rotating motion takes some time to be communicated to the extreme end. The movement is gradually transmitted, step by step as it were, from shaft to shaft, and the engine is often in full rotation before the last shaft is at work. The same thing will be caused in a long set of boring-rods. This effect can be but seldom ascribed to any play of the keys in the wheel or coupling-boxes, and a play of this kind would not be sufficient to produce such a retardation. Most of us have noticed, on a windy day, the perpetual twisting of the little tin fish which is often suspended from a line in order to be used as a sign in shops where they sell fishing-tackle. A breath of air will sometimes set the fish twisting at the end of the wire for almost the whole of the day. This is also an effect of the elasticity of torsion of the iron wire used as the line. As long as this action is kept within the limit of the torsional elasticity of the wire it can be repeated for ever. This is even the case with a wire of lead, and with thin cylinders of pipe-clay. Professor Robison took a leaden wire 1-15th of an inch in diameter and 10 ft. long. He fixed one end to the ceiling and let the wire hang down vertically, after affixing to the lower end an index like the hand of a watch. On a stand below was a circle divided into degrees, with its centre corresponding to the lower point of the wire. If the index be turned twice round in order to twist the wire, 'when the index is let go it will turn backward again by the wire untwisting itself, and make almost four revolutions before it stops, after which, it twists and untwists many times, the index going backwards and forwards round the circle, diminishing, however, its arch of twist each time, till at last it settles precisely in its original position.' The great elasticity of that familiar substance, india-rubber, makes its distortion an exaggerated, and therefore plain, symbol of what takes place in stiffer materials. The effect produced on an iron shaft by torsion is similar to that produced by twisting a round slip of india-rubber, the difference consisting in, that the torsion, in the case of the shafting, is on a larger scale, and with, of course, more rigid materials. A single shaft, fitted with a tooth wheel at each end, the one wheel driving, while the other is being driven, also undergoes the internal angular displacement, called torsion. The displacement of the molecules will be clearly less in the case of a short shaft, while it will increase with the distance between the planes perpendicular to the axis round which takes place the rotation. A centre line passing exactly through the axis would not be subject to be twisted, but the further any fibre from this axis would lie, the more would the fibre have a tendency to be displaced. If we suppose that an india-rubber shaft, for instance, is to be cut up into a large number of thin discs on the same axis, then, on the application of a twist, each disc would have the tendency to rotate, and the distance passed through would be greater the further from the centre. But all the molecules that happened to be on the same radius before the torsion would be on the same radius after the shaft had been twisted. It will also be seen that the infinite number of thin discs, of which we have supposed our shaft to consist, will undergo the same angular displacement, as all the discs between the resisting and propelling forces are under the same influence. The displacements, undergone by a line of the fibres that we may have supposed to lie parallel to the axis, are added to each other. The relative displacement of two particles at opposite ends of the shaft would thus be in proportion to the distance between the two ends. Looking, again, at our india-rubber shaft, and supposing that before being twisted it had been marked on the outside of its circumference with a line parallel to its axis, then this straight line or fibre would be twisted, by the torsion, into a spiral. As all the molecules that had been on the same radius before the torsion would be on the same radius after the torsion, the pitch of this screw-line would be the same for all the fibres, whatever their distance from the axis. If, however, we suppose tangent lines drawn from different radii to this line along the axis, then the inclination of these tangents would increase with the distance from the end of the shaft. It will be seen that the resistance of torsion bears a relation to tensile or compressile resistance, and more especially to the first. A shaft submitted to torsion does not get longer, and the thin discs we have fancied are at the same distance from each other, but the fibres drawn out spirally have been lengthened to the amount, that the twisted fibre is longer than when straight, and having the same length as the shaft.

"It is by a somewhat similar reasoning, supported by simple calculations, that General Morin explains how it happens that, when a solid is fixed at one of its extremities, and is urged by a force acting in a plane perpendicular to its length, and tending to twist it, the angles of displacement of each of its longitudinal fibres are:—1st, proportional to the distance of these fibres from the axis of the figure; 2d, in proportion to the distance of the section considered from the section which is fixed. The torsion of a shaft twisted at one of its end's by the driving power, and at the other by the resistance, is the same as if the shaft were fixed at the section where the resistance takes place, and twisted at the place where the power is acting. It is stated that the proportionality of the angles of torsion to the sum of the moments of the extraneous forces, and to the length of the solids, or the distance between the extreme sections, has been verified experimentally for angular displacements, within which the limits of elasticity are not altered.

"The first who appears to have investigated the phenomena attendant on torsion appears to be Coulomb. His torsion balance consisted of a wire suspended by its extremity, and stretched by a weight upon a somewhat similar plan to that of Dr. Robison. To the wire was fixed a needle, the point of which rotated on a graduated circle. When the weight at the end was turned round —the wire being left to remain perpendicular—the particles of the wire returned to their first position, and, at the same time, moved the weight and the needle. The velocity acquired carried both beyond the first position, and they thus would go on making a series of diminishing oscillations like a pendulum.

"It is clear that in machines it is necessary to confine the amount of the angle of torsion—the pitch of the spiral formed by the torsion—within very narrow limits determined by the necessity for not greatly affecting the elasticity. The greatest displacement will be undergone by the points situated at the greatest distance from the centre. The angles of displacement will also be in proportion to the length of the cylinder, so that the amount of torsion applied should be all the less as the shaft is longer. This means, in other words, that the angle of the twist should have a value limited by the kind of material used, and the mode of its employment. In general, the angle of torsion is not allowed to exceed half a degree, and, according to Gerstner, it should not be more than 0·1 of a degree.

"There are, perhaps, few cases in practice in which any part of a machine is subjected to torsion alone. It is also, as in the instance of machine and engine shafts, subjected to a cross-bending effort; and, in the case of rivets and short bolts, to a shearing strain. When this occurs, and it is wished to make the part as light as is consistent with safety, both the cross-bending and torsional strains should be calculated, and in order to use the largest amount of two. It is well known that the teeth of the wheels have to be made strong enough to resist any action similar to that of combined twisting and bending, which could easily arise from the whole force of the two wheels being taken by one corner of a single tooth. The formulæ given for the teeth of wheels do take this action into account.

"There is nothing more dangerous and more likely to lead to either immediate rupture, or to injury that will sooner or later lead to rupture, than what is termed a 'kink,' in either a chain cable, a common chain, a wire rope, or a hempen rope. In all these cases the effect of the torsion is increased by the leverage of the kink—that is to say, the tension exerted on both ends is multiplied by the leverage of the kink, and the safe angle of torsion being so slight, the material is very easily unduly strained. It first takes a set, the pull continues, the strains increase, they increase still further as the breaking load is approached, until at last rupture ensues, and the ship, or mining cage, as the case may be, is at the mercy of the unreasoning and destructive powers of Nature. The liability to kinks in any rather great length strained in a machine greatly increases with the length. This affords another reason besides those we have adduced in our columns why cables should not be tested in such long lengths as 60 or 75 fathoms. The effects furthering, and ultimately causing, rupture are in all cases so greatly aided by sudden strains, and by impulsive forces generally, that the great advantages of friction-couplings for shafting are plainly to be seen. These couplings bring the motion, and consequently the torsion, gradually on to the shaft; there is little or no jar and vibration, and the shafts are not so liable to be unduly twisted in a way that will ultimately cause rupture. The friction-coupling is due to the late J. G. Bodmer; it is his most meritorious invention, and will probably last longer than any other of his productions.

"Some simple practical rules, not generally known, for calculating the diameters of shafts, are the following. They give the diameter of the necks of the bearings, the body of the shaft being of course made of a larger diameter:—For a cast-iron shaft, not subjected to shocks, make the diameter in centimetres equal to sixteen times the cube root of the number of horse power to be communicated by the shaft, divided by the number of revolutions. If the shaft be subjected to shocks, this formula will do for a wrought-iron shaft, but if cast-iron be taken, the co-efficient, 16, must be increased to 19 or 28, according to the force of the shocks. 28 should be taken for the shafts of rolling-mills for plates. Wrought-iron shafting is strong enough if it is worked equably, by making the diameter in centimetres fourteen times the cube root of the number of horse power, divided by the number of revolutions. With the old-fashioned wooden shafts the co-efficients must be increased to 36, and for the wooden shafts still occasionally used for helve hammers, to 80. Adcock's 'Engineer's Pocket Book' for 1857 gives complete tables of dimensions of cast-iron and wrought-iron shafts.

" A very useful approximate rule, indeed, for practice, and one not generally known, is that a wrought-iron shaft *one inch* in diameter will transmit *one-horse power*. It does not, of course, take into account any variations in the number of revolutions, which may be supposed to be about 100 per minute, and to be accompanied with the average amount of shocks that generally take place in shafting. This rule may be extended up to certain limits, but, of course, proportionately increasing the cross-sectional area of the shaft. On reckoning it out it will be found to agree with the more acccurate, and also somewhat empirical formula we have given above."

90. The following article on "*Hydraulic Lifts*" is from the "Building News:"—"The ingenious means occasionally resorted to in the process of scientific experiments are often of the most interesting and original character. Such was that adopted towards the close of the seventeenth century for testing the compressiveness of water, known as the Florentine experiment. Proceeding upon a knowledge that the solid content of a sphere is greater than that of any other figure of equal surface, and that, consequently, by altering the shape of a sphere, its capacity must be reduced, the academy caused a hollow globe to be filled with water, then carefully closed and subjected to pressure. Under this treatment it was noticed that some of the liquid appeared in the form of dew upon the surface of the metal, and the property of incompressibility was thereupon assigned to water. This tenet continued in acceptation till our countrymen, Canton and Perkins, demonstrated, by experiments of more convincing accuracy, *that* water is compressible to the extent of about a twenty thou-

sandth part of its volume for each atmosphere employed. Œrstead, Callodon, and Sturm, are also names of note in similar investigations. But observations of such extreme delicacy are rather scientifically interesting than practically available, and the alteration of volume producible in water by any moderate change of pressure is so insensible as to leave it in the class, it may be said the type, of inelastic and incompressible fluids. It, therefore, combines some of the properties of a solid substance with advantages especially appertinent to its own class.

"Solids transmit motion in the direction in which they are themselves impressed, but fluids transmit it equally and instantaneously in every direction. This momentary diffusion of motion gave rise to Mr. Wishaw's ingeniously-contrived hydraulic telegraph, an invention that, in the absence of galvanism, would probably have acquired a permanent celebrity. The property of transmitting or exerting pressure simultaneously in all directions is peculiar to fluids. If a vessel full of any substance of this nature have several equal orifices made in various parts of its surface, and fitted with pistons, then if any one of these pistons be pressed inwards with a given power, all the others will be pressed outwards with the same force. All the pistons except the first may be collected into one contiguous movable surface, and the weights or forces must be also collected and applied to preserve equilibrium. Taking the area of the first piston as 1, and that of the collected series as 10, the ratio of power will be similar, and ten pounds will be requisite on the larger to counteract a single pound on the smaller. This principle is popularly illustrated by a simple machine known as the hydrostatic bellows, and thus made: —Two boards of equal size have a water-tight flexible substance (as leather) firmly fixed to their respective edges, so that the vessel thus formed may expand and collapse freely. A small vertical pipe communicates with the interior, and if water be poured down this pipe, the upper board will rise, even though loaded with a considerable weight, and when raised as high as the apparatus allows, it will be seen that a short column of water in the small pipe is a sufficient counterpoise for a weight upon the board proportionate to the increase of sectional area possessed by the bellows over the pipe.

"It occurred to Joseph Bramah, the engineer, to apply pressure to the water in the supply-pipe, and thus was produced the extraordinary machine, whether regarded as an elegant adaptation of physical laws or for its stupendous power, called Bramah's Press. To make our future ground secure, it may be well to consider this contrivance more closely, and the pump he employed to force in the water may be first examined. When, by the action of the piston in an ordinary force-pump, water has entered the barrel, from which it cannot again descend, a downward motion of the plunger drives it upwards through a side pipe, but this method is objectionable for deep wells, as the rod is apt to bend. To obviate this effect, a hollow piston, with a valve at the upper edge, has been substituted for such cases, and this first descends through the water in the barrel, but upon drawing the rod up the valve closes and raises the water in its passage. It is preferable for deep wells, as the rod acts tensively, and the name of 'lift pumps' has been appropriately given to this kind. A third sort has the pole plunger piston, that is to say, a solid bar of metal fitting loosely to the interior of the barrel, and working through a close collar or stuffing-box. This was selected by Bramah for his press, and instead of the ordinary valve for preventing the return of the water to the well, he introduced one of solid metal with a long guide or tail. Such, then, was the condition to which the hydrostatic press had been brought in the time of its inventor, whose useful life closed just half a century ago. He had fully developed, indeed, the principle of a machine that admitted of new and extended application, but hardly of improvement. Among those who have extensively and skilfully adapted the principle to manufacturing purposes may be mentioned Messrs. Maudsley and Field, and in connection with structural works Messrs. Easton and Amos have acquired pre-eminence. The presses they furnished for raising the Britannia and Conway tubular bridges are extraordinary examples, and one of these has been thus described by the resident engineer of the former colossal work:—'It consists only of an exceedingly thick and heavy iron cylinder, like a mortar; a strong piston or plunger, also of iron, called the ram, works up and down inside this cylinder, and is fitted with a leather collar at the shoulder, so as to be water-tight. Water is forced into the cylinder by a force-pump through a small hole, which we may compare to the touch-hole of the gun, and this water gradually forces the piston up. Now, the whole secret of the immense power of these machines consists simply in the prodigious force with which the water is driven into them, and which, in the present instance, is so great that it would throw the water to a height of nearly twenty thousand feet, which is more than five times as high as Snowdon, and five thousand feet higher than the summit of Mont Blanc! The whole affair, in fact, exactly resembles the piston of a steam engine; but instead of using *steam* at thirty or forty pounds pressure to the inch, *water* is used at a pressure of eight or nine thousand pounds. The cylinder, of course, requires to be very strong to withstand this pressure. The sides of the largest of the presses used in raising the Britannia tubes are 11 inches thick, and the weight of the cylinder alone 16 tons; it is of cast-iron, in one piece. The ram or piston is 20 inches in diameter. The whole machine complete weighs above 40 tons. It is the largest press in the world, and is, indeed, the most powerful machine ever constructed; and, if worked to its utmost power, would be alone quite capable of raising one of the tubes. Its action, nevertheless, is guided and controlled by one man with the most perfect precision and ease. The water is forced into the presses by two steam engines of 40-horse power each, with tubular boilers, as in a locomotive. The diameter of the pumps is $1\frac{1}{16}$th inch, and that of the ram being 20 inches, their respective areas are in the proportion of 1 to 354.' Messrs. Easton and Amos are at present employed in constructing, for the Brighton Hotel, a series of hydraulic lifts, which have been lately described by Mr. Whichcord, the architect of that edifice.

"A square shaft or tower, about eight feet across internally, is built up the entire height of the hotel, with apertures for communicating with each storey. Within this shaft the ascending room is suspended by a chain passing over a wheel at the top and loaded to the proper degree with balance weights. The room is fitted up in the manner of a railway carriage, with a central lamp, and, the gearing being carefully made and adjusted, it is expected that the motion will be nearly or entirely imperceptible. The earliest instance of this sort of "upstairs omnibus" was that used at the Colosseum, where steam power was employed for the operation; but at the Grosvenor, the Westminster, and other large modern hotels, examples will be found of the kind now under consideration. There is a noticeable difference between the hydraulic machines we have briefly reviewed in passing and that suited for the propulsion of these lifts. Bramah's press was capable of exerting enormous power, but the scope of its action was limited to a few feet. The large ram at the Britannia bridge had but a six feet stroke, and at that interval of height the apparatus required to be re-adjusted. It occupied half an hour in rising a couple of yards, and another half hour was consumed in preparation for the next stage. In the domestic lift, on the other hand, half a ton is much in excess of the ordinary load, but this load has to be raised by one continuous motion ten times as high and sixty times as fast. The motion is accomplished by the following means:—The basement floor may be considered as the mid-level of the apparatus, and a well must be sunk as much below the level as the car is to be raised above it. In this well (which may be of small diameter) is sunk the cylinder or barrel pipe, and within this, fitting loosely, is the lifting ram or plunger, consisting of another pipe the whole length of the barrel and working closely through a water-tight stuffing box at the top. It has some resemblance to the pole-plunger of a pump; but, instead of being solid, it is hollow, and instead of drawing water, it is forced by it.

"At the Brighton Hotel, motive power will be derived from a cistern at an elevation of more than a hundred and twenty feet. There are five lifts, viz.:—one for passengers from the ground to the fifth, or any intermediate floor, a height of fifty-six feet. It will be capable of raising half a ton, that is, the weight of eight average persons of ten stones each, the whole distance in one minute; and is estimated to cost, exclusive of cistern, £600 to £650. The second rises from the basement to the fifth floor, a height of seventy-seven feet, and is constructed on a different principle to the foregoing. A horizontal cylinder and piston give motion to rack and pinion gearing, which, acting on a revolving drum, hoists the load. Its power is equal to a weight of six hundred pounds, and the cost is calculated at £400 to £450. The third lift, for raising wine from the cellar to the bar, or a height of sixteen feet; and one of the same range for taking dinners from the basement to the large coffee-room, have respectively a power of fifty pounds and a hundred pounds, and cost £75 and £115.

"The remaining lift carries dinners and provisions from the basement to any of the five superior storeys. It rises eighty feet, has a power of one hundred pounds, and is estimated to cost £300.

"In the construction of these lifts, safety, smoothness of action, and precision in stopping and starting, are said to have been well attended to, and complete means of communication by bells and speaking tubes are provided at all the stages. The system is presumed to be adequate to the requirements of the large establishment it is intended to serve, as well as to remove the otherwise natural objection to the upper storeys.

"It is observed that the application of hydraulic power to buildings may be productive of important changes in their arrangement, and the architect of the Brighton Hotel thinks the tardy employment of this power in London is chiefly due to the low pressure of the water supply. He conceives that a perfect system of water-works should provide in every street, or at least in the principal thoroughfares, 'a main pipe, the pressure in which should always be capable of throwing jets of water in sufficient volume to put out any ordinary fire without the use of engines.' We agree with Mr. Whichcord's opinion concerning the convenience of lifts in all large establishments, such as hospitals, hotels, offices, and domestic buildings; we will even go a step in advance and pronounce that, in this particular department of its application, hydraulic science is as yet but in its infancy, and that, when the intellects of our architects and engineers are fairly directed to the object, it will be found that, by the combination of pneumatic springs, or other auxiliaries, hoists of much greater power than those we have been considering will become common in warehouses, post-offices, and banks. Remove, for instance, from the great postal edifice in St. Martin's-le-Grand the obstacles presented by its stairs, and the area of the whole building would be as good as doubled; vanquish the exhausting power of height, and we shall see storey peep o'er storey, as Pope saw 'Alps on Alps arise.'"

91. *Wheel-Cutting Machines.*—"It is scarcely necessary to urge," says 'the Mechanics' Magazine,' "upon any practical mechanic, the great value of a good wheel-cutting machine. It is well

known that this description of special tool was amongst the first machines that made their appearance in English engineers' workshops. Messrs. Fox, of Derby, appear to have been the originators in England of an engineer's tool for cutting and dividing the teeth of wheels. Brass wheels and wooden-wheel patterns of a smaller diameter than six inches, and of fine pitches, have their rims generally cast to the depth of their teeth, which are divided and cut out of the casting by the machine. Circular, or rose-cutters, are often formed in the same way.

"If a cast-iron toothed wheel be cast perfectly true, it is, of course, better to leave it untrimmed. To take the skin off a casting, always reduces its strength, but it also diminishes the duration of the teeth of a wheel. The skin on a casting is somewhat like the skin produced by case-hardening a piece of wrought-iron. For many years Mr. Whitworth has turned out the change-wheels of his lathes, &c., without any trimming. Larger wheels, however, are often trimmed up, as it is not so easy to cast a large toothed wheel quite true. The wooden cogs of mortice wheels are also generally shaped by hand, and this is more especially the case with the cogs of bevel gearing. Cast-iron wheels intended to work with mortice wheels, generally have their teeth trimmed up by hand. This is a costly and tedious operation, but its necessity is apparent. The wooden cogs of a mortice wheel would be speedily worn away by the rough surface of cast-iron teeth.

"Steel circular cutters of the exact shape of the tooth are generally used for cutting spur-wheels. It will be seen at once that it would be impossible to cut a bevel tooth by means of a circular cutter, without setting the cutter at an angle. The teeth of a bevel-wheel, of course, advance and recede, both as to depth and breadth. Even when a correct circular cutter is used, the wheel is not completely finished by this process; it must be trimmed up by hand-filing. It is scarcely possible to get a correct bevel-wheel by means of a circular cutter.

"In our number for October 24th, 1862, p. 253, under the heading of 'Machine-tool Substitutes for the File,' we alluded at some length to the subject of circular cutters, and we there proposed to make a circular cutter for iron upon the same plan as the cutters used in 'Biddell's patent oat-mills.' It is evident that the circular cutters used for wheel-cutting machines might be made in the same way. Circular cutters, formed of one piece of steel, often spring while being hardened, and are also very liable to warp while undergoing this latter operation. When in use, should any teeth be broken off, the whole cutter must be turned up, softened down, and re-cut. There is also a difficulty in sharpening the edges of the teeth when the cutter gets worn. Mr. James Nasmyth, of Patricrift, some thirty years ago, made circular cutters out of a number of separate knives, in the following manner:—

"He built up the circular cutter out of a number of separate steel cutters, the inside of each cutter being of a wedge shape, and the whole number required were arranged in radii from the centre of the disc. A wrought-iron ring was shrunk on the circular bundle of cutters, so that it could be turned up in the lathe, just as if the cutter were in one solid piece. One side of the cutters is first turned up, and is then fitted into the chuck of the circular shaping or wheel-cutting machine. The chuck is furnished with a set-screw, and this screw is caused to press upon one of the separate cutters, which thus acts as a wedge between the other cutters. The wrought-iron ring is then knocked off, and the other part of the circular cutter is turned up in the lathes, so that all the separate knives or cutters are of the same shape.

"On slackening the set-screw, the separate knives can be easily taken out of the chuck, and filed up to the required shape. On being properly hardened, the knives are replaced in the chuck. They are then screwed up by the set-screw, and the whole circular cutter is thus ready for use. Before the modern improvements in moulding, enabling us to cast wheels with greater precision, wheel-cutting and dividing machines seem to have been in greater demand than at present. We have seen, in an old German periodical for 1843, a design for forming a circular cutter for toothed wheels, upon a plan somewhat similar to that of Mr. Nasmyth. The German design was avowedly suggested by Mr. Nasmyth's cutter. A circular cutter for the teeth of wheels must, of course, cut on three sides, taking up the sides and bottoms of the teeth. This kind of circular cutter must also be fixed on a mandrel, and requires to take the shape of a wheel. It is thus impossible to fix such a cutter on the chuck of a lathe; it must be independent of all such support. The way described was the following :—The separate cutters were filed up to a wedge shape, and arranged in radii together; a wrought-iron ring being then shrunk on the whole. This steel disc was then placed on a lathe, and the centre bored out to the size of the spindle upon which it was to be fixed. The disc was then fixed on a mandrel, properly turned up to the required shape, and a circular groove was then formed some distance from the centre. This groove was made of a conical or bevelled shape, and a ring was fitted into this groove. The ring thus keeps the separate cutters together, when the outside ring is taken off. If this inside ring be once tightly driven into the groove, the outside ring can then be taken off. The steel disc or cutter is then placed on a mandrel, and turned up in a lathe to the required shape. There is a boss on the spindle of the circular cutter, and a nut is screwed up against the other side. The separate cutters are thus kept from being pressed out. These independent cutters can also be separately taken out, sharpened, and hardened, just like Mr. Nasmyth's cutters.

"In our volume for 1849 will be found a self-acting method, proposed by a student of St. John's, Cambridge, for cutting the teeth of the drivers of pin wheels or trundles. We do not know whether this plan has ever been carried out.

"There were three machines in the International Exhibition for cutting the teeth of wheels; two of these used circular cutters. One was exhibited by Mr. Whitworth, of Manchester, and figured in the western annex. The second machine was sent by Cook and Sons; it was intended more especially for horological wheels, and was on the same general principle as Mr. Whitworth's machine. The machine exhibited in the International Exhibition by Mr. Whitworth was intended to cut spur, bevel, or screw wheels, in metal or wood. It could cut wheels up to ten feet in diameter. This machine consisted of a long bed, similar to a lathe bed. A circular cutter was used, which was intended to be set at an angle when bevel-wheels were required. The circular cutter was on a vertical spindle, working in an adjustable headstock. The speed of this cutter could be varied to suit wood or metal. The wheel to be operated upon was fixed on the end of a mandrel fitted in a sliding bracket. There was an ordinary dividing apparatus for pitching the teeth. This machine is amongst the best tools of Mr. Whitworth. It, no doubt, does its work very efficiently, with respect to spur and screw-wheels, but it is subject to the objections we have previously alluded to; when speaking of cutting out bevel-wheels by means of a circular cutter. The third wheel-cutting machine was exhibited by John Hunt and Co., of Bow. We have also heard of this firm in connection with anti-friction metal bearings. It was a special tool for dividing and cutting bevel gearing. Although in an out-of-the-way corner, it excited some attention, from its exquisite ingenuity, and as an example of right adaptation of means to an end. The attendant asserted that the machine could pitch and trim more wheels in one day than could be achieved in a week by a good millwright. The apparatus consists, essentially, of a shaping machine with a reciprocating tool. This tool has a stroke of about three inches. The slide is made upon the plan first adopted by Mr. Nasmyth, of Patricrift. The tool box slides on a top and bottom V, and is therefore less subject to any side deviation through wear. In front of the tool-holder are two fixed bearings, carrying a cross shaft, through the centre of which is a socket holding a mandrel. On the bottom end of this mandrel is fixed the wheel or pattern to be operated upon. On the top end is adjusted the dividing plate or apparatus. This mandrel has a motion on a vertical plane, and another motion horizontally; out of a composition of these two movements, the varying depth and breadth of the bevel teeth are produced. The vertical motion is obtained by means of a worm working in a toothed segment. The feed motion is communicated by a cam on the driving shaft working into a ratchet wheel. This wheel, in its turn, works the worm and segment. The depth of tooth for the bevel gearing is thus obtained. The form of the teeth is produced by means of a lever attached to the mandrel on which the work is fixed. In the other end of the lever is fixed the shape of the tooth upon a somewhat increased scale. This templet acts against a steel straight-edge on a line with the tool. The vertical motion acting upon this lever works the tooth down, and thus transmits the motion from the templet to the tooth of the wheel being produced. The templet is kept against the steel straight-edge by means of a spring. There is an ingenious spring and detent motion, throwing the vertical movement out of gear when the tool reaches the bottom of the tooth. The dividing plate, to which we alluded before, is set by hand when each tooth is finished, and it is kept in position by a lever and point. This lever is adjustable, in order to regulate the thickness of the teeth. The pitch is given by the holes in the plate. After cutting one side of the teeth, round the whole circumference of the wheel, a left-handed cutter is substituted for the previous tool, which we will suppose to have been right-handed. The templet or shaper is also changed to the other side. The machine is then put in motion to complete the shape of the teeth.

"In our volume 52, for 1850, p. 97, will be found an account (extracted from the *Franklin Journal*) of 'a machine for cutting teeth for bevelled gear,' then patented in America by George H. Corliss. The machine is not illustrated, but, as far as can be gathered from the description, its principle is slightly similar to the machine of Messrs. Hunt and Co. 'A reciprocating cutter that moves in a slide is used, which cutter vibrates on an axis that coincides, or nearly so, with the apex of a cone representing the bevel of the wheel to be cut, and by which vibration the depth of the cut is determined.' It is thus seen that the *reciprocating cutter* is adjustable.

"The *work* is adjustable in Messrs. Hunt and Co.'s arrangement."

92. "*Self-Stopping Gear for Tools.*—It has lately become the practice for a certain class of machinists to affix self-acting gear to lathes and similar tools, so that when the carriage reaches a specified point, either the feed is thrown out and the carriage stops, or else both feed and lathe are stopped and the work thus saved from injury. This is a good plan, and one that might be generally adopted with economy on every machine. Such an attachment would be cheap, and might save ten times its cost at times when either accident or carelessness had jeopardized the tools. It amounts to an insurance from damage upon the tools so fitted; and certainly any manufacturer who has paid for broken gear and brackets, or stripped nuts in the feeding apparatus, will acknowledge that anything which promises immunity from such disablement is worth attending to. It may be said that if a man pays attention to his business he is in no danger of breaking tools;

but that is not a good argument against the adoption of preventives against loss; for accidents will happen in the best regulated shops, and after the wreck of machinery lays on the floor it is hard to look at it and say 'This might have been guarded against by a little forethought and the outlay of a few dollars.' Such attachments as we have advocated cost but little primarily, but may save large sums in repairs and rebuilding tools. In addition to these improvements much advancement has been made in adapting lathes and other machines to do work that has until recently been accomplished only by the use of several cutters shaped for a special purpose. As, for instance, the curves in the necks of connecting-rods, valve stems, &c.; also the octagons, or hexagons, which are sometimes formed upon the same parts of an engine. In some shops in this country these are done wholly by the lathe itself, automatically, it may be said, since the turner has nothing to do but to keep his tools sharp and the work running and the ends shape themselves, 'rough-hew them' how the previous operator will.

"These additions are also a safeguard against idleness on the part of shiftless men, for the lathe stops when the feed has reached a certain point; and if the turner be off gossiping, or otherwise neglecting his duty, the result is shown by the action of the self-stopping arrangement and subsequent inaction of the tool. In many ways these simple attachments commend themselves, and employers, enterprising mechanics, and others, should see that their tools are so fitted without delay."—*Scientific American.*

93. *Experiments with Tools Needed.*—On this subject, which sometimes has been singularly overlooked, the "Scientific American" has the following remarks:—"Theory is one thing and practice another, and sometimes it happens, very awkwardly, that the experience of the workshop refuses to agree with the laws philosophers lay down. Just at this time the interest in the economy of working steam is very great; whether it shall be used expansively or non-expansively for some purposes is still a mooted point, but the experiments now going forward will settle this vexed question, we hope, at once and for ever.

"There is another and a very important point in the economy of the workshop, which is the power required to drive tools. Let us know what is the best form for a roughing tool. Out of half-a-dozen turners but one will be found who has a tool that cuts at all, the rest merely grate or tickle the top of the metal, so that some few miserable raspings are taken off. That this is a manifest loss to the company or proprietor is evident, and proceeds solely from a want of knowledge of the right principles. To obtain the knowledge in question we must experiment, not guess, and we think that a series of trials, with a view to ascertain the best form of edge for a roughing tool, would not be time thrown away.

"A good plan would be to take a small lathe and a train of gearing similar to those used for churn powers. Let a pulley be applied to this gearing and a belt from it directly to the lathe. A weight suspended from the drum of the gearing would represent the power. Now, let a tool be put in the slide-rest and set to work with a stated feed, speed, and depth of cut. The time required to run 1 inch, or more, should be accurately noted, and the tool removed and replaced by another. This, in turn, should be carefully watched, and the result recorded. In this way the diamond-point, the round-nose, the side-tool, the 'no kind of tool,' would all find their appropriate places, and the results would show very satisfactorily, if the experiments were well conducted, how much power was required to cut 1 inch, with given feed and speed and depth of cut. Of course, the same shaft should be used for all the tools to cut on. The conditions would not vary with larger cuts and heavier feed. Another point gained would be the knowledge of how much horse-power, expressed in foot-pounds by the fall of the weight in a given time, was required for a certain number of lathes of a known length of shears and swing. Roughing off work is the heaviest that is done on a lathe, if we except cutting screws of quick pitches, and the expression would be the maximum power required for a machine shop.

"Much other interesting and valuable information might be obtained which does not now occur to us; for instance, the loss of time and money through working with dull tools, or those that were too soft, &c., and we hope that some enterprising foreman or manufacturer will think it worth while to institute these experiments."

DIVISION FOURTEENTH.

MISCELLANEOUS.

94. *The Laws of Friction.*—"Friction, under a great variety of conditions, though not under all possible ones of practical occurrence—so ably investigated many years ago by Coloumb, and afterwards by Morin—has been submitted to a new course of experiments by M. H. Bochet, whose results have been communicated in 1858 and 1861 in Memoirs to the Academy of Sciences of Paris.

"They are of an important character in a practical light, and tend materially to modify the fundamental laws of friction as enunciated by Morin, viz., that its co-efficient is independent of extent of surface, or of velocity, and is proportionate to the pressure only.

"M. Bochet's experiments were conducted upon cases of *sliding* only, and at all velocities between 0 and 25 metres per second, and were made on iron of various degrees of polish—on various woods, hard and soft, wet and dry, resinous and non-resinous—on leather and gutta percha—and with large variations of surface rubbed.

"In all cases the frictional surfaces were dragged, under the known weights of railway waggons, over the surfaces of rails, in very various states—wet, dry, rough, polished, and oiled. He has also studied afresh the subject of the friction at starting from rest into motion, which Morin announced was always greater than the friction for continued motion. He describes with care the precautions taken to ensure exactness, and the dynamometer and other instruments employed by him in obtaining his results, which are given graphically by curves, &c.

"The following are amongst some of the most important of the results he has arrived at:—

"1st. Friction, under conditions apparently perfectly identical, is never precisely alike, so that its amount cannot be represented by a well-defined curved line (*une courbe unique*), but by a zone, through which a mean curve may be viewed as the nearest coefficient.

"2d. Friction diminishes with the velocity, all other things being the same.

"3d. Friction varies with the surface rubbed (*cæteris paribus*), or with the *specific pressure, i.e.*, the pressure on the unit of surface. The limits of variation are very small when the specific pressure and the velocity are both very small; but becomes sensible when either is great.

"M. Bochet deems further experiments needful to discover the exact law of this variation.

"4th. The friction of wood on iron rails varies within wide limits, according as the rails are dry, moistened, or greased. On the contrary, iron on iron rails, so long as the specific pressure is very great (as in the case of a wheel applied at a single point of its circumference to the rail), has almost precisely the same friction, whether the rails be dry, moist, or even greased. This result, assuming it perfectly established, quite conflicts with the popular notion, and that accepted amongst railway engineers, which attributes slippage, &c., to moist or greasy rails.

"5th. The state of polish powerfully influences the friction of iron on iron—much less so that of wood on iron.

"6th. The friction of dry wood on iron is greatly in excess of that of iron on iron.

"7th. The influence of the juices, resinous or otherwise, of fresh woods, is small on their friction, unless in the case of resinous woods moistened with water, in which case it is largely increased. Soft woods have a larger co-efficient of friction than hard ones.

"8th. There is no special increase of friction on starting from rest to motion, except for wood or leather, on moist or greased rails; in all cases of these pressures on dry rails, gutta percha on rails moist or dry, iron on iron rails, dry, moist, or greased; the friction at starting (*frottement du depart*) is precisely the same as that of a low velocity. The starting friction is greater, however, at high velocities; and in the cases first named, the starting friction is double that corresponding to slow uniform motion.

"There are three physical conditions, viz., molecular attraction, roughness of surface, and speciality of abrasion in rubbing, which, acting more or less together, appear to M. Bochet sufficient to account for all his observed facts. The following general formula he considers to express his results sufficiently nearly—

$$F = p\left\{\frac{K-y}{1+\alpha y} + y\right\}$$

in which F is the value of the friction or ITS co-efficient; $p =$ the total pressure.

"K and y are two co-efficients, separately variable, according to condition. The value of K being always greater (more or less) than that of y; $\alpha =$ a third co-efficient, probably slightly variable, in accordance with an unknown law, but which may be viewed with sufficient exactness as constant, and $= 0·3$ when the velocity, v, is expressed in metres per second.

"K and y vary with the materials, their state of surfaces, &c., and have large limits.

"The most energetic frictions are between soft wood and leather, gutta percha, &c., and dry iron rails, in which $K = 0·70$ frequently, occasionally falling to 0·40—usually $= 0·60$, for soft, and 0·55 for hard woods.

"For iron on iron rails, unless the surfaces be very large and uneven, $K = 0·40$ to 0·25.

"Polished iron on polished rails, $K = 0·30$ to 0·20, and occasionally as low as 0·12. Wood or leather on greased rails, $K =$ 0·16, and down to 0·05, at very small velocities. The value of F differs vastly with different substances and conditions; but the greater its original value, the more rapidly its value diminishes with increase of velocity, so that, in all substances, and in all cases, the tendency is for the value of F to become the same at extremely high velocities; in fact, it may be said that, with v infinite, F is constant for all bodies and all conditions of friction, and that, probably, then its value becomes $= 0$. This is one of the most important deductions from this investigation, which is purely experimental in its character. One conclusion, we may presume, at once flows from it, viz., that the friction of projectiles, in leaving the piece, is very small, and cannot be calculated on the usually-received laws of friction as delivered by Morin; and that even in the case of the compressed lead of the Armstrong shot, the amount of friction may be greatly less than it has been assumed, upon the basis of those laws; and again, that the friction of an undeformed projectile in passing through an iron or other target may be greatly less than has been imagined."—*Practical Mechanics' Journal.*

95. *The Concentration of Power.*—"On the concentration of power depends," says the "Mechanics' Magazine," "the solution of important mechanical problems daily encountered by the engineer in the practice of his profession. In its practical form the concentration of power is embodied in the reduction of the dimensions of any motor to minimum limits, no matter what its individual construction, or the nature of the principles under whose administration it gives forth power. The problem thus stated involves in its solution many points of technical detail, which can only meet with proper treatment at the hands of those practically, as well as theoretically, acquainted with the working of machinery, because all the difficulties met with in dealing with small machines intended to develop a high power are encountered in their working, seldom or never in their mere construction. The whole subject is one possessing no common interest, the struggle for concentrated power having produced some of the most elegant and important mechanical arrangements ever called into existence by the excogitations of mankind.

"It is needless to complicate the subject just now by any disquisition on the origin of power. We know that no machine, or system of machines, however complex or ingenious in construction, can do more than direct into the required channels certain proportions of those forces which are developed by particular laws of nature over which we possess a very limited control. To originate power in themselves is beyond the capacity of wood, iron, stone, or, in short, any constructive materials at our disposal. The water-wheel stands still until the stream is permitted to flow into its buckets; but the stream does not possess volition—it also would stand still but for the action of gravitation, a force in the abstract wholly independent of man's control or influence; obeying certain well-known laws, from which it never departs, and perpetually operating throughout the entire universe. Why a larger body should attract a smaller one we do not know; we can only recognise and avail ourselves of the fact. In like manner the steam engine is incapable of doing more than converting to useful purposes a certain proportion of the force stored up in the fuel which heats the water from which the steam is raised. In either the fall of water or the combustion of fuel a certain force is merely set free or called into action; it is never created by the aid of machinery, of the existence of which all the forces in nature are wholly and entirely independent. Thus, whenever a pound of coal undergoes the process of combustion, power previously stored up is set free; and precisely the same mechanical effort is requisite to evaporate a pound of water in an open vessel as in a closed generator connected with a steam cylinder and piston. Were it not that pure force or power has existence independently of mechanism, there would be little room for improvement in the construction of machines. We should expect to find their dimensions bear an invariable proportion to the amount of power which they were intended to produce, while the least possible variety would be permitted in matters of detail, on which their working would doubtless almost, if not altogether, depend. It is therefore, perhaps, fortunate that the existence of power is wholly separate and distinct from that of machinery, for, as it is in the abstract incapable of change or alteration in its nature, we are enabled to adopt just that arrangement of wood, iron, &c., in separate parts which we find most convenient, well knowing that so long as a few laws are attended to which will prevent the waste of force, its nature, character, or existence, can be in no way imperilled. And we thus find that the dimensions of a machine really bear no relation whatever to the amount of power which it may render available other than those which are impressed by certain properties of the materials of which it is composed, such as their tensile or transverse strength, their liability to wear by friction, and the nature of the modes by which the developed forces are subsequently transmitted. In practice we meet with instances of the truth of this proposition continually. The ponderous Cornish engine, with all its arrangements of colossal beam, huge cylinder, and vast boilers, develops less power, perhaps, than the little locomotive which hauls a train of coal waggons laden with material for the supply of its furnaces. It is needless to multiply examples with which all our readers must be sufficiently familiar.

"Power is force in motion, and therefore the question of relative velocity is a matter of great importance in the construction of all machines, but more especially of those which are intended to concentrate a great capacity for work in a very small compass. Most of the forces at our disposal will operate, under certain conditions, at any speed deemed most desirable. These conditions are in general easily secured, and, therefore, we find that nothing but considerations, totally apart from the development of power *per se*, prevent us from resorting to the use of even minute mechanism whenever its employment becomes desirable from the exigencies of situation, &c. Practically speaking, the great obstacle to the concentration of power is found in friction. A given strain being placed at our disposal, the amount of mechanical effect, or, more exactly, power, which that force or strain can give out, will be measured directly by the space which it passes over in a given time. Consequently, small machines intended to do much work must run at a high speed. A resistance of 1 lb. overcome at a speed of 33,000 ft. per minute, is a horse power just as much as 33,000 lb. overcome at the velocity of 1 ft.; but at high speeds all the trouble ever given by friction becomes magnified, and special arrangements for lubrication, and particular forms and dimensions for the rubbing parts or surfaces must be adopted, or the machine will altogether fail in the performance of its duties. When the friction problem is solved no difficulty whatever is met with in the concentration of power, provided the conditions under which that power is produced in the first instance, by some one or other of the natural forces, are complied with. Thus, a cannon ball, at the moment it leaves the muzzle in its flight, is the very impersonation of concentrated power due to high velocity. This, perhaps, is scarcely an instance strictly analogous to any thing found in machinery. Turbines, however, now and then furnish fine examples of the production of immense power within a very small space. At St. Blazier, in the Black Forest, a Fourneyron turbine, only 20 in. diameter, under a fall of 172 ft., gives 56 horse power, although its entire weight is but 105 lbs. Another turbine at the same place, of but 13 in. in diameter, under a head of 354 ft., makes 2,200 revolutions per minute, using 1 cubic foot of water per second, and driving 8,000 spindles, besides looms, &c., in the mill to which it is attached. In cotton *mills*, spindles are frequently driven at 11,000 revolutions per *minute*. Now, if one of these spindles is fitted with a disc 12 in. in diameter, its periphery will attain the enormous velocity of 33,000 ft. per minute, and therefore it will require just 1 lb. of resistance at this periphery to render a horse power necessary to overcome it; and *vice versa*, were the force impressed on the disc sufficient to overcome this resistance, it would give out a horse power. The late Mr. Richard Roberts has driven spindles for the purpose of experiment, at 60,000 revolutions per minute; a greater speed, perhaps, than was ever before attempted in any machine. High speed lathes, circular saws, and some other machines supply us with examples, where an immense amount of power is concentrated within a very small space. These are, however, strictly speaking, negative examples illustrating the expenditure, rather than the development, of force.

"As the power of steam is the most universally applicable of all the forces used for driving machinery, its concentration becomes a matter invested with considerable importance. A great deal has been done in the production of small high speed engines of late years, but a great deal more remains to be done before the principle can be regarded as approaching those limits, beyond which it may be neither safe nor prudent to carry it. The 'Great Britain' locomotive has frequently given out 1,000 horse power for many minutes together, with a pair of 18-in. cylinders 24-in. stroke, the weight of the engine in working order being little over 35 tons, or, with the tender, 50 tons. This may, perhaps, be considered as a maximum effort which it would not be advisable to attempt to maintain. Taking the work done, then, at but half this, or 500 horse power, we have still over 14 horse power per ton; or, if we neglect the weight of the wheels as in no way necessary to the development of this power, we have at least 15 horse power per ton of machinery. One of the steam fire engines, tried last year at Sydenham, developed nearly 30 horse power, the weight being under 50 cwt. This estimate of power does not pretend to strict accuracy, as the indicator was not used, and the power was calculated merely at an assumed pressure, some 20 or 30 lbs. less than that in the boiler. Still if we disregard the weight of the wheels, driving seats, &c., we find that the amount of power developed very nearly equals that of a first-class locomotive, weight for weight. Modern express engines give out 350 horse power as a matter of daily occurrence, and even goods' engines sometimes a great deal more. It is needless to say that in all these cases the power is obtained by an extremely high velocity of piston. In stationary engines, seldom confined in space. the march of improvement goes slowly, but, nevertheless, steadily on; and we trust ere long to see the clumsy beam and its appendages banished for ever in favour of high speed horizontal engines, working expansively. The 'Allen' engine, exhibited in 1862, inaugurated a change of practice, which is slowly making its way. This engine had a piston speed of 600 ft. per minute, and ran 150 revolutions with an ease, steadiness, and absence of heating, not greater, perhaps, than was to be expected from the care taken in designing the machine to the minutest details; but very satisfactory, nevertheless, in that it furnished a complete refutation to arguments now and then brought forward, and dug up, as it were, from old-fashioned practice, to prove that a high speed engine must in the nature of things be a failure.

"In order, then, to concentrate power, it is only necessary to impart a high velocity to some member of a system of mechanism which first receives the direct effect of the original moving force, as the piston of a steam engine, or the bucket vanes of a turbine. No theoretical objections exist to the adoption of this course. The practical objections are found to reside chiefly in friction, and the difficulties met with in carrying out a complete and thorough system of lubrication. In the case of vertical spindles heavily loaded, and running at high velocities, it is necessary that the footstep should be worked to some curve, which will extend the bearing surface and prevent the extrusion of the lubricant. In the case of steam engines, the main shaft bearings seldom give trouble if properly made, especially if the weight of the fly-wheel is sufficient to keep the shaft down steadily in the lower brasses. The connecting rod head, with its brasses and the crank-pin, are not so easily dealt with, and it cannot be denied that the annoyance which these occasion, has done much to retard the introduction of high speed engines. The fact is, that the brasses will not permit of that amount of looseness or play which may exist in any other bearings almost; because of the destructive hammering action which ensues. It is not easy to say why tightening a brass should make it heat; we find in every-day practice that a bearing which supports perhaps 1 cwt. per square inch, without undue friction so long as it is left moderately slack, will become almost red hot in a few minutes, if an additional pressure of not more than a few pounds per square inch is brought on it by screwing down the cap. Until we can give a satisfactory explanation of this phenomenon, it is not easy to see how its occurrence can be guarded against. Meanwhile, it is the source of all the trouble ever met with from a connecting rod end. The best remedy appears to consist in increasing the bearing surface very considerably, and providing an effectual method of lubrication, either by a telescope pipe from an overhead vessel of oil, or, in cases where the engine stands for a few hours out of the twenty-four, by boring a large cavity in the crank-pin, and filling it with tallow, a transverse aperture conveying the lubricant when melted to the surfaces where its presence is required. Attention to little matters of detail and good workmanship are really all that are required to ensure the success of any motor running at a high speed.

"Notwithstanding a great reduction in the dimensions of an engine, power can scarcely be said to be concentrated while the boilers remain very large. In many cases, a small boiler is imperatively dictated, and it yet remains to be seen if peculiar arrangements cannot be adopted, by which a very small furnace and a fierce combustion will do the work of one much larger with equal economy. Hitherto, fire boxes have been rapidly burnt out under such conditions; perhaps this has been occasioned by the over thickness of the plates. Locomotive fire boxes frequently burn down to a thickness of little more than one-fourth of an inch very quickly, although they will last for years without much subsequent deterioration. A generator might possibly be constructed with excessively thin cold-drawn steel tubes, through the substance of which the heat would pass so quickly to the water that their destruction would be almost indefinitely retarded."

96. *Substances for preventing and removing Boiler Incrustations.*—"The following is a list of substances which have been used, with more or less success, in preventing and removing the incrustations which are formed by using hard water in boilers:—

"*Potatoes.*—By using about one-fiftieth of potatoes to the weight of water in a boiler, scale will be prevented but not removed. Their action is mechanical; they coat the calcareous particles in the water, and prevent them from adhering to the metal.

"*Extract of Tannin.*—A mixture has been used of 12 parts chloride of sodium, $2\frac{1}{2}$ parts caustic soda, $\frac{1}{8}$th extract of oak bark, $\frac{1}{2}$ of potashes, for the boilers of stationary and locomotive engines. The principal agent in this appears to be the tannin of the extract of oak bark.

"*Pieces of Oak-wood* suspended in the boiler and renewed monthly, prevent all deposit, even from waters containing a large quantity of lime. The action depends principally upon the tannic acid.

"*Ammonia.*—The muriate of ammonia softens old incrustations. Its action is chemical; it decomposes the scale. In Holland it has been used with satisfaction in the boilers of locomotives. About two ounces, placed in a boiler twice per week, have kept it clean, without attacking the metal.

"*Fatty Oils.*—It is stated that oils and tallow in a boiler prevent incrustations. A mixture composed of 3 parts of black lead, and 18 parts tallow, applied hot, in coating the interior of a boiler, has given great satisfaction in preventing scale. It should be applied every few weeks.

"*Molasses.*—About 13 pounds of molasses, fed occasionally into a boiler of eight-horse power, have served to prevent incrustations for six months.

"*Saw dust.*—Mahogany and oak saw dust have been used to prevent and remove scale; but care must be exercised not to allow it to choke up pipes leading to and from the boiler. Catechu contains tannic acid, and has also been used satisfactorily for boilers. A very small amount of free tannic acid will attack the iron; therefore, a very limited quantity of these substances should be employed.

"*Slippery Elm Bark.*—This substance has also been used with some success, in preventing and removing incrustations.

"*Soda.*—The carbonate of soda has been recommended by Professors Kuhlman and Fresenius, of Germany, and Crace Calvert, of England. It is now employed with satisfaction in the boilers of engines in Manchester.

"*Tin Salt.*—The chloride of tin is equal to the muriate of ammonia; and is similar in its action in preventing scale.

"The *Extract of Tobacco* and *Spent Tanners' Bark* have been employed with some degree of satisfaction. The sulphate (not the carbonate) of lime is the chief agent in forming incrustations. By frequent blowing off, incrustations from carbonate of lime in water will be in a great measure prevented."—*Scientific American.*

97. *Soldering.*—"Soldering is the art of uniting surfaces of metals together by partial fusion, and the insertion of an alloy between the edges, which is called solder, it being more fusible than the metal which it unites. Solders are distinguished as hard and soft, according to their difficulty of fusion. Hard solders usually melt only at a red heat, but soft solders fuse at lower temperatures. In applying solder, it is of the utmost importance that the edges to be united should be chemically clean—free from oxide—and they should be protected from the air by some flux. The common fluxes used in soldering are borax, sal ammoniac, and rosin. Hard silver solder is composed of four parts of fine silver and one of copper, made into an alloy and rolled into sheets. It is quite difficult of fusion. Soft silver solder is composed of two parts of silver, one part of brass, and a little arsenic, which is added at the last moment in melting them. It will be understood that these alloys are commonly run into convenient bars or strips for use. Silver solders are used for soldering silver work, gold, steel, and gun-metal. A neater seam is produced with it than with soft solder. It is commonly fused with the blow-pipe. A strip of thin silver solder is laid on the joint to be closed, the blow-pipe is brought to bear upon it, when it melts and runs into the joint, filling it up completely. Button solder is employed to solder white metals, such as mixtures of copper and tin. It is composed of tin ten parts, copper six, brass four. The copper and brass are first melted, then the tin is added. When the whole is melted the mixture is stirred, then poured into cold water and granulated, then dried and pulverised in a mortar for use. This is called granulated solder. If two parts of zinc are added to this alloy, it makes a more fusible solder. Fine gold, cut into shreds, is employed as a solder for joining the parts of chemical apparatus made of platinum. Copper, cut into shreds, is used as a solder for iron. Hard silver solders are frequently reduced to powder,

and used in that condition. Soft solder consists of two parts of tin and one of lead. An excellent solder is made of equal parts of Banca tin and pure lead; it is used for soldering tin-plate, and, if well made, it never fails. The following is a useful table of solders, with their fusing points :—

No.	Parts of Tin.	Lead.		Melting deg. F.
1	1	25		558
2	1	10		541
3	1	5		511
4	1	3		482
5	1	2		441
6	1	1		370
7	1½	1		334
8	2	1		340
9	3	1		356
10	4	1		365
11	5	1		378
12	6	1		381
13	4	4	1 Bismuth	320
14	3	3	1 ,,	310
15	2	2	1 ,,	292
16	1	1	1 ,,	254
17	1	2	2 ,,	236
18	5	3	3 ,,	202

The alloy No. 8 is used sometimes for soldering cast-iron and steel; the flux used for this purpose is sal ammoniac, but common resin may be employed. Gold and silver are sometimes soldered with pure tin and a flux of resin. Copper, brass, and gun-metal are soldered with No. 8 and a flux of resin or sal ammoniac. The chloride of zinc is used for soldering sheet and plate iron as a flux with the same solder. Lead and tin pipes are soldered by plumbers with Nos. 6, 7, and 8, and a flux of resin and sweet oil. In soldering with soft brass, the ends of the article to be soldered are secured together by a wire, and granulated solder and powdered borax are mixed in a cup with a small quantity of water, and spread along the joint with a spoon. The article is then placed in a clear fire, and the solder melts at a bright red heat, when the article is then removed from the fire. In soldering small articles with the blow-pipe, they are supported on a piece of charcoal, or, what is better, pumice-stone, and the flame is ejected upon the solder. In soldering lead pipes, the parts to which the solder is not to be attached are usually covered with a mixture of lamp-black and size. In soldering any articles, care must be exercised to have the edges of the plates or articles perfectly clean, or the solder will not adhere. A flux is employed for the purpose of preventing oxidation. Resin and sal ammoniac, powdered and mixed together, make a good flux for copper and sheet-iron soldering. In other cases, a strong solution of sal ammoniac is used to moisten the edges of the joint. Then the resin is sprinkled upon it, and the solder applied. The chloride of zinc is made by dissolving pieces of zinc in muriatic acid. It is well adapted for soldering zinc plates and pipes, and is applied with a brush to moisten the edge of the article to be soldered. The solder is then applied in the usual way with a tool. Zinc is a very difficult metal to solder, because it is so easily coated with oxide, and it also volatilises with heat."—*Mechanics' Magazine.*

98. *On the Density of Steam.*—The following is an abstract from a paper read before the Royal Society of Edinburgh, by W. J. Macquorn Rankine, C.E., LL.D., F.R.S.S., London and Edinburgh, &c.

1. "The object of the present paper is to draw a comparison between the results of the mechanical theory of heat, and those of the recent experiments of Messrs. Fairbairn and Tate on the density of steam, published in the 'Philosophical Transactions' for 1860.

GENERAL EQUATION OF THERMODYNAMICS.

2. "The equation, which expresses the general law of the relations between heat and mechanical energy in elastic substances, was arrived at, independently and contemporaneously, by Professor Clausius and myself, having been published by him in Poggendorff's 'Annalen' for February 1850, and communicated by me to the Royal Society of Edinburgh, in a paper which was received in December 1849, and read on the 4th of February 1850. The processes followed in the two investigations were very different in detail, though identical in principle and results; Professor Clausius having deduced the law in question from the equivalence of heat and mechanical energy, as proved experimentally by Mayer and Joule, combined with a principle which had been previously applied to the theory of substantial caloric, by Sady Carnot, while by me the same law was deduced from the

'hypothesis of molecular vortices,' otherwise called the 'centrifugal theory of elasticity.'

3. "Although, since the appearance of the paper to which I have referred, the notation of the general equation of thermodynamics has been improved and simplified in my own researches, as well as in those of others, I shall here present it, in the first place, precisely in the form in which I first communicated it to this society, in order to show the connection between that equation, in its original form, and the law of the density of steam, which has since been verified by the experiments of Messrs. Fairbairn and Tate. The equation, then, as it originally appeared in the twentieth volume of the 'Transactions of the Royal Society of Edinburgh,' p. 161, is as follows:—

$$\delta Q' = -\frac{\tau - \kappa}{CnM}\left\{\delta V\left(\frac{1}{V} - \frac{dU}{dV}\right) - \delta\tau \frac{dU}{d\tau}\right\}; \quad . \quad . \quad . \quad (1)$$

in which the symbols have the following meanings:—

τ, the absolute temperature of an elastic substance, as measured from the zero of gaseous tension, a point which was then estimated to be at 274°·6 Cent. below that of melting ice, but which is now considered to be more nearly at 274° Cent., or 493°·2 Fah. below that temperature.

κ, a constant, expressing the height on the thermometric scale of the temperature of total privation of heat above the zero of gaseous tension. This constant was then only known to be very small; according to later experiments, it is either null or insensible.

nM, the ideal of theoretical weight, in the perfectly gaseous state, of an unit of volume of the substance, under unity of pressure, at the temperature of melting ice.

C, the absolute temperature of melting ice, measured from zero of gaseous tension (that is to say, according to the best existing data, $C = 274°$ Cent., or 493°·2 Fah.).

V, The actual volume of unity of weight of the substance.

δV, An indefinitely small increment of that volume.

$\delta\tau$, An indefinitely small increment of temperature.

U, A certain function of the molecular forces acting in the substance.

$+\delta Q'$, The quantity of heat which appears, or $-\delta Q'$, the quantity of heat which disappears during the changes denoted by δV and $\delta\tau$, through the actions of molecular forces, independently of heat employed in producing changes of temperature; such quantity of heat being expressed in equivalent units of mechanical energy.

"The equation having been given in the above form, it is next shown (in the same volume, p. 163), that the differential co-efficients of the function U have the following values:—

$$\frac{dU}{dV}=\frac{1}{V}-CnM\frac{dP}{d\tau}; \quad . \quad . \quad . \quad (2)$$

$$\frac{dU}{d\tau}=-\frac{\varkappa}{\tau^2}-CnM\int dV\cdot\frac{d^2P.}{d\tau^2} \quad . \quad (3)$$

4. "The physical law, of which the general equation just cited is the symbolical expression, may be thus stated in words:—The mutual transformation of heat and mechanical energy during any indefinitely small change in the density and temperature of an elastic substance, is equal to the temperature, reckoned from the zero of absolute cold, multiplied by the complete differential of a certain function of the pressure, density, and temperature; which function is either nearly or exactly equal to the rate of variation with temperature of the work performed by indefinite expansion at a constant temperature.

5. "It may be remarked that the quantity,—

$$\phi=\mathfrak{k}\text{ hyp. log. }\tau+\frac{1}{CnM}(\text{hyp. log. }V-U)=\mathfrak{k}\text{ hyp. log. }\tau+\int\frac{dP}{d\tau}dV \quad . \quad (4)$$

> ($\mathfrak{k}$ being the real specific heat of the substance in units of mechanical energy), is what, in later investigations, I have called the 'thermodynamic function;' and that by its use, and by making $\varkappa=0$, equation 1 is reduced to the simplified form,
>
> $$-\delta Q'=\tau\delta\phi-\mathfrak{k}\,\delta\tau; \quad . \quad . \quad . \quad (5)$$
>
> but the following notation is more convenient;—Let δh denote the whole heat absorbed by the substance, not in units of mechanical energy, but in ordinary thermal units, and J the value of an ordinary thermal unit in units of mechanical energy, commonly called 'Joule's Equivalent,' so that
>
> $$J\delta h=\mathfrak{k}\delta\tau-\delta Q';$$

then the general equation of thermodynamics takes the form

$$J\delta h=\tau\delta\phi \quad . \quad . \quad . \quad . \quad . \quad (6)$$

6. "For the purposes of the present paper, the most convenient form of the thermodynamic function is that given in the second line of equation 4; but it may nevertheless be stated that, in a paper read to this society in 1855, and which now lies unpublished in their archives, it was shown that another form of that function, viz.,

$$\varphi=\left(\mathfrak{k}+\frac{P_0V_0}{C}\right)\text{ hyp. log. }\tau-\int\frac{dV}{d\tau}\,dP, \quad . \quad (7)$$

was useful in solving certain questions; $\frac{P_0V_0}{C}$ denoting the same thing with $\frac{1}{CnM}$ in equation 1.

APPLICATION OF THE GENERAL EQUATION OF THERMODYNAMICS TO THE LATENT HEAT AND DENSITY OF STEAM.

7. "At the time when the general equation (1) was first published, sufficient experimental data did not exist to warrant its application to the computation of the density of a vapour from its latent heat. But very soon afterwards various points, which had previously been doubtful, were settled by the experiments of Mr. Joule and Professor William Thomson; and, in particular, Mr. Joule, by his experiments published in the 'Philosophical Transactions' for 1850, finally determined the exact value of the mechanical equivalent of a British unit of heat, to which he had been gradually approximating since 1843,—viz.,

$$J=772 \text{ foot-pounds;}$$

and Messrs. Joule and Thomson in 1851, 1852, and 1853, made experiments on the free expansion of gases, especially dry air and carbonic acid, which established the very near, if not exact, coincidence of the true scale of absolute temperature with that of the perfect gas thermometer; that is to say, those experiments proved that $\varkappa$ in the equation (1) is sensibly $=0$. When, with a knowledge of these facts, equation (1) is applied to the phenomenon of the evaporation of a liquid under a constant pressure, and at a constant temperature, it takes the following form:—

$$Jh=\tau\frac{dP}{d\tau}(V-v) \quad . \quad . \quad . \quad . \quad (8)$$

where

J denotes Joule's equivalent, or 772 foot-pounds per British unit of heat (a degree of Fah. heat in a pound of liquid water).

h, The heat which disappears during the evaporation of 1 lb. of the liquid; that is, its latent heat of evaporation in British units:—

τ, The absolute temperature (= temperature on Fahrenheit's scale + 664°·2 Fah.).

P, The pressure under which the evaporation takes place.
V, The volume of 1 lb. of the vapour.
v, The volume of 1 lb. of the liquid.

"As the latent heat of evaporation of various fluids is much more accurately known by direct experiment than the volume or density of their vapours, the most useful form in which the equation (8) can be put, is that of a formula for computing the volume of a vapour from its latent heat, viz.:—

$$V = v + \frac{Jh}{\tau \frac{dP}{d\tau}}, \quad . \quad . \quad . \quad . \quad . \quad (9)$$

"8. Results of this formula were calculated by Messrs. Joule and Thomson, and by Prof. Clausius for steam, and showed, as had been expected, a greater density and less volume than the law of the perfectly gaseous condition would give. Some results of the same kind, and leading to the same conclusion, were also computed by me and published in the 'Philosophical Transactions' for 1853–54. But for some years no attempt was made by any one to make a table for practical use of the volumes of steam from equation (9); because the scientific world were in daily expectation of the publication of direct experimental researches on that subject by M. Regnault.

"9. At length, in the spring of 1855, having occasion to deliver to the class of my predecessor, Professor Gordon, a course of lectures on the mechanical action of heat, and finding it necessary to provide the students with a practical table of densities of steam founded on a more trustworthy basis than the assumption of the laws of the perfectly gaseous condition, I ventured upon the step of preparing a table of the densities of steam for every eighteenth degree of Fahrenheit's scale, from 86 deg. to 410 deg. inclusive, with the logarithms of those densities and their differences, arranged so as to enable the densities for intermediate temperatures to be calculated by interpolation. Those tables were published in a lithographed abstract of the course of lectures before mentioned, which is now out of print. The same tables, however, have since been revised, and extended to every ninth degree of Fahrenheit, from 32° to 428°, and have been printed at the end of a work 'On Prime Movers.' An account of the original tables was read to the British Association in 1855.

"10. In the unpublished paper before mentioned, as having been read to this society in 1854, the densities of the vapours of ether and bisulphuret of carbon, under the pressure of one atmosphere, as computed by equation (9), are shown to agree exactly with those calculated from the chemical composition of those vapours.

"11. The method of using equation (9), to calculate the volume of 1 lb. of steam, is as follows :—

"I. Calculate the total heat of evaporation of steam from 32°, at a given temperature T° on Fahrenheit's scale, by Regnault's well-known formula $1091{\cdot}7 + 0{\cdot}305\ (T^\circ - 32^\circ)$ . . (10)

"II. From that total heat subtract the heat required to raise 1 lb. of water from 32° to T° Fah., viz. :—

$$\int_{32^\circ}^{T} c\,dT;$$

c being the specific heat of water; the remainder will be the latent heat of evaporation of 1 lb. of steam at T°; that is to say,

$$h = 1091{\cdot}7 + 0{\cdot}305\ (T - 32^\circ) - \int_{32^\circ}^{T} c\,dT \quad . \quad . \quad . \quad . \qquad (11)$$

"In computing the value of the integral in this formula, use has been made of an empirical formula founded on M. Regnault's experiments on the specific heat of water, as to which see the 'Transactions' of the Society for 1851, viz. :—

$$\int_{T}^{T} c\,dT = T - T' + 0{\cdot}000000103 \left\{ (T - 39^\circ{\cdot}1)_3 - (T' - 39^\circ 1)_3 \right\} \quad . \qquad (11a)$$

"III. The absolute temperature is given by the formula,

$$\tau = T + 461^\circ{\cdot}2 \text{ Fah.} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (12)$$

"IV. The value of $\tau \dfrac{dP}{d\tau}$ is deduced from the following formula, first published in the 'Edinburgh Philosophical Journal' for July, 1849 :—

$$\text{com. log. } P = A - \frac{B}{\tau} - \frac{C}{\tau^2}; \quad . \quad . \quad . \quad . \quad (13)$$

from which it follows that—

$$\tau \frac{dP}{d\tau} = 2{\cdot}3026 \ P \left(\frac{B}{\tau} + \frac{2C}{\tau^2}\right); \quad . \quad . \quad . \quad (14)$$

the values of the constants for steam being—

A, for pounds of pressure on the square foot, . . 8·2591;
log. B for Fahrenheit's scale, ... = 3·43642;
log. C ,, ,, ... = 5·59873.

"V. The volume of a cubic foot of liquid water at the temperature T may be computed with sufficient accuracy for the present purpose by the following formula :—

$$v \text{ nearly} = 0{\cdot}00801 \left(\frac{\tau}{500} + \frac{500}{\tau}\right). \quad . \quad . \quad (15)$$

"VI. These preliminary calculations having been made, the formula 9 can now be applied to the calculation of the volume of 1 lb. of steam (making $J = 772$); and by this process the tables already mentioned were computed.

COMPARISON OF THE RESULTS OF THEORY WITH THOSE OF MESSRS. FAIRBAIRN AND TATE'S EXPERIMENTS.

"12. The experiments of Messrs. Fairbairn and Tate on the density of steam are described in a paper which was read to the Royal Society of London, as the Bakerian lecture, on the 10th of May, 1860, and published in the 'Philosophical Transactions' for that year. The results of those experiments give what is called the 'relative volume' of steam: that is, the ratio which its volume bears to that of an equal weight of water at the temperature of greatest density, 39°·1 Fah.: but in the following table of comparison each of those relative volumes is divided by 62·425, the weight of a cubic foot of water at 39°·1 in lb., so as to give the volume of 1 lb. of steam in cubic feet. The numbers of the experiments are the same as in the original paper; those made at temperatures below 212° being numbered from 1 to 9, and those made at temperatures above 212° from 1′ to 14′.

Comparison of the Theory, with the Experiments of Messrs. Fairbairn and Tate.

Number of experiment.	Temperature Fahrenheit.	Volume of 1 lb. of steam in cubic feet.		Difference.	Difference ÷ exper. vol.
		By theory.	By exper.		
1.	° 136·77	132·20	132·60	— 0·40	$-\frac{1}{330}$
2.	155·33	85·10	85·44	— 0·34	$-\frac{1}{250}$
3.	159·36	77·64	78·86	— 1·22	$-\frac{1}{65}$
4.	170·92	60·16	59·62	+ 0·54	$+\frac{1}{110}$
5.	171·48	59·43	59·51	— 0·08	$-\frac{1}{744}$
6.	174·92	55·18	55·07	+ 0·11	$+\frac{1}{501}$
7.	182·30	47·28	48·87	— 1·59	$-\frac{1}{30}$
8.	188·30	41·81	42·03	— 0·22	$-\frac{1}{191}$
9.	198·78	33·94	34·43	— 0·49	$-\frac{1}{70}$
1′.	242·90	15·61	15·11	+ 0·50	$+\frac{1}{30}$
2′.	244·82	14·77	14·55	+ 0·22	$+\frac{1}{66}$
3′.	245·22	14·67	14·30	+ 0·37	$+\frac{1}{39}$
4′.	255·50	12·39	12·17	+ 0·22	$+\frac{1}{55}$
5′.	263·14	10·96	10·40	+ 0·56	$+\frac{1}{19}$
6′.	267·21	10·29	10·18	+ 0·11	$+\frac{1}{93}$
7′.	269·20	9·977	9·703	+ 0·274	$+\frac{1}{35}$
8′.	274·76	9·158	9·361	— 0·203	$-\frac{1}{47}$
9′.	273·30	9·367	8·702	+ 0·665	$+\frac{1}{13}$
10′.	279·42	8·539	8·249	+ 0·290	$+\frac{1}{28}$
11′.	282·58	8·145	7·964	+ 0·181	$+\frac{1}{44}$
12′.	287·25	7·603	7·340	+ 0·263	$+\frac{1}{28}$
13′.	292·53	7·041	6·938	+ 0·103	$+\frac{1}{66}$
14′.	288·25	7·494	7·201	+ 0·293	$+\frac{1}{24}$

REMARKS ON THE DIFFERENCES BETWEEN THE THEORETICAL AND EXPERIMENTAL RESULTS.

"13. The differences between the theory and the experiments as to the volumes of steam at temperatures below 212°, are, with few exceptions, of very small relative amount; and they are at the same time so irregular as to show that they must have mainly arisen from causes foreign to the data used in the theoretical computations.

"14. Above 212°, also, the differences show irregularity, especially in the case of experiments 8′ and 9′, where a fall of temperature is accompanied by a diminution instead of an increase in the volume of one pound of saturated steam, as determined by experiment. But still those differences, presenting as they do in every case but one an excess of the theoretical above the experimental volume, show that some permanent cause of discrepancy must have been at work, although they may not be regular enough to determine its nature and amount, nor large enough to constitute errors of importance in practical calculations relating to steam engines.

"15. So far as it is possible to represent those differences by anything like a formula, they agree in a rough way with a constant excess of about 0·27 of a cubic foot in the theoretical volume of one pound of steam above the experimental volume; and this also represents in a rough way the difference between the curves, whose ordinates express respectively the results of the theoretical formula and those of an empirical formula deduced from the experiments, so far as those curves, as shown in a plate annexed to the paper referred to, extend through the limits of actual experiment on steam, above 212°.

"16. As the principles of the mechanical theory of heat may now be considered to be established beyond question, it is only in the data of the formula that we can look for causes of error in the theoretical calculation. I shall now consider those data, with reference to the probability of their containing numerical errors.

"I. *Total Heat of Evaporation.*—It is very improbable that this quantity, as computed by M. Regnault's formula, involves any material error.

"II. *Sensible Heat of the Liquid Water.*—The empirical formula from which this quantity is computed was determined from experiments by M. Regnault, which agree extremely well amongst themselves. (For the investigation of the formula see 'Trans. Royal Soc. Edin.' vol. xx., p. 441.) The subtraction of the sensible heat from the total heat leaves the latent heat, upon which the increase of volume depends; hence, to account for an error in excess of the formula for the volume by means of an error in the computation of the sensible heat, it must be supposed that the specific heat of liquid water above 212° increases much more rapidly than M. Regnault's experiments show, so as to produce a correspondingly more rapid diminution in the latent heat of evaporation. It is easily computed, for example, than to account for an error in excess of 0·27 of a cubic foot in the volume of one pound of steam at 266°, by an error in defect in the sensible heat, we must suppose that error to amount to about 24 British thermal units per pound of water; but such an error is altogether improbable.

"III. *Absolute Temperature.*—The position of the absolute zero may be considered as established with a degree of accuracy which leaves no room for any error sufficient to account for the differences now in question.

"IV. *Function* $\frac{dP}{d\tau}$.—The same may unquestionably be said of this function, which represents the mechanical equivalent of the latent heat of evaporation of so much water as fills 1 cubic foot more in the vaporous than in the liquid state.

"V. The volume of one pound of the liquid water is itself too small to affect the question.

"VI. The received value of the mechanical equivalent of a unit of heat cannot err by so much as $\frac{1}{300}$th part of its amount.

CONCLUSIONS.

"17. It appears, then, that none of the data from which the theoretical calculations are made are liable to errors of a magnitude sufficient to account for the differences between the results of those calculations and the results of Messrs. Fairbairn & Tate's experiments, small as those differences are in a practical point of view. Neither does there appear to have been any cause of error in the mode of making the experiments. There remains only to account for those differences the supposition that there was some small difference of molecular condition in the steam, whose density was measured in the experiments of Messrs. Fairbairn & Tate, above 212°, and the steam, whose total heat of evaporation, as measured by M. Regnault, is the most important of the data of the theoretical formula, a difference of such a nature as to make a given weight of steam in Messrs. Fairbairn & Tate's experiments occupy somewhat less space, and therefore require somewhat less heat for its production than the same weight of steam in M. Regnault's experiments at the same temperature. That difference in molecular condition, of what nature soever it may have been, was in all probability connected with the fact, that in the experiments of Messrs. Fairbairn & Tate the steam was at rest, whereas, in those of M. Regnault, it was in rapid motion from the boiler towards the condenser. It is obvious, however, that in order to arrive at a definite conclusion on this subject, further experimental researches are required.

99. The following article on *Superheated Steam* is taken from the *Mechanics' Magazine:*—"It is not very easy to say when the employment of steam, heated above the temperature due to its pressure, was first proposed as a means of economizing fuel. Like many other inventions or discoveries, it is claimed by several individuals, who certainly did not all hit on the idea simultaneously. The weight of evidence goes to show that superheated steam can trace its origin to America, where, some fifteen or twenty years ago, a Mr. Frost conducted some experiments on steam heated apart from water. These gave such remarkable results, that the attention of the Institute of Arts and Sciences at New York was called to the subject, which received further development at their hands. Subsequently, Dr. Haycraft, of Greenwich, made a number of experiments on what he termed 'anhydros steam.' He tried his plans on an engine with a 9-inch cylinder and 3 feet stroke with very considerable success. His apparatus burned out, however, from its faulty construction, and he appears to have abandoned further trials in disgust. Whatever the claims of rival inventors may be, it is certain that superheated steam was not brought prominently before the engineering world until 1856. In 1857, Mr. Penn's apparatus was fitted on board the 'Valetta,' with the immediate result of a saving of 20 per cent. in the consumption of fuel. Since then superheated steam has steadily advanced in public favour; indeed, it is far from improbable that ere many years elapse, the employment of the principle will become all but universal in our steam ships.

"That a certain amount of economy must follow from the employment of superheated steam, is as plainly demonstrable as a mathematical proposition. What the *exact* amount may be depends altogether on the construction of the engine and boiler, and the degree of expansion at which the engine is worked. It is almost needless to say that it can never arrive at the pitch which the first promoters of its application imagined. Frost and Haycraft considered it quite possible to expand steam sevenfold without raising its temperature much over 350°. That which is so obviously opposed to theory can never be correct in practice; the utmost saving of fuel which has yet been attained being 30 per cent., and this, be it remembered, only in cases where the boilers have been very defective, and failed to supply dry steam to the engines previously to the application of the superheater.

"Steam not in contact with water, if quite dry, may be considered to expand in pretty nearly the same ratio, for successive increments of heat, as any of the fixed gases, or at the rate of 1-480th of its volume for each degree of Farenheit's thermometer. Thus, by heating it to 480° above its own temperature, it would be doubled in volume, or, if confined, in pressure; but, it must be remembered, only at a loss of sufficient heat to convert a body of water into as much steam as would be capable of performing more work than that due to the increase in the volume, or pressure, of the steam superheated. The true sources of economy are not to be found in any such expansion—although that is, of course, useful as far as it goes—but in the power superheating gives us of maintaining the temperature of the cylinder, valve chest, &c., at a very high point, and thus counteracting the cooling effects due to expansion, and also because all the free moisture or spray, which is suspended in a state of almost infinite subdivision in the steam, is vaporized in passing through the pipes of the superheater, and thus rendered available for the subsequent production of power in the cylinder. Thus, the best boilers show least gain from the employment of the principle when the engines do not work expansively, because they produce what is usually termed dry steam. Boilers of defective design, on the contrary, very frequently prime continuously; not sufficiently, it is true, to interfere with the working, or endanger the stability of the engines, but still quite enough to be wasteful. Superheating invariably gives excellent results in such cases, both directly, in the saving of coal, and indirectly, by preventing the injurious action which dirty water always exerts on valve faces and pistons. The advantage to be derived in this way, however, is as nothing when compared with the facilities which superheated steam affords for carrying expansion to its maximum.

"If we suppose steam of 60 lbs. pressure admitted to a cylinder for one-sixth of the stroke, we shall find, that whereas its temperature on entrance was about 295° Fah., yet, on the completion of the stroke, it will, if the stroke is a long one, have fallen more than 70° in consequence of its expansion. Be the cylinder ever so well protected outside, it being composed of comparatively thin metal, soon becomes cooled down to the temperature of the steam in contact with it. Thus, on the commencement of the next stroke, the steam, on entering, is at once chilled and condensed by contact with a metal surface nearly—from one source or another—100° cooler than itself. The result is that expansion, under such circumstances, is a source of waste instead of economy, because, had the steam been kept to full pressure nearly through the stroke, the cylinder would never have had time to cool sufficiently to do much harm. The fact of this loss of heat taking place in expanding, unless special provision is made to prevent it, is beautifully illustrated in Cornish engines without jackets, the pistons of which, though perfectly tight when near the bottom of the cylinder, are frequently found to blow through at the commencement of the down stroke, from the fact that the upper part of the cylinder is permanently larger in diameter, owing to its higher temperature, than it is near the bottom, where only cooler steam reaches it.

"'Lagging' a cylinder is only a negative remedy; a means of prevention, not of cure. Cylinders waste heat inside as well as out, by radiation into the condenser, and the reduction of temperature due to expansion. Felt and boards cannot possibly restore this; and unless special means are provided for doing so, it is simply hopeless to expect economy. Fortunately we are not confined to one arrangement. Four different systems of 'cylinder heating,' as we may term it, are more or less employed. These are: the use of a jacket, supplied with saturated or common steam; or with heated air; or with superheated steam; or the use of superheated steam, to work the engine; and of all the plans yet adopted, this seems to be almost beyond comparison the best. Not only does it provide a supply of pure gaseous steam, free from moisture, but it heats perforce every particle of metal with which it comes in contact, so that not the cylinder alone, but the lids and piston are raised directly to the same temperature. The surface presented by a large piston is very considerable, and it is, of course, beyond the power of any jacket to provide for the condensation which it may occasion if not kept up to the full initial heat of the steam in contact with it. But the principal advantage possessed by superheated steam is the beautiful simplicity of all the arrangements connected with it. As now constructed, the necessary apparatus can be provided for about £2 per horse-power nominal. Experience proves that tubes last well, that leakages are rare, and that the expenses for repairs are small. When employed, as—like almost everything else—it should be in moderation, no danger exists of injury to valve faces or cylinders. A temperature of 300° to 360° seems most suitable; and a heat such as this certainly cannot injure the most delicate surface met with in a valve or a piston. By its use, simple lagging may act as a very efficient substitute for the costly and heavy jacket. A little more time, and the experience which follows, as a matter of course, will, we believe, place the superheater in a position which will entitle it to be considered indispensable to every steam engine which pretends to even a moderate amount of economy."

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