CHEMICAL TECHNOLOGY;

OR,

CHEMISTRY,

APPLIED TO THE ARTS AND TO MANUFACTURES.

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FIRST AMERICAN EDITION, WITH NOTES AND ADDITIONS,

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OF PHILADELPHIA.

VOL. I.

ILLUSTRATED WITH
TWO HUNDRED AND FOURTEEN ENGRAVINGS ON WOOD.

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PREFACE BY THE ENGLISH TRANSLATORS AND EDITORS.

Among the many advantages which Dr. Knapp's "Chemical Technology" presents, not the least will be found in the novelty of the arrangement of his materials in the form of groups of monographs upon particular branches of chemical industry. A connected view of allied chemical arts is, therefore, presented to the Reader, while the experience of one branch is brought more immediately to bear upon the whole, for the benefit of any one individual manufacture.

A knowledge of the nature and effective value of fuel in the production of heat is a matter of primary importance to every manufacturer, and a work devoted to the Chemical Arts, necessarily commences with a chapter upon that subject. The preparation of wood charcoal, which is described at some length in the first group of the present volume, will be chiefly valued abroad, and in those countries where mineral coal is not accessible; but the production of coke is a branch of industry daily increasing in importance from the extensive application which is made of it for the generation of steam and for smelting purposes; and as the quality of coke is mainly dependent upon the process of manufacture, and this process has been very much altered and improved within the last few years, we have described in the Appendix, with some minuteness, the most approved methods of coking now in use. A description of the apparatus and materials used in the manufacture of the new patent fuel has also been here introduced, as this substance promises to become a valuable substitute for coal in many of its applications.

In connection with the consumption of fuel and the generation of heat, we have also thought it right to notice some of the more recent plans for economizing the heat produced by the combustion of coal in open fire-places, and we should feel gratified if the few remarks upon the ventilation and heating of buildings, both public and private, upon which we have ventured, should be the means of inducing architects and builders to bestow more consideration upon these points, so conducive to health and comfort, in the construction of dwellings, than they are usually in the habit of doing. The limits of the present volume would only admit of a short description of two out of the many methods proposed for securing the more perfect consumption of smoke, and consequent saving of fuel in boiler and furnace fires.

The chemical process concerned in the production of heat is identical with that practised for obtaining artificial light; the mode of conducting the process, however, is different, and this claims naturally the second place in our author's arrangement of materials. Here, again, the improvements in the manufacture of the different substances used for illumination, and more particularly those which have reference to coal gas, its purification, measurement, mode of consumption, the introduction of substances for giving light, which could not previously be used, &c., have obliged us to append much to the original matter in Dr. Knapp's volume.

The second group comprises the production of the alkalies and earths, the agents concerned in their manufacture, and their various applications in the arts. This group is not completed in the present volume.

The wasteful nature of some of our manufacturing operations will readily be inferred from the matter inserted upon sulphur and sulphuric acid, and this applies no less to the coal employed in smelting. It is estimated that the sulphur wasted at Swansea, to the absolute destruction of all surrounding vegetation, would suffice for the manufacture of all the alkali produced in the kingdom, and this fact, coupled with the loss of 3,000,000 tons of coal in the smelting of iron alone, prove sufficiently that our practice is still sadly deficient. Wherever the fault may lie, it must be attributed in no small degree to ignorance; and this, again, doubtless arises from the difficulty attending the acquisition of sound scientific knowledge in this country.

We have no *Gewerbe Schule*, no *Ecole des Mines*, no *Ecole Polytechnique*, and it is no reply to assert that without such institutions, this nation has maintained its position. We have had the race entirely to ourselves to within a very recent date, and if the means of acquiring scientific information were as easy with us, as is the case amongst our competitors in the application of chemical facts abroad, we should in all probability no longer have to complain of Glasgow goods being dyed at Barmen, of the importation of nearly all the ultra-marine used here, and other similar indications of our inefficient knowledge or manipulation.

The little progress which has been made for a long series of years in the soap manufacture, (a description of which closes the present volume,) is one instance only, amongst many others, which all bear witness to the injurious tendency of government restrictions upon manufacturing industry. The individuals who are themselves exposed to the scrutinizing *surveillance* of the exciseman, can alone feel and properly appreciate the annoyance of official interference, and the limitation which it imposes upon their exertions, but the interests of the whole country are sacrificed when the excise laws interfere with the improvements of processes, and put a bar, as they do in so many cases, to the development or progress of our manufactures.

Our translation of Dr. Knapp's work is a humble effort to afford the most recent information, with a descriptive account of the latest improvements, to those interested in the progress of our chemical manufactures. References have been made in the text to the matter in the Appendix.

The ease with which all calculations where temperature is concerned, may at once be understood by the use of the centigrade thermometer, has induced us to retain that thermometric scale throughout; but wherever the temperature referred to has some immediate practical bearing, we have inserted the corresponding degree upon the scale of Fahrenheit, as the one most generally in use in this country.

We have also subjoined a comparative scale of German, French and English Weights and Measures, as it was not considered expedient to alter the Hessian measures adverted to by our Author.

We cannot conclude these prefatory remarks without expressing our great obligations to the Publisher, who has spared no expense in illustrating the text by the introduction of very numerous wood-cuts, thus obviating the necessity for lengthened description, and essentially augmenting the value and usefulness of the work.

London, *December*, 1847.

PREFACE BY THE AMERICAN EDITOR.

In offering to the American public an edition of Dr. Knapp's work on Technology, it is, perhaps, hardly necessary to advert to the useful, and therefore important, bearing of its subject on the welfare of every class, and every member of society. Whatever may be their theoretical differences of opinion as to the relative value of the *useful* and the *ornamental* arts, men commonly agree, at least in this, that each for his individual self finds no serious objection to any art which ministers directly to his personal comfort and well being, how much soever its discoverer or inventor may have been decried as a "*utilitarian.*"

If, in any part of the world, the arts which contribute to the general welfare be held in esteem, it is certainly, in a pre-eminent degree, desirable that they should be cultivated and well understood in a country where "the greatest good of the greatest number" is the predominant maxim of all social and civil institutions.

The reader will remark that extensive American additions have been made to the first section of the work,—the new matter being generally distinguished by brackets, unless inserted in the form of notes appropriately distinguished. The experiments of Mr. Marcus Bull on woods, those of the editor, of Dr. S. L. Dana, and others, on coals, are, in a condensed form, presented in this part of the work.

The heating of dwellings and other buildings has also claimed some additions.

The American experiments on coal-gas, rosin-gas, sperm oil, lard-oil, crude lard, "pine-oil," "chemical oil" and camphine, afford a series of useful comparisons, especially interesting to the American reader, since the materials from which light is, in these cases, procured, are among the abundant products of our own soil and industry.

The volume closes with an addition to the appendix, showing what experience has proved in regard to the absolute cost of manufacturing illuminating gas on a large scale, and what are the points of economy yet to be studied in relation to this important subject.

The facts there exhibited, derived from authentic published documents, prove the wisdom and expediency of providing that so pressing a necessity as that for abundant and cheap light, should, like the supply of pure water, uncontaminated air, and the means of extinguishing conflagrations, be regarded as a *public* interest by every populous town and city. It is believed that the facts herein set forth may be found conducive to so desirable an end.

It has sometimes been attempted to surround the subject of gas-making with a certain air of mystery, as if some profound secret were involved in the preparation of "so subtile a compound" as coal gas. Yet the facts and statements exhibited in the present work will make it clear that a faithful adherence to a few simple principles will enable persons of moderate scientific attainments to comprehend the subject without any very rare gifts, or any costly researches.

A table of contents and a complete list of the illustrations arranged under distinct heads, have been prepared, and will be found greatly to facilitate reference to the subjects contained in this volume.

The copious supply and excellent character of illustrations in the work, of which this is a republication, have called for few additions in this particular. The reader will, it is believed, find that, in the mechanical execution of this volume, our artisans have fully sustained the character gained by their previous efforts in this series of illustrated scientific works.

PHILADELPHIA, *May*, 1848.

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English (and Russian) foot.	French metre.	Paris foot.	Prussian, Danish, and Rhenish foot.
1	.3047945	.9382928	.9711361
3.280899	1	3.078444	3.186199
1.065765	.3248394	1	1.035003
1.029722	.3138535	0.9661806	1

II. Square measure.

Square foot.	Sq. metre.	Square foot.	Square foot.
1	.09289969	0.8803934	0.9431053
10.76430	1	9.476817	10.15187
1.135856	.1055207	1	1.071232
1.060327	.09850405	0.9335049	1

III. Cubic measure.

Cubic foot.	Cubic metre.	Cubic foot.	Cubic foot.
1	.02831531	0.8260668	.9158836
35.31658	1	29.17385	32.34587
1.210556	.03427727	1	1.108728
1.091842	0.9019342	.03091584	1

IV. Measures of capacity.

English gallon, =277.27384 cubic inches	French litre, =.001 cubic metre.	Prussian quart, =64 cubic inches.
1	4.543458	3.967977
.2200967	1	0.8733386
.2520176	1.145031	1
Bushel, = 8 gallons.	**Hectolitre, =100 litres.**	**Scheffel, =3072 cubic inches.**
1	0.3634767	.6613296
2.751208	1	1.819455
1.512105	0.5496150	1

V. Weights.

English pound, avoirdupois.	French.		Prussian, Hanoverian, Brunswick, and Hessian pound.
	Kilogram.	Livre, poids de marc.	
1	.4535976	.9266439	.9698245
2.204597	1	2.042879	2.138072
1.079163	.4895058	1	1.046599
1.031114	.4677110	.9554758	1
Hundred weight. = 112 lbs. avd.	**Quintal métrique. = 100 kilo.**	**Quintal, =100 livres (old measure).**	**Centner, = 110 lbs.**
1	0.5080293	1.037841	0.9874577
1.968390	1	2.042877	1.943702
0.9635386	0.4095058	1	0.9514536
1.012702	0.5144821	1.051023	1

The United States standard gallon has a capacity of 231 cubic inches, and contains 8.3388822 avoirdupois pounds, or 58372.1754 Troy grains of distilled water at 39°.83 Fah., the barometer being at 30 inches. The U. S. standard bushel contains 2150.42 cubic inches, and 77.627413 pounds avoirdupois of distilled water at 39°.83 Fah.—Am. Ed.

TECHNOLOGY;

OR,

CHEMISTRY APPLIED TO THE ARTS

MANUFACTURES.

INTRODUCTION.

THE term "Technology," first employed by Beckmann (1772) to denote that branch of knowledge which forms the subject of this work, comprises in its literal signification the systematic definition (λογος) of the rational principles upon which all processes employed in the arts (τεχνης) are based. We include, therefore, under this head, every occupation which furnishes us with those products that are rendered necessary by our physical wants, either immediately in accordance with the laws of nature, or which have grown out of the social conditions under which we live.

Although nature, in her great abundance, presents us with everything that is requisite for the supply of our wants, from the humble demand which the simple life of the Indian hunter makes upon her, to the refined and complicated wants of the civilized inhabitant of Europe; yet it has seemed fit to a higher intelligence inseparably to connect the possession of the treasures which are offered to us, with an immense amount of labour and application in their acquirement. Few things are found in the state in which we can make use of them; hence it becomes the real object of manufacture, so to *transform the raw materials of nature*, that they may be adapted to the wants of society.

The material part of nature, in whatever form it may appear, is subjected, in its entire essence, and in all the changes which it undergoes, to eternal, immutable laws, which man adapts and conforms, with more or less success, to his purposes, but which he is utterly incapable of subverting or altering in the slightest degree. Every transformation of matter, which is effected by art or manufacture, is therefore strictly confined within the limits of these laws of nature; all the phenomena that occur in the material world are entirely dependent upon them; and the study of these phenomena, or the study of nature, has for its object the investigation of these laws.

The practical investigation of the laws of nature led at an early period to a division of the subject into two parts: the one, Physics, or Natural Philosophy, which has reference to the more outward phenomena attending a change of form (Mechanics in particular); and the other, Chemistry, which relates to the inward nature of the changes that are observed.

The principles upon which the processes of manufacture depend, are therefore precisely those which form the subject of chemical and physical investigation; and the distinction which we have drawn above, with reference to the phenomena and laws of nature, applies with equal force to manufacture, and obliges us to separate *mechanical*, which alters the form of the raw material (fibre into cloth, iron into sheet-iron, &c.), from *chemical* manufacture, which entirely changes its nature (sand, potash and lime into glass, common salt into soda, hides into leather, &c.)

Classification.—The vast amount of matter which must necessarily be included in a scientific work upon manufactures, is generally arranged under the heads of *chemical* and *mechanical* manufacture. A separation of this kind is, however, strictly speaking, impossible, and by no means in accordance with the nature of the subject. There hardly exists any branch of manufacture which is exclusively chemical, or which is based solely upon mechanical principles; the practical man chooses that mode of transforming the crude material which is most subservient to the object in view, without consulting science, upon which depend the principles he adopts. Nevertheless, the distinction which we have drawn, when carried out with caution, will assist both the learner and the teacher, for by its means those facts and phenomena are brought together which depend upon the same principles, and are separated from others which require more extended acquirements in order to be fully understood. A strict separation of the mechanical from the chemical part of the subject would only tend to give a partial and erroneous view, and lead to a confused perception of the whole; it is, therefore, customary to call those branches of manufacture *mechanical*, which are chiefly dependent upon mechanical principles; and by *chemical* manufactures we understand those in which chemical processes form the leading feature.

In the various scientific treatises which have appeared upon manufactures, the different authors have not followed the same method of arrangement. Those who have written with a view to popular instruction, and whose object it has been to present merely a true account of successive and particular operations, without entering into the causes of the effects produced, have simply described the processes as they are practised; this we call *empirical* technology. Those, however, who wish to gain an insight into the leading scientific phenomena and laws which are the key to the whole art, as well as to be made acquainted with the practical manipulation, who require an explanation of the facts as well as the facts themselves, can only have their wish gratified by the *rational* mode of arrangement. Lastly, the subject may be treated in such a manner, that all like or similar processes, modes of manipulation, or instruments, are classed together, without reference to the particular branch of manufacture in which they are employed, *e. g.*, founding, rolling, modes of separation, alloying of metals, &c.; this would be *general* or comparative technology; or the transformation of the raw material may be described as it actually takes place, following the natural order of the processes as they succeed one another, *e. g.*, the art of brewing, the iron-manufacture; this is designated special technology, or technology proper.

The subject of the present work is chemical technology, in the sense which I have defined above; the *rational* method will be followed in conjunction with the arrangement which I have distinguished as *special;* it, therefore, comprises a description of the processes and an explanation of the scientific principles, upon which those arts and manufactures are based that are chiefly of a chemical nature. The want of intimate connection between the several branches which excludes technology from the cycle of the purer sciences, leaves the arrangement of the matter, whatever plan may be adopted in general, very much at the option of the author. Technology proper is divided by some into sections, corresponding with the various arts that are of common occurrence, (distilling, tanning, preparation of iron.) Others make the nature of the crude material a means of classification, (working of iron ores, products from corn, from hides;) others again classify according to the nature of the products, (*e. g.*, preparation of leather, of brandy, manufacture of cast-iron, &c.) In this work the latter mode will generally be adopted, but not upon all occasions. The individual branches of manufacture, when not too insignificant to merit attention, are collected together into groups; the members of each group are connected either by a process common to all, (as combustion, fermentation,) or are dependent the one upon the other, in the several processes of manufacture.

Rise and Progress of the Arts and of Technology.—A scientific treatise upon manufactures presupposes a gradual development of the subject through a long series of years. Amongst the ancients, prior to the Christian era, when virtue and valor were not distinguished from each other, individual bravery was held in the very highest estimation, and any occupation connected with manufacture was considered a dishonorable retreat from the pursuit of arms, and only fit to be followed by menials. Tradition, however, affords some remarkable exceptions, as in the case of heroes following the plough; and Homer sings of the queen at her loom, and of kings' daughters engaged in domestic cares. The nobles and clergy of the middle ages—the former engaged in the art of war, and the latter caring for the interests of the faith—looked with like disdain upon the arts and upon husbandry, and left both to the care of serfs. Manufactures, springing up with difficulty upon the soil of feudal dependency, at last took refuge and found more propitious ground amongst the freemen, who, combined in common defence against the oppression of the nobles and of the time, surrounded and protected themselves by the walls of their towns. The increasing power of the cities, aided by their common alliance, (Hanseatic league,) went hand in hand with the progress of the arts, which, indeed, became the very essence of their power, and was promoted alike by external security, as well as by internal freedom and equality amongst individuals. It was in the towns that the manufacturing class was first acknowledged by history; and obtained that rank amongst the other classes of the community which the consciousness of its own power and weight had so deservedly gained for it, a position which the more liberal opinions of the present day, common alike to all civilized nations, can never refuse it. As soon as prosperity increased the influence of the traders and manufacturers, they endeavored to protect themselves from becoming over numerous and from too great competition, with which they were threatened by the pressure of the times, the want of communication, and the insufficient amount of exchange and export trade. These objects, as well as the desire to introduce more order and regularity into their internal concerns, gave rise to the guilds, or corporate societies, institutions, which at the present time—not from any fault in themselves, but from the reform which society has undergone, having survived the outward necessity which gave rise to them—have lost their importance, and are gradually sinking into decay. Notwithstanding the beneficial influence of these institutions in giving a sound foundation for the acquirement and exercise of the individual trades, in distributing wealth more equably, and in imprinting a high moral respectability upon the whole trading community; yet the closeness of the corporations and their disputes concerning the boundaries of the different departments, their abuses of ceremony, their misuse and total neglect of industrial power, were serious obstacles to all progress. The appearance of the fifteenth century with its important inventions, created an era in political and social institutions. The mariner's compass, the discovery of the maritime route to the East Indies and to the American continent, emancipated navigation and commerce, whilst the introduction of fire-arms completely reformed the whole system of warfare. The relationship existing between the nobles, the towns, and the country was undermined. The great advances which have been made in later centuries and in our own, are, however, by no means alone due to political reform. *The compass was yet wanting that should be a guide through the wide fields of knowledge, and establish an interchange of ideas.* Up to this date—and indeed we here find the true characteristic of *former times*—the spirit of invention had no other allies than matured experience and practical method, which can boast, unquestionably, of having accomplished great and remarkable things, but for which purpose many hundred years were required. All the knowledge that distinguished individuals acquired, was only known to the few, and as there was no way of communicating ideas, the great mass received no benefit or advantage from it. At length the art of printing was invented, and with its aid knowledge was circulated, expanding and fructifying, in every direction. The dawning consciousness of knowledge raised the veil which had obscured the mysterious workings of nature, and the spirit of inquiry entered upon this new field with the most signal success.

But before this offspring of peace could obtain a firm footing, the more important interests connected with religious opinion, contending both with the pen and the sword, forced those of the arts and manufactures completely into the back ground. The thirty years' war annihilated crops and harvest for a considerable time, until recurring peace relaid the foundations for the establishment of manufactures—again to be undermined in the course of time. The consciousness of political power gradually becoming stronger, gave rise to differences of opinion, and parties were formed, whose dissensions could only be settled by the force of arms, which being resorted to, proved destructive to all other interests. The revolution, as a silent but not the less impressive reform, which continues to exert an influence even at the present day, rejected without mercy whatever traditions of antiquity would not adapt themselves to the spirit of the times. The soil which modern industry found propitious to the spread of its firm and powerful roots, was prepared for it by the equality established amongst burghers, and their rights of representation, by the freedom of trade, the remodelling of the system of taxation, and other equally salutary institutions. After severe struggles, science was at length fostered by a long peace, and with it the arts and manufactures; for it is peculiarly the characteristic of *our times*, that science is brought practically to bear upon the useful arts in all their great variety, and that the progress of the one necessarily creates fresh activity in the other.

Objects of Technology.—As a consequence of its historical development, the nature of manufacturing industry has very much altered its former position, and assumed one of a higher character. As the source of public prosperity, it has become the surest and broadest foundation for national power, and as such, its culture and safety must be the primary care of every wise government. The power and affluence of a country depend not only upon its natural advantages, but chiefly upon the degree of skill and ingenuity with which the industrious classes make use of those advantages. This is the most palpable aim of manufacturing industry, but it is not the highest, nor is it the one most peculiarly its own. The mere improvement of the temporal condition of single individuals, or of the whole community, would, notwithstanding its great importance, be a secondary object, if its real tendency were not to free mankind from the burdens attendant upon existence and from the cares of life—to ennoble, indeed, his moral and intellectual nature. It is science, and above all, the science of nature, which is destined to be, in this sense, the surest guide in all practical undertakings; the union of theory with practice has already performed wonders, and indeed the great novelty and true greatness of modern industry consist in the beginning which it has made towards the removal from our race of the ancient curse of working by the sweat of our brows, and in having subjected the powers of nature to the yoke, and compelled them to become our willing and potent helpers. Man has been released from those laborious occupations which are now effected by water, steam, wind, and machinery, that he may apply his powers to more noble aims.

As the demands made by our physical wants are peremptory, it becomes the highest problem for manufacturing industry, to produce a supply, at as little cost of labor or power as possible. To do this, however, the archives of science must be consulted, and it must constantly be borne in mind that our endeavors are most likely to be crowned with success, when they tend to elucidate and explain the laws of science with a view to enrich the arts with more definite and productive principles of action.

GROUP 1.

BRANCHES OF MANUFACTURE DEPENDING UPON THE PROCESS OF COMBUSTION.

When the chemical combination of two bodies takes place with the evolution of light and heat, (as with antimony and chlorine, copper and the vapor of sulphur, &c.,) the process is called *combustion*. The most common case, and that which has been made use of from the most ancient times as a source of light and heat, is that in which bodies, naturally predisposed, are subjected to the energetic action of atmospheric oxygen, which is present at every part of the surface of the globe. For practical purposes, the process in question may be considered under two points of view. Combustion is effected either for the production of *heat*, or as a source of *light* for purposes of *illumination*. The nature of the chemical process and of the bodies employed, as well as in most cases the practical arrangements, render it impossible to attain both ends with advantage at the same time; hence the production of heat and light, although pertaining to the same group, form distinct branches of manufacturing industry.

I.—OF FUEL AND THE PRODUCTION OF HEAT.

Of Fuel.—Nearly all operations carried on in the arts require the application of artificial heat, and hence the means of obtaining this, becomes the very first consideration in every manufacture, and consequently of the highest importance to the external prosperity of the nation. It is a fact, *e. g.* that the political power of Great Britain is due to the greater development of her manufactures, and that this is entirely dependent upon the abundant supply of those means of producing heat with which she is gifted above the other nations of Europe. The peculiar substance of plants (and more particularly of trees) is under all circumstances, whether found upon or under the surface of the earth, peculiarly adapted to supply these means from the ease with which it undergoes combustion, and from its extensive distribution as well as constant reproduction. This substance itself, as well as those products resulting from its partial decomposition, inasmuch as they are used for the production of heat, are collectively called *fuel*. Under this term we include, *wood*, *turf*, *brown-coal*, *common coal*, and *anthracite*, which occur as such in nature; also *charcoal*, both from wood and turf, and *coke*, which are artificially produced.

Of Wood.—The trunk, the roots, and the larger branches of trees are all called *wood*. Wood is composed of three different substances:

firstly, *woody fibre*, a combination of carbon, hydrogen, and oxygen, which, constituting the cells and vessels of the plant, makes up the chief part of its bulk; secondly, the *constituents of the sap* contained in the vessels; and lastly, *water*. Recently felled wood necessarily contains all three constituents. The two first only are supporters of combustion, and produce heat; the water, on the contrary, whilst the wood is burning, takes up a portion of the heat produced, to convert it into vapor. As woody fibre and water are common to all kinds of wood, the difference which has been shown to exist between different woods must entirely depend upon the constituents of their sap, and upon their structure (density). Notwithstanding the great difference, chemically speaking, in the constituents of the sap, (the coniferous woods containing resinous matter; the beach and birch extractive; and the oak tannin), yet the accurate analysis of dried woods has shown them to contain the three constituents nearly in the same proportions as pure woody fibre, *i. e.*, the constituents of the sap form a very small proportion of the whole bulk of the wood, and yet their action becomes very perceptible when the wood is applied to practical purposes. The amount of water in wood has more influence, and is of much more importance. This is generally greatest at the time of the flow of the sap, and least, when the growth of vegetation is less rapid; for which reason, wood should always be felled at the latter period, unless other more potent reasons prevent it. Amongst these may be mentioned,—the important secondary uses for which it is cultivated, as for the tannin in the bark, or the district upon which it stands may be a moor or mountainous, and inaccessible at such seasons. As the amount of water (sap) in wood differs according to the time of year,* and is greater in the young shoots and twigs than in the more solid stem, so it is likewise different in woods of a like nature but of different botanical species, as the following numbers (given by Schübler and Hartig) show.

100 Parts of fresh cut wood from the

	Water		Water
Hornbeam (Carp. betul.) contains	18.6	Pine (P. sylvestr. L.) contains	39.7
Willow (Sal. caprea)	26.0	Red Beech (Fagus sylvat.)	39·7
Sycamore (Ac. pseudoplat.)	27.0	Alder (Betul. alnus)	41.6
Mountain Ash (Sorb. aucupar.)	28.3	Asp (Popul. tremula)	43.7
Ash (Fraxin. excelsior)	28.7	Elm (Ulmus campestr.)	44.5
Birch (Betula alba)	30.8	Red Fir (P. picea Dur.)	45.2
Wild service tree (Crataeg. terminal.)	32.3	Lime Tree (Tilia europæa)	47.1
Oak (Querc. robur)	34.7	Italian Poplar (Pop. dilatat.)	48.2
Pedicle Oak (Q. pedunculata)	35.4	Larch (Pin. larix)	48.6
White Fir (Pin. abies dur.)	37.1	White Poplar (Pop. alba)	50.6
Horse-chestnut (Aescul. hippocast.)	38.2	Black Poplar (Pop. nigra)	51.8

In recently felled wood, therefore, $\frac{1}{5}$ *to* $\frac{1}{2}$ *of its weight is water, and in that used commonly for fuel above* $\frac{1}{3}$, *a quantity which very much diminishes by keeping the wood dry and exposed to the air, but is not entirely removed under any circumstances.* The tendency of the air to take up aqueous vapor, which occasions the drying of wood,

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* The wood of *Pin. abies* contained in January 53, in April 61, that of *Frax. excelsior* in January 29, in April 39, per cent. of water.

attains gradually a kind of equilibrium, with the hygroscopic property of the wood itself, which enables it, on the other hand, to take up moisture; and when this occurs, no further drying can be effected, and the quantity of water retained remains unchanged within very narrow limits. In this state of equilibrium, in which alone wood is made use of, the wood is said to be *air dried.* The remaining moisture can only be expelled with the aid of heat, and the last portions only with such difficulty, that the wood begins at the same time to decompose, and becomes brown.

Rumford heated the following air-dried woods so long at a temperature of 277° F. as they lost weight, without being chemically changed, and found that 100 parts of

Oak wood lost - - -	16.64	Fir wood lost - - -	17.53
Elm wood " - - -	18.20	Birch " " - - -	19.38
Beech " " - - -	18.56	Lime " " - - -	18.79
Maple " " - - -	18.63	Poplar " " - - -	19.55*

For practical purposes, such a complete state of dryness can seldom be attained, so that the wood used for fuel after exposure to the air for 10 or 12 months, contains from 20 to 25 per cent. of water. The former number taken as the mean, gives us in 100 lbs. of air-dried wood only 80 lbs. of real fuel. Wood, several years old, kept in a warm room for six months, still retained about 17 per cent. water (Winkler).† Woods are commonly divided into the *hard* and *soft* kinds, a distinction grounded upon the facility with which they are worked, and upon their powers of producing heat. The former, amongst which are numbered, oak, beech, white and red, birch, elm, and alder, contain in the same bulk more solid fibre, and their vessels are narrower and more closely packed than those of the softer kinds, which include that of the pine, fir, white fir, larch, lime, willow, and poplar. High situations, much exposed to wind, and a poor soil, cause the annual rings to be less developed, and consequently more closely packed than is the case with wood, which is protected and growing on the more fruitful soil of valleys. The specific weight of wood must necessarily stand in a certain relation to its hardness, and increase in a like proportion. For this reason, and as knowledge of this kind is useful to the practical man, several experimenters have turned their attention to the subject. Wood not being a homogeneous substance, its specific gravity, which is made up of the weight of the solid matter with that of the water contained in it, and of the air of the pores,‡ and these different constituents occurring in variable pro-

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* The same kinds of wood freed in the same manner from all water at 277° F., and exposed in shavings to the air, absorbed in winter (45° F.) from 17—19 per cent., and in summer (62° F.) from 6—9 per cent. of water within 24 hours, which facts easily explain why wood is dried with so much difficulty.

† The wood composing the beam of a room 150 years old, and preserved from moisture, had a spec. grav. 0,682, and contained 10.5 per cent. water.

‡ Thus Rumford calculated from the specific gravity of the fresh wood from sappy trees, and from that of its solid parts, that 1 cub. ft. of fresh oak wood contained 390 cub. in. of solid fibre, 360 cub. in. of sap, and 240 in. of enclosed air. Poplar wood in the same state contains in the cubic foot, 243 cub. in. of fibre, 219 cub. in. of sap, and 538 cub. in. of air; lime-wood, 265 cub. in. wood, 365 cub. in. sap, and 370 cub. in. of air.

portions, could not be ascertained with that degree of certainty to which we are accustomed in scientific investigations.

This difficulty was very much increased by the modes of experimenting being different and often inappropriate. Wood itself, supposing it free from pores containing air, is distinctly heavier than water. Thus, after destroying the pores by rasping and by determining the volume of the raspings, the specific gravity of lime wood was found to be 1.13, of fir wood 1.16, of oak wood 1.27, of beech wood 1.29. Rumford's experiments led to the conclusion that the massive part of all woods without distinction had a specific gravity of about 1.5. Experience has shown that wood sinks after long immersion in water, when the air has been expelled.

In the following table the respective weights of the different kinds of wood are given, according to the best authors, and in the state in which they are used: that being practically of the greatest importance:

SPECIFIC GRAVITY OF THE DIFFERENT KINDS OF WOOD; WATER BEING UNITY.

Variety of Wood.	I. Recently felled.	II. Dried in Air.	III. Strongly dried.	IV. Strongly dried.	V.	VI.
Quercus robur (Common Oak)	1.0754	0.7075	0.6441	0.663	0.929	0.650
Q. pedunculata (Pedicle Oak)	1.0494	0.6777	—	0.663	—	0.650
Salix alba (White Willow)	0.9859	0.4873	0.4464	0.457	0.585	—
Fagus sylvatica (Beech)	0.9822	0.5907	0.5422	0.560	0.852	0.752
Ulmus campestris (Elm)	0.9476	0.5474	0.5788	0.518	0.600	0.568
Carpinus betulus (Hornbeam)	0.9452	0.7695	—	0.691	—	0.728
Pinus larix (Larch)	0.9205	0.4735	—	0.441	—	0.565
Pinus sylvestris (Scotch Fir)	0.9121	0.5502	0.4205	0.485	—	—
Acer pseudoplatanus (Sycamore)	0.9036	0.6592	0.5779	0.618	0.755	0.645
Fraxinus excelsior (Ash)	0.9036	0.6440	0.6137	0.619	0.734	0.670
Betula alba (Birch)	0.9012	0.6274	0.5699	0.598	—	0.738
Sorbus aucuparia (Mount. Ash)	0.8993	0.6440	—	0.552	—	—
Pinus abies, Duroi (Fir)	0.8941	0.5550	0.4303	0.493	0.550	0.481
Pinus picea, Dur. (Silver Fir)	0.8699	0.4716	0.3838	0.434	—	0.763
Crat. torminalis (Wild service)	0.8633	0.5910	—	0.549	0.874	—
Aesculus hippoc. (Horse chestnut)	0.8614	0.5749	—	—	—	0.551
Betula alnus (Alder)	0.8571	0.5001	—	0.443	0.800	0.538
Tilia europæa (Lime)	0.8170	0.4390	0.3480	0.431	0.604	0.559
Populus nigra (Black Poplar)	0.7795	0.3656	—	0.346	0.383	0.387
Populus tremula (Aspen)	0.7654	0.4302	—	0.418	—	—
Pop. italica (Italian Poplar)	0.7634	0.3931	0.4402	—	—	—
S. caprea (Gr. round 1 Sallow)	0.7155	0.5289	—	0.501	—	—
Guaiacum Wood	Griffith.	1.3420	—	—	—	—
Ebony		1.2260	—	—	—	—

The columns I. and II. give the weights ascertained by Hartig: and column III. the less accurate determination of Wernek. His specimens of wood were dried in an oven until they ceased to lose weight, and then the loss which they sustained, on being immersed in water, was determined. In the IVth column, the results obtained by Winkler are given, who weighed an exact cubic inch of each wood.

According to another calculation, 1 cub. ft. of air-dried lime-wood, contains 558 cub. in. of fir-wood, 586 cub. in. of oak-wood, 381 cub. in. of beech-wood, 457 cub. in. of air in the pores.

The Vth column contains Mushenbroek's numbers, and the last those of Karmarsh. The American, Mr. Marcus Bull, whose determinations are most trustworthy, obtained them by the method of immersion, taking the precaution, however, to cover each specimen with a varnish of specific gravity = 1.000, which, without giving rise to error, ensured the presence of the whole quantity of air in the wood. The European woods, as shown in the table, are therefore nearly one half lighter than water, so that 1 cubic foot of dried beech wood weighs 34. 3lbs. av., 1 cubic foot of oak wood 40.6 lbs., &c. It must further be mentioned that wood dried in the air decreases in bulk, often as much as 0.1 of the whole. In mountainous districts, where the wooded parts are steep and intersected with rapid streams, the latter are frequently made use of for transporting the wood for fuel. In the Black Forest, Salzburg, &c., large quantities of wood are floated down in this manner. Looking more closely, however, into this practice, it appears that the advantage of cheap transport is partly counterbalanced by an inferiority in the quality of the wood so transported. Long immersion in water must necessarily dissolve out all the soluble matters, and thus diminish its volume and power of producing heat, which is actually found to be the case. Wernek asserts, that one cubic foot of wood may lose by being floated 1 lb. of its weight.

Daily experience teaches that wood, when burnt, always leaves an incombustible residue, the ash; this consists of earthy and alkaline salts, which the living plant has taken up from the soil for its own purposes. This amounts generally to about $\frac{1}{70}$, but sometimes from $\frac{1}{30}$ to $\frac{1}{70}$ of the original wood.

It has already been stated that the proximate constituents of wood, as regards the relative proportions of their elements, do not differ much from pure woody fibre (wood purified from extractive matter and water). The knowledge of these relative proportions not only explains the peculiar properties of the individual woods, but is essential in estimating their relative values. Schödler and Petersen, with this object in view, have furnished us with the following results of the elementary analysis of woods dried at 100° C., and previously pulverized:

In 100 parts they found:

Species of Wood.	Carbon.	Hydrogen.	Oxygen.	Species of Wood.	Carbon.	Hydrogen.	Oxygen.
Pure woody fibre .	52.65	5.25	42.10	Populus nigra . .	49.70	6.31	43.99
Quercus robur . .	49.43	6.07	44.50	Tilia europæa . .	49.41	6.86	43.73
Fraxin. excelsior .	49.36	6.075	44.57	Salix fragilis . . .	48.44	6.36	44.80
Acer campestris .	49.80	6.31	43.89	Pinus abies . . .	49.95	6.41	43.65
Fagus sylvatica . .	48.53	6.30	45.17	Pinus picea . . .	49.59	6.38	44 02
Betula alba . . .	48.60	6.375	45.02	Pinus sylvestris . .	49.94	6.25	43.81
Ulmus campest . .	50.19	6.425	43.39	Pinus larix . . .	50.11	6.31	43.58

It will be seen that the composition of different woods does not vary so much as might have been anticipated from their various properties, and yet it must not be overlooked that, whilst hydrogen and oxygen are contained in woody fibre in the same proportions as those in which they unite to form water (1 : 8), this relative proportion is exceeded by the hydrogen in the different woods, and in a variable manner.

[The following general table[*] exhibits the most important practical results of Mr. Bull's researches on the heating power and other properties of forty-six species of American woods. The high estimation in which these carefully conducted experiments are held in every part of Europe, added to their intrinsic usefulness, renders it highly proper that the American reader should have easier access to them than it is practicable to obtain from the works in which they have hitherto appeared. They are here presented entire.

Names of Woods.	Specific Gravities of dry Wood.	Avoirdupois pounds of dry Wood in one cord.	Product of Charcoal from 100 parts of dry Wood by weight.	Specific Gravities of dry Coal.	Pounds of dry Coal in one bushel.	Pounds of Charcoal from one cord of dry Wood.	Bushels of Charcoal from one cord of dry Wood.	Time 100 of Heat were maintained in the room, by the combustion of one pound of each Wood.	Value of specified quantities of each Wood, compared with Shell-bark Hickory as the standard.
								H. M.	Cord.
White Ash (Fraxinus Americana)	.772	3450	25.74	.547	28.78	888	31	6 40	77
Apple Tree (Pyrus malus)	.697	3115	25	.445	23.41	779	33	6 40	70
White Beech (Fagus sylvestris)	.724	3236	19.62	.518	27.26	635	23	6	65
Black Birch (Betula lenta)	.697	3115	19.40	.428	22.52	604	27	6	63
White Birch (Betula populifolia)	.530	2369	19	.364	19.15	450	24	6	48
Butter-nut (Juglans cathartica)	.567	2534	20 79	.237	12.47	527	42	6	51
Red Cedar (Juniperus Virginiana)	.565	2525	24.72	.238	12.52	624	50	6 40	56
American Chestnut (Castanea vesca)	.522	2333	25.29	.379	19.94	590	30	6 40	52
Wild Cherry (Cerasus Virginiana)	.597	2668	21.70	.411	21.63	579	27	6 10	55
Dog Wood (Cornus florida)	.815	3643	21	.550	28.94	765	26	6 10	75
White Elm (Ulmus Americana)	.580	2592	24.85	.357	18.79	644	34	6 40	58
Sour Gum (Nyssa sylvatica)	.703	3142	22.16	.400	21.05	696	33	6 20	67
Sweet Gum (Liquidambar styraciflua)	.634	2834	19.69	.413	21.73	558	26	6	57
Shell-bark Hickory (Juglans squamosa)	1.000	4469	26.22	.625	32.89	1172	36	6 40	100
Pig-nut Hickory (Juglans porcina)	.949	4241	25.22	.637	33.52	1070	32	6 40	95
Red-heart Hickory (Juglans laciniata?)	.829	3705	22.90	.509	26.78	848	32	6 30	81
Witch-hazel (Hamamelis Virginica)	.784	3505	21.40	.368	19.36	750	39	6 10	72
American Holly (Ilex opaca)	.602	2691	22.77	.374	19.68	613	31	6 20	57
American Hornbean (Carpinus Americana)	.720	3218	19	.455	23.94	611	25	6	65
Mountain Laurel (Kalmia latifolia)	.663	2963	24.02	.457	24.05	712	30	6 40	66
Hard Maple (Acer saccharinum)	.644	2878	21.43	.431	22.68	617	27	6 10	60
Soft Maple (Acer rubrum)	.597	2668	20.64	.370	19.47	551	28	6	54
Large Magnolia (Magnolia grandiflora)	.605	2704	21.59	.406	21.36	584	27	6 10	56
Chestnut White Oak (Quercus prinus palustris)	.885	3955	22.76	.481	25.31	900	36	6 30	86
White Oak (Quercus alba)	.855	3821	21.62	.401	21.10	826	39	6 20	81
Shell-bark White Oak (Quercus obtusiloba ?)	.775	3464	21.50	.437	22.99	745	32	6 20	74
Barren Scrub Oak (Quercus catesbæi)	.747	3339	23.17	.392	20.63	774	38	6 30	73
Pin Oak (Quercus palustris)	.747	3339	22.22	.436	22.94	742	32	6 20	71
Scrub Black Oak (Quercus banisteri)	.728	3254	23.80	.387	20.36	774	38	6 30	71
Red Oak (Quercus rubra)	.728	3254	22.43	.400	21.05	630	30	6 20	69
Barren Oak (Quercus ferruginea)	.694	3102	22.37	.447	23.52	694	29	6 20	66
Rock Chestnut Oak (Quercus prinus monticola)	.678	3030	20.86	.436	22.94	632	28	6	61
Yellow Oak (Quercus prinus acuminata)	.653	2919	21.60	.295	15.52	631	41	6 10	60
Spanish Oak (Quercus falcata)	.548	2449	22.95	.362	19.05	562	30	6 20	52
Persimon (Diospyros Virginiana)	.711	3178	23.44	.469	24.68	745	30	6 30	69
Yellow Pine, Soft, (Pinus mitis)	.551	2463	23.75	.333	17.52	585	33	6 30	54
Jersey Pine (Pinus inops)	.478	2137	24.88	.385	20.26	532	26	6 40	48
Pitch Pine (Pinus rigida)	.426	1904	26.76	.298	15.68	510	33	6 40	43
White Pine (Pinus strobus)	.418	1868	24.35	.293	15.42	455	30	6 40	42
Yellow Poplar (Lyriodendron tulipifera)	.563	2516	21.81	.383	20.15	549	27	6 10	52
Lombardy Poplar (Populus dilatata)	.397	1774	25	.245	12.89	444	34	6 40	40
Sassafras (Laurus sassafras)	.618	2762	22.58	.427	22.47	624	28	6 20	59
Wild Service (Aronia arborea)	.887	3964	22.62	.594	31.26	897	29	6 20	84
Sycamore (Acer pseudo-platanus)	.535	2391	23.60	.374	19.68	564	29	6 30	52
Black Walnut (Juglans nigra)	.681	3044	22.56	.418	22	687	31	6 20	65
Swamp Whortle-berry (Vaccinium corymbosum)	.752	3361	23.30	.505	26.57	783	29	6 30	73

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[*] The original memoir of Mr. Bull (read April 7, 1826) is found in the Transactions of the Amer. Phil. Soc., vol. iii., New Series, pp. 1—60.—Am. Ed.

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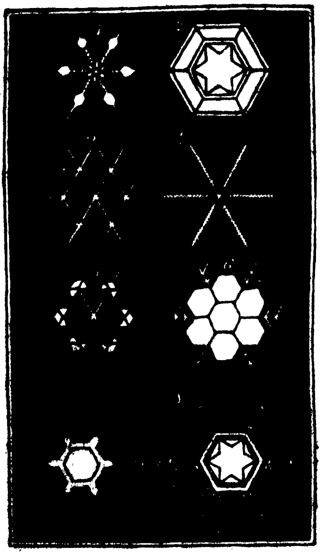

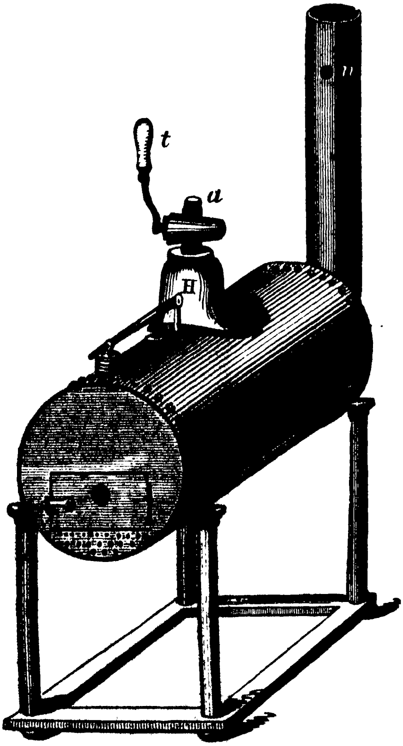

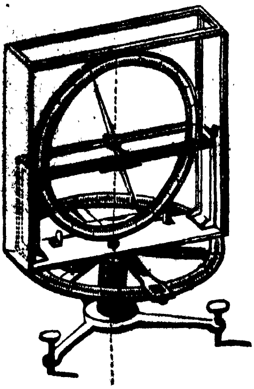

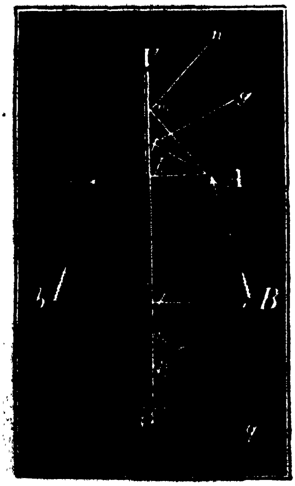

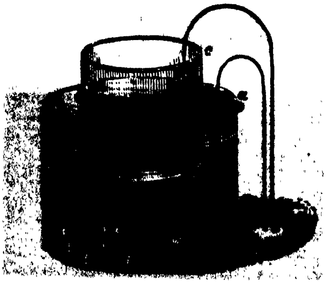

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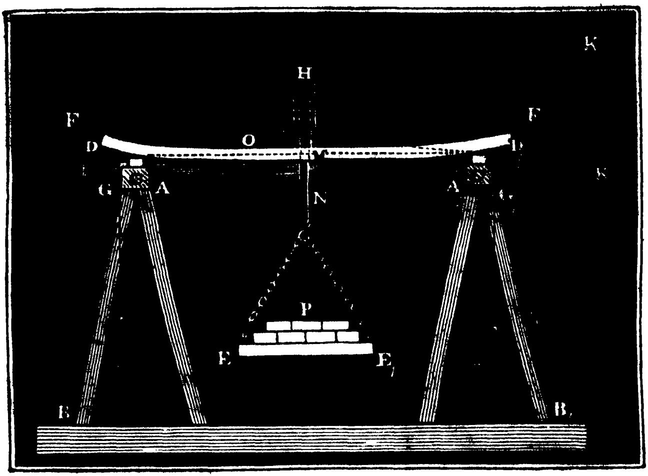

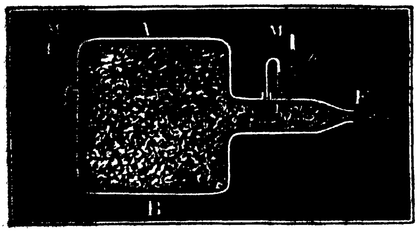

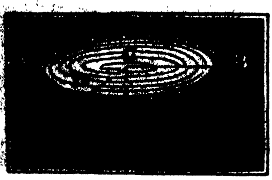

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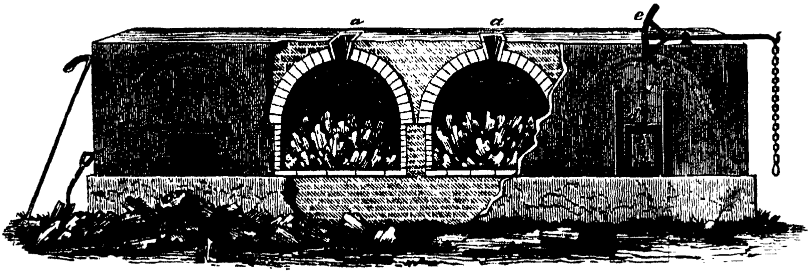

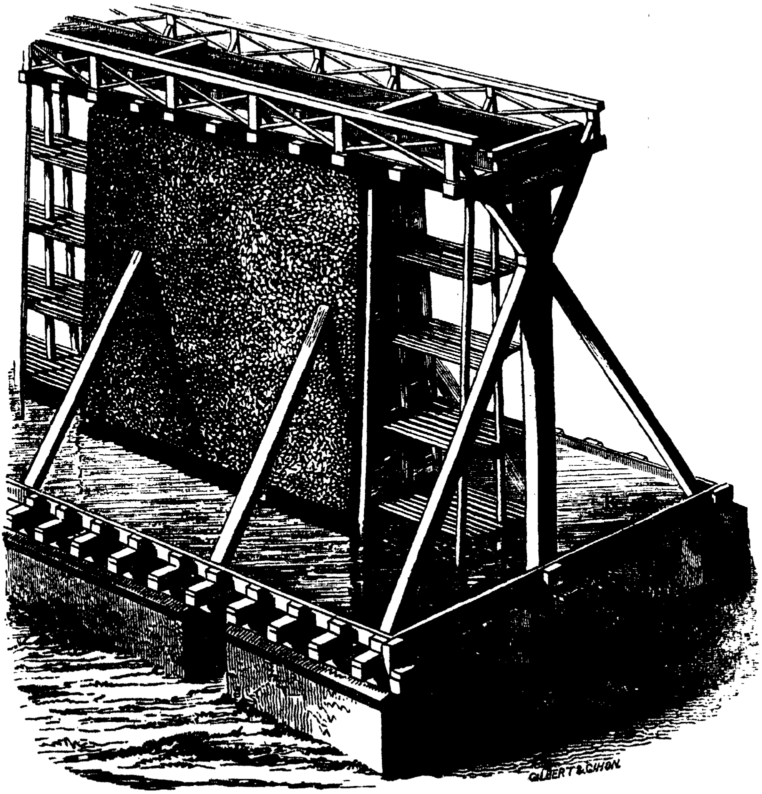

To be followed by works on Pharmacy, Chemistry, Astronomy, Heat, Hy-

Of Peat.—When the soil of a district assumes the form of a flat basin of greater or smaller dimensions, so that the water which collects cannot freely flow off, but stagnates for a length of time (forms a moor), which is not of uncommon occurrence in the temperate zones, and is favored by the tardy evaporation, then water plants of all kinds, sedges, rushes, reeds, algæ, mosses, even shrubby plants, as willows, &c., avail themselves of the propitious situation, and quickly form a thick covering of vegetation. With the change of season these die and fall to the ground, making room for a second crop in the following spring; this goes on from year to year until the hollow bog is completely filled up, although in a very loose manner. The remains of the plants immersed in water quickly undergo decay; they lose their original solidity with the simultaneous evolution of gases (marsh gas, carbonic acid) of a disagreeable and partly noxious odor, at the same time that they take up oxygen from the atmosphere and from compounds contained in the soil and water surrounding them, *e. g.*, sulphates, which they reduce, they become brown and soft, and eventually are converted into an earthy, black-colored mud. The debris of plants, reduced to this state by decay, or in which the process is still going on, is called *peat.* Smaller deposits are found almost in every country, but districts of immense extent occur, in the formation of which, the waters of the sea appear to have borne a part, as may be seen upon the low shores of the North Sea and German Ocean (Holland and North Germany).* Sometimes the peat formation appears to have taken place at successive periods; the mass is then generally divided by layers of sand. Although peat sometimes occurs immediately at the surface, it is frequently covered with sand or mould, but is always found in horizontal layers of moderate thickness. Peat belongs to the more extensively diffused kinds of fossil fuel, and is obtained of two kinds, which are solely distinguished by their geological age, or by the amount of decay which they have undergone. They are:

1. *Recent peat*, in which the structure of the roots and stems is still perfect, and which possesses a very porous, specifically light texture, is soft and exceedingly fragile. Passing from light brown to blackish brown, and containing the roots and fibres which are really foreign to it, disseminated through an earthy matrix, it gradually verges, without any marked distinction, into the

2. *Older peat*, in which all organic structure has disappeared, and the fibrous has given place to an earthy texture. Those kinds of peat must be considered the oldest, the earthy fracture of which has become so fine in the grain, so free from fibre, and so dense as to appear smooth and shining like wax (pitch peat?). All kinds of peat belonging to this class are decidedly heavier than those belonging to

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* Whilst in very mountainous countries peat-moors of 20 to 30 feet in extent are frequent in hollows, they cover whole districts in Holland. They vary quite as much in thickness, generally not exceeding a few feet, whilst in Holland they extend to a depth of 2 fathoms, and in Ireland to 30 feet.

gradually removed. The thickness of the cake is the length of the bricks, which are kept upright. To effect the complete desiccation, the first is taken out and laid transversely upon the second, the third is laid upon the fourth, and so on; this order is afterwards reversed when the pieces are piled up. In some places, the peat mud is scooped out with buckets on to a dry place, and when the water has drained from it, is made into bricks with moulds. Too large an amount of water in the peat may completely destroy its value, and render it incapable of being piled. Its value increases in rapid proportion with its dryness, density, and firmness. If it possesses these qualities in an inferior degree, it suffers by carriage and by keeping, the upper layers of the heap compressing and breaking the lower layers, which thus become valueless. The porosity and brittleness of peat prevent its application in all cases where fuel and matters to be heated are piled up to a height one upon the other. Independent of this, the fact is of great importance, that dense peat comprises, in *a like bulk*, much more combustible matter than porous peat. This fact has led, in recent times, particularly in Ireland, to the construction of presses for the purpose of improving the quality of the peat. The difficulty of introducing at the same time a quick, cheap, and effective machine, has not yet been entirely overcome. It is evident that such a press, in addition to the advantages named, would also very much aid the drying process. In one experiment, a brick weighing 8 lbs. lost 2.5 lbs. of water under the press. The longer peat is kept and allowed to dry in appropriate sheds, the more it will improve as a heating agent. The amount of water in air-dried peat varies much more than is the case with wood; and the subject has not been much examined. Another constituent, which is of little consequence in wood, is present sometimes in such quantity in peat, as to render it quite useless; this is the ash, which in peat is of a twofold nature: *firstly, the quantity of ash peculiar to the vegetable matters;*[*] and *secondly, all the earthy matter which has collected during the deposition of the peat.* This is essentially different, both in quantity and quality, from the ash of wood, and is much more subject to variation. Thus in 100 parts of peat, the following quantities of ash have been observed.

Inasmuch as this has not been dissolved out by the bog-water.

Variety of Peat.	Ash.	Observer.
Grass Peat, brownish yellow	1 — 1.5	Karmarsch.
Pitch Peat	1.2 — 8	
Young, dark brown	to 5 to 7	
Old earthy Peat	10	
Black, firm, from Neumünster	2.2	Suersen.
" " Sindelfingen	7.2	Schübler.
Brown, loose, from Schwenningen	2.3	
Very old Peat, from Vulcaire, near Abbeville	5.58	
" " Long "	4.61	
Not so old, from Champ de feu "	5.35	
Near Berlin, 1. Stage	9.3	Achard.
" 2. "	10.2	
" 3. "	11.2	
Black, old from Möglin	14.4	Einhof.
Brown, young	14.3	
Moor, in Eichsfeld, 1. sort	21.5	Buchholz.
" " 2. "	23.0	
" " 3. "	30.5	
" " 4. "	33.0	
In 41 sorts, from the Erzgebirge	1 — 24	Winkler.

Peat may, therefore, contain from 1 per cent. to ⅓ of its weight of ash. Carbonates of the alkalies are never found in it, but phosphates, *sulphates, &c., are. Einhof found 15.25 lime, 20.5 alumina, 5.5 oxide of iron, 41 silica, 15 phosphate of lime, 1.55 common salt and gypsum, in 100 parts of ash; Schübler even found 34 per cent. of* phosphates in the ash of peat from Schwenningen, upon the presence of which its chief value as a manure is based. As has already been remarked, the weight of peat depends upon its state of dryness, upon its age and density. Karmarsch gives the following as the weight of different kinds of Hanoverian peat: 1. Light colored, young grass peat, nearly unchanged moss, 0.113 to 0.263. 2. Young brown and black peat, an earthy matrix intersected with roots, 0.240 to 0.600. 3. Old earthy peat without any fibrous texture, 0.564 to 0.902. 4. Old peat, pitch peat, 0.639 to 1.039. Moulded peat from Griesheim (near Darmstadt), of good quality, has been found to weigh 0.706, so that 1 cubic foot would weigh on an average 35 lbs. av., and 100 bricks (at 56 cubic inches), $113.^4$ lbs. They leave after incineration a mass of ash, which, although less in bulk, retains the form of the brick, and is certainly very considerable in quantity.

A cubic foot of the earthy peat examined by Karmarsch gives nearly 3 lbs. of ash; the ash of all similar kinds of peat is injurious for several reasons; partly in causing dust and taking up much room, which in large towns, where it cannot be immediately employed as manure, involves expense in removing it; partly* by acting chemi-

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* In a fire, by means of which 80 measures = 320 lbs. of water were converted into steam in 9 hours, 240 lbs. of peat were consumed. The ash of this calculated at 20 per cent. would leave 48 lbs. daily on the hearth, and would amount in the year to 175 cwt., the removal of which must be attended with expense.—[This product of 1⅓ parts of steam to 1 part of fuel is certainly a very low result.—Am. Ed.]

cally in smelting processes, besides decreasing, of course, the quantity of combustible matter.

The manner in which peat is produced, (see brown and common coal,) would indicate an amount of carbon in it, above that contained in woody fibre. Regnault found, in three kinds of peat, after deducting the ash, the amount of which has already been stated, the following proportions:—

Peat from Vulcaire . . .	57.03 Carbon	5.63 Hydrogen	31.76 Oxygen
" Long	58.09 "	0.93 "	31.37 "
" Champ de feu .	57.79 "	6.11 "	30.77 "

The last column includes the very small quantity of nitrogen in peat, which is recognized by the ammoniacal vapors that it produces on heating.

Fossil Fuel of the Ante-historical Era.—The steady and gradual operations of nature, at the present day, supply certain districts with a stock of fuel of no mean quality, by the constant interment of the lower kinds of vegetation in the manner described above; but in the noisy activity of her more youthful career, the wants of the future races of human beings were never overlooked, and, indeed, they were more abundantly and better cared for during the time that the creating powers were fully employed in giving a habitable shape to our future dwelling-place. The science of geology teaches us, that at a certain period, our planet,—cooled down to a certain temperature, and thus admitting the vapors previously pertaining to the atmosphere to be precipitated—was covered by a shoreless ocean over the whole of its hardened surface, by a world of water in the full sense of the word, whilst its interior still remained in a state of incandescent fusion. This internal mass, void of all elasticity, and constantly compressed with immense force into narrower limits, by its hardened crust of stone, at length burst its barriers, and gushing forth through innumerable fissures, became solid, and formed so many elevations which appeared as islands in the vast ocean. A period of rest succeeding, accompanied by more than a hot-house temperature, and an atmosphere rich in carbonic acid, gave rise to an insular flora of gigantic dimensions, but resting upon an unsteady soil; for the same disturbances recur, fresh elevations of the ocean's bottom gradually straighten its boundaries and force the waters over the insular forests, burying them under masses of mud and deposit, or carrying them off to more quiet parts of the ocean. In all probability, the numerous strata of the transition formations have been produced by repetitions of the same process. The heat and moisture tended to accelerate the carbonization of the buried vegetation. It would, however, be going too far to maintain that the process of carbonization had already ceased, after Lyell has shown that it is still progressing, although in a different manner. The great rivers of the American continent, far removed, in some parts, from the civilized world, and unrestrained in their course by artificial dykes or dams, destroy and lay waste primeval forests, sometimes by inundations, sometimes by undermining their banks, and carry down innumerable trees, particularly at the time of their overflow, whose roots have been laid bare by the water. These, after remaining for a long period in the water, which the various impediments to their progress tend to lengthen, become so heavy that they can no longer float, and if not carried away by currents into the sea, are deposited in the deltas of the rivers with the debris of rocks, sand, and mud, which the river is constantly bearing from the interior towards the coast, here to undergo the same change as in the former case. This change, as in the case of peat, is of a purely chemical nature, occasioned by the presence of moisture in the earth, the partial access of atmospheric air, and sometimes by the enormous pressure of the superincumbent layers of rock.

	$36\,C + 44\,H + 22\,O$,
Take from these 3 equivs. carb. acid.	$3\,C \qquad + 6\,O$
	$33\,C + 44\,H + 16\,O$
and from the remainder 1 equiv. hydrogen . .	$2\,H$
	$33\,C + 42\,H + 16\,O$,

this result, then, represents exactly the composition of the brown-coal of Laubach.† In a similar manner we obtain the composition

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[*] This whole reasoning relative to different *ages* of anthracite and bituminous coal fails in regard to the southern anthracite field of Pennsylvania, where the hard anthracite of the Lehigh becomes the free burning bituminous coal at the Susquehannah. It also fails in the South Wales coal field.—AMER. ED.

[†] The analysis of this and of the following will be given in the sequel.

of the brown-coal of Ringkuhl, near Cassel, if from the wood
as before . . . . . . $= 36\,C + 44\,H + 22\,O$
we take 4 equivs. carbonic acid . . . . $= 4\,C + 8\,O$
it leaves . . . . . . $= 32\,C + 44\,H + 14\,O$
5 equivs. water . . . $= 10\,H + 5\,O$
leaves . . . . $32\,C + 34\,H + 9\,O$
and 2 equivs. hydrogen . $= 4\,H$
we have finally . . . $32\,C + 30\,H + 9\,O =$ brown coal from Ringkuhl.

In both cases we have the same kind of combinations formed, only in different proportions. In the formation of bituminous coal other products occur; thus, $24\,C + 26\,H + O$ expresses very exactly the relation of the atoms in the splint coal of Newcastle, and its formation is explained by deducting the following compounds from the elements of wood.

Wood . . . . $= 36\,C + 44\,H + 22\,O$
9 equivs. carbonic acid $= 9\,C + 18\,O$
leaving . . . . . . $27\,C + 44\,H + 4\,O$
3 equivs. water . . . $= 6\,H + 3\,O$
$27\,C + 38\,H + 1\,O$
3 equivs. carburetted hydrogen . . . . . $= 3\,C + 12\,H$
$24\,C + 26\,H + O =$ splint coal.

The main point, in the progressive decomposition of buried wood, is the production of carbonic acid from its own constituents. In the case of brown coal, when atmospheric oxygen is not so completely excluded, this combines with a portion of hydrogen, which is not the case in the formation of coal. Nothing results here but a breaking up of the elements of woody fibre into the four products: carbonic acid, water, light carburetted hydrogen, and coal. In the former case, the mouldering process is predominant, but decay (eremacausis) also does its part; the latter is solely a mouldering process. It is more than probable, that the carbonic acid accompanying the mineral waters of the carboniferous deposits, is produced at the same time as the light carburetted hydrogen, which has been observed to constitute the chief mass of the fire-damp. In a similar manner, the formation of all the varieties of coal may be explained; it is, however, hardly necessary to mention, that the foregoing formulæ are merely introduced for illustration, and are only true as regards the actual *atomic relations* of the individual elements. With reference to the occurrence of coal, it is met with in three distinct layers or strata; commencing with the lowest we find it:

1. In the *coal formation*, which is subdivided into the older *transition formation* (anthracite), and the more recent *coal formation* (bituminous coal).

2. In the *secondary formation*, both in the older *Keuper* and *Jura* formations, and in the more recent *chalk*.

3. In the *tertiary formation*, fresh water limestone, shell limestone, &c., with *brown coal.*

Of Brown Coal.—The coal of the tertiary formation, or brown coal, is not always uniform in appearance. In some kinds the vegetable remains are so well preserved, their structure so distinctly retained, even the more tender parts, as leaves and fruit, are so little altered, that a botanical diagnosis of such antediluvian plants has been undertaken with success. They appear as flattened stems, crossing each other in all directions, of a more or less dark color, of a soft, mellow consistence, their fracture following the direction of the fibre of the wood. They are called *lignite*, *fossil*, and improperly bituminous *wood.* The coal of the Wetterau (Salzhausen, Laubach) belongs to this class. Other kinds present only occasional distinct indications of vegetable structure, and appear throughout as a stratified mass, of a dark, nearly black color, possess an earthy fracture, and are called *earthy brown coal* or *pitch coal;* to these belong, amongst others, those of Meisner near Cassel. Lignite is often mixed with these, and both kinds are often present in the same specimen. Although sometimes occurring at the surface, they are mostly obtained from a considerable depth. Fresh from the pit they are impregnated with water, which evaporates upon exposure to the air before they are used, the amount of evaporation depending upon their degree of porosity. Reinsch found lignite from the Bavarian Upper Pfalz, to contain 43, and earthy brown coal, from the same locality, to contain 30 per cent. of water. Generally, however, the amount of moisture in brown coal is greater. At least Varrentrapp found that fresh coal, from Helmstedt and Schöningen contained 48 per cent. of water. After being completely dried (when a great reduction of volume occurred) they re-absorbed 8 per cent. Coal of this kind, kept some time piled up, contained 29; exposed to the air in summer 20, and in a warm room after four weeks, 8 per cent. of water. The amount of ash is in itself inconsiderable; it is, however, frequently increased to an injurious extent by the infiltration of water containing salts, and by an admixture of earthy matter, as will be seen from the following table.

	Variety of Coal.		Ash.	Observer.
Bohemian.	Lignite from Auszig		5.35 %	Balling.
	" "		5.51	
	" Hegendorf		6.93	
	" Neundorf		5.13	
	" Coulang		1.50	
	Earthy from Grünlas		6.66	
Bavarian Ob.-Pfalz.	" " Verau		10.00	Reinsch.
	Lignite " "		3.40	
	" Greece		9.02	Regnault.
	" Usnach		2.19	
	" Cologne		5.49	
	Earthy from Dax		4.99	
	" Bouches du Rhône		13.43	
	" Nieder-Alpen		3.01	
Cassel.	Earthy Stangen coal	Meiszner	15.47	Kühnert.
	" Pitch coal		2.43	
	" " from Hirschberg	Ringkuhl	0.81	
	Cannel coal " "		2.76	
	Middle sort " "		3.20	
	Lowest sort " "		4.92	
	Pitch coal from Habichtswalde		1.33	
	" " "		3.33	
	Stillberger coal (Söhrwald)		6.95	
	Lignite from Hirschberg		1.29	
From Duren, on the left Bank of the Rhine.	" Iceland		8.8	Karsten.
	" " (another specimen)		27.5	
	" Utweiler		0.9	
	" Grube Urwelt		4.6	
	" " "		27.05	
	" Friesdorf		1.69	
	" "		14·9	
Near Bonn, on the right Bank of the Rhine.	" Putzchen		4.4	
	" "		17.4	
	" Stöszchen		14.4	
	" "		28.2	
	" Orsberg		43.2	
	" "		58.0	
	Coal from Schöningen	Brunswick	7.8	Varrentrapp.
	" Helmstedt		8.4	
	Slate coal from Azberg		45.	Reinsch.
	" " Aga Reusz		6.0	

The amount of ash, even in the same deposit and in different parts of the same piece, varies more than is the case with peat; this is seen from Karsten's experiments. Reinsch found in the ash of lignite, from Verau: 3,6 gypsum, 1,2 hyposulphate of potash, 25,4 hyposulphite of lime, 50 protosulphate of iron, 20 sand. The ash of earthy coal gave: gypsum 3, hyposulphite of lime 7, green vitriol 57, sand 33. Varrentrapp's examination of Brunswick coal showed: gypsum 75.5, magnesia 2.58, alumina 11.57, oxide of iron 5.78, carbonate of potash 2.64, silica and clay 19.27. Brown coal, such as that of Orsberg, consisting of one half mineral matter, cannot be considered fuel, but can be made use of for other purposes (see alum). In addition to the ash and the elements of wood, brown coal contains a small quantity of nitrogen (0.5 to 1.5 per cent.) which has not been taken into account in the following analyses.

Brown Coal contains in 100 parts.[*]	Carbon.	Hydrogen.	Oxygen. Nitrogen.	Observer.
Earthy from Dax	70.49	5.59	18.93	Regnault.
“ Bouches du Rhône	63.88	4.58	18.11	
“ Nieder-Alpen	70.02	5.20	21.77	
Earthy, consisting of stems from Meiszner	70.12	3.19	7.59	Kühnert.
“ Pitchcoal	56.60	4.75	27.15	
“ “ from Ringkuhl, Hirschberg	60.83	4.36	24.64	
“ “ “ Habichtswald	57.26	4.52	26.10	
“ Cannel coal, Ringkuhl	66.11	4.82	18.51	
“ allied to Pitch coal, Habichtswald	54.18	4.20	26.98	
“ lowest vein, at Ringkuhl	52.98	4.09	21.91	
“ middle “ “	54.96	4.01	22.31	
“ Stillberger	50.78	4.62	21.38	
“ Helmstädt, Prince William mine	68.57	4.84	19.87	Varrentrapp.
“ “ another mine	67.88	6.85	17.46	
“ Schöningen, mine Treue	63.71	5.07	22.79	
“ “ another pit	64.80	4.54	23.12	
Lignite, from Ringkuhl	51.70	5.25	30.37	Kühnert.
“ Greece	61.20	5.00	24.78	Regnault.
“ Cologne	63.29	4.98	26.24	
“ Usnach	56.04	5.70	36.07	
“ Laubach	57.28	6.03	36.10	Liebig.

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[*] In the grand-duchy of Hesse, brown coal has been found at the following places: (1) in Upper Hesse, near Lauterbach or Zell, at Laubach (Hessenbrücken), Salzhausen, Friedberg (Dorheim, Bauernheim), Eberstadt, Obererlenbach, Grünberg (Zeche Buderus). (2) In the province Starkenburg, near Seligenstadt.

[†] As earthy matter, oxide and sulphuret of iron, have higher specific gravities than the organic constituents of coal, a high specific gravity is, when *other* things are equal, *primâ facie* evidence of impurity. So we have ever found it.—AM. ED.

[‡] “In the mountains of Cataja,” as this distinguished traveller relates, “a kind of black stone is dug up, which, laid upon the fire, burns like wood, and when once ignited, continues to burn for a long time, so that, if placed upon the fire in the evening, it will burn during the whole night. The stone when first ignited produces a small flame like other coal; it then continues to glow, and gives off much heat.”

means, "the air became infected with smoke." A deposit of coal is always composed of a series of layers (beds) which are separated from each other by sandstone, clay, or slate, and they are observed to vary in number from 2 to 60. The thickness of the layers increases with the depth, and varies from ⅔ of a line to several feet; so that it is always necessary, although the coal frequently appears at the surface, to work it at a considerable depth. At Newcastle-upon-Tyne the bed becomes sufficiently thick at a depth of 400 feet; but is covered with such a massive rock of sandstone, that, in some cases, all wooden supports are unnecessary in the workings. Near Gittersee, in the valley of Plauen, near Dresden, there are seven beds, between which six thin layers of soft clay intervene. The great number of the varieties of mineral coal has given rise to distinctions which are based partly upon age (locality), partly upon appearance, and partly upon quality. In all kinds of coal, without exception, the structure of the wood from which they have been formed is entirely obliterated; partial impressions of single parts of the plants alone indicate their origin. They form a compact, deep brown, or quite black mass, sometimes dull, but generally possess a fatty or vitreous lustre, often exhibiting a play of colors; they present a finely granular fracture, not at all fibrous, and are much heavier than wood, bulk for bulk; they occur more or less stratified, and nearly always are fissured at right angles to the plane of stratification, in a manner similar to that which is observed when a doughy mass becomes dry. These fissures are often narrower; and first appear when the coals are broken up; but not unfrequently they are found open and filled with mineral substances, as iron pyrites, calcareous spar, galena, dolomite, heavy spar, gypsum, clay, and soda salts. Independent of the causes which have been adduced, and which are destructive of connection in the coal mass—stratification of different masses and clefting, or "cleats"—and which produce the sharp, angular appearance of the fragments, the hardness and solidity of the coal are in general not very great. The fracture of the shining kinds of coal is conchoidal; of the other kinds it is even. Common coal, as it is used in grates and under boilers, is frequently accompanied by a small quantity of a kind of coal which at first sight can be distinguished from the great bulk by its color and structure, and still more by the difficulty with which it burns; this often appears in thin layers parallel with the plane of stratification, or is disseminated throughout the whole mass of the vein. This so-called *fibre-coal* is richer in carbon, and is only coal somewhat more advanced in the process of decomposition than the principal mass. A more accurate examination proves, that fibre-coal is only an exemplification of that process which is going on in all coal. We find everywhere, and particularly in the younger deposits, that the mass is a mixture of coal, rich in carbon, with such as is comparatively poor; a mixture, therefore, of coal in two stages of decomposition, of which the one is black, of a pitchy lustre, and conchoidal fracture, the other more dull, brown, and even. Perhaps an unequal facility of decomposition in the different parts of the plants may be the cause of it; but this is contradicted by both stages occurring stratified, and in all manner of relations towards each other, from thin veins frequently alternating, to veins of several inches in thickness, and by fragments of these appearing to be homogeneous. The knowledge of this fact is of importance, as the applicability of the coal mainly depends upon it; besides, upon it are founded the distinguishing characters given by mineralogists, although it stands in no connection with the inward properties of the coal. Compact masses of common coal, with a pitchy lustre, are called *pitch coal;* more distinctly stratified kinds splitting in a horizontal direction, *slate coal;* such as falls into very thin layers, *leaf coal;* and that which is dull and more massive, *coarse coal*, &c. The specific gravity of coal is from 1.2 to 1.45. Coal fresh from the pit loses, when exposed to the air, its extraneous moisture without parting with all its water, retaining, according to its nature, from 1 to 12 per cent.; artificially dried coal absorbs from the atmosphere hygroscopic moisture. Coal leaves, on an average, less ash than brown coal or turf, but, in consequence of the substances contained in its fissures, more than wood, its ash is distinguished by containing no alkalies, but only alumina, silica, oxide of iron, &c. Upon this point and the specific gravity of coal,* the necessary information is contained in the following table, which is calculated for 100 parts of coal.

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* *For the specific gravities and earthy materials of American coals, as well as their weight in a cubic foot, in a marketable state, see the general table on a subsequent page.—Am. Ed.*

	Description of Coal.	Specific Gravity.	Ash in 100 Parts.	Observers.
	Wylam Banks, Newcastle	1.302	13.912	Richardson.
	Glasgow Coalfield	1.307	1.128	
	Wigan, in Lancashire	1.319	2.545	
	Parrot coal, Edinburgh	1.318	14.566	
	Jarrow, Newcastle	1.266	1.676	
	Chief mass of coal from Glasgow	1.286	1·421	
	Garesfield, Newcastle	1.280	1.393	
	South Hetton, Durham	1.274	1.519	
Coal formation.	Alais, Rochelle	1.322	1.41	Regnault.
	Rive de Gier (P. Henry)	1.315	2.96	
	Flenû from Mons	1.276	2.10	
	" "	1.292	3.68	
	Cimentière, Rive de Gier	1.288	3.57	
	" "	1.294	2.99	
	Cauzon, "	1.298	2.72	
	" "	1.311	5.32	
	Lavaysse	1.284	5.13	
	Epinac	1.353	2.53	
	Commentry	1.319	0.24	
	Blanzy	1.362	2.28	
	Rive de Gier, grand Croix	1.298	1.78	
	" "	1.302	1.44	
Second Format.	Anthracite, Lamure, Dep. de l'Isère	1.362	4.57	
	" Macot	1.919	26.47	
	Common coal, Obernkirchen, Lippe-Sch.	1.279	1.0	
	Céral, Dep. Aveyron	1.294	11.86	
	Noroy, Vogesen	*1,410*	*19.20*	
	St. Girons	*1.316*	*4.08*	
	St. Colombe	*1.305*	*0.89*	
	Czernitz, Upper Silesia	*1.362*	*5.80*	Karsten.
	Gnade Gottes, Lower Silesia	*1.285*	*4.65*	
	Glück hülf, " "	*1.276*	*0.8*	
	Sulzbach, Duttweiler, Saarbrücken	1.258	0.15	
	Wettin, Saalkreis	1.466	24.4	
	Sälzer and Neuack, Westphalia	1.288	0.7	
	Pottschappel, Saxony	1.454	27.7	
	Königin Louise, Upper Silesia	1.280	1.2	
	Königsgrube, " "	1.285	0.6	
	Merchweiler, Saarbrücken	1.282	0.9	
	Frischauf, Lower Silesia	1.518	23.4	
	Hundsnaker, Westphalia	1.338	0.6	
	Beata, Upper Silesia	1.383	11.9	
	Brazils	1.483	28.4	Lampadius.
	Coarse coal, mixed with Pitch coal	1.48	20.9	
	Slate coal	1.24	22.7	
	" with Fibre coal	1.20	26.3	
	Anthracite sort of coal	1.37	22.5	
	Slate coal with a little Fibre coal	1.25	20.2	
	Hard Slate coal with layers of Pitch coal	1.42	24.0	
	Slate coal with predominating layers of Anthracite and Fibre coal	1.35	23.4	

No connection can be traced between the amount of ash contained in coal, and its mode of stratification, or other properties. The mode of its production indicates that the elements in wood and coal must be the same, only differing in the relative proportions of each. A mechanical admixture of iron pyrites is remarkable in all kinds of *coal, and is exceedingly objectionable for many of its applications. In some kinds it may be seen in distinct crystals, in others it is so finely disseminated as only to be discerned by chemical means.* Analysis has shown a small proportion of nitrogen in this description of coal, as in brown coal, which, under certain circumstances, is evolved as ammonia, and is of importance in the arts. The more recent investigation of Regnault and Richardson, as well as those of Karsten, will here find appropriate notice.*

	Description of Coal.	Carbon.	Hydrogen.	Oxygen and Nitrogen.	Observers.
	Wylam banks, Newcastle	74.823	6.180	5.085	Thomas. Richardson.
	Glasgow Coalfield	82.924	6.491	10.457	
	Wigan, Lancashire	83.753	5.660	8.039	
	Parrot coal, Edinburgh	67.597	5.405	12.432	
	Jarrow, Newcastle	84.846	5.048	8.430	
	Chief coal from Glasgow	81.208	5.452	11.923	
	Garesfield, Newcastle, Deep Bank	87.952	5.239	5.416	
	South Hetton, Durham	83.274	5.171	3.036	
Coal formation.	Alais, Dep. du Gard	89.27	4.85	4.47	Regnault.
	Corbeyre, Rive d. Gier	87.85	4.90	4.29	
	Rive de G., Grand croix, marèchal	87.45	5.14	5.63	
	" " " raffaud	87.79	4.86	5.91	
	Flenû from Mons 1	84.67	5.29	7.94	
	" " 2	83.87	5.42	7.03	
	Riv. d. G., Cimetière, bourrue	82.04	5.27	9.12	
	" " batarde	84.83	5.61	6.57	
	" Cauzon, "	82.58	5.59	9.11	
	" " gr. masse	81.71	4.99	7.98	
	Decazeville, Dep. Aveyron, Lavaysse	82.12	5.27	7.48	
	Epinac	87.12	5.10	11.25	
	Commentry, Dep. l'Allier	83.72	5.29	11.75	
	Blanzy	76.48	5.23	16.01	
Second formation.	Anthracite, Lamure, Dep. de l'Isère	89.77	1.67	3.99	Regnault.
	Anthracite, from Macot	71.49	0.92	1.12	
	Obernkirchen, Lippe-Schaumburg	89.50	4.83	4.67	
	Céral, Dep. Aveyron	75.38	4.74	9.02	
	Neroi	63.28	4.35	13.17	
	Saint-Girons	72.94	5.45	17.53	
	Saint-Colombe	75.41	5.59	17.91	
	Leopoldinengrube, Upper Silesia	73.88	2.765	2.475	Karsten.
	Königsgrube, from " "	78.39	3.21	14.77	
	Wellesweiler, Saarbrücken	81.32	3.21	14.47	
	Sälzer and Neuak, Westphalia	88.68	3.21	8.11	
	Eschweiler	89.18	0.44	2.94	
	Hundsnak, Westphalia	96.02	3.207	6.45	

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* With reference to the specimens for examination, Richardson classified his according

Although nitrogen is found in all kinds of coal (1 to 2 p. c. Richardson, Regnault), yet no such intimate relation has been traced between it and the qualities of the coal, as is the case with the three other elementary constituents. With the growing increase of carbon, the color becomes of a darker brown until it is quite black; the lustre is raised gradually from that of pitch to a vitreous hue. On the contrary, coal with a less amount of carbon is more solid than such as contains more. The hardness (property of being scratched) depends upon the relative proportions of hydrogen and oxygen, and is augmented by an increase of the latter.

Anthracite.—The oldest of all kinds of fossil fuel, the anthracite, belonging to the transition formation, must be regarded as the last product of the decomposing process in coal, and notwithstanding its similarity in outward appearance, it distinctly differs, both in composition, and by the manner in which it burns, from the other species of coal. As these are related to brown coal, so is anthracite to common coal. In an extended sense, certain kinds of coal, as those of Lamure and Macot in the table, are classed with this on account of the similarity in their properties; these, however, are not due to an advanced stage of the process of decay, but to the agency of heat accompanying the later elevations of primary rocks. Anthracite is eminently homogeneous; it is black, has a decidedly vitreous lustre, a powerful play of colors, and a conchoidal, sharp-edged fracture. Its structure is massive. The amount of ash, composition and specific gravity of those specimens which have been examined, are given below.

Locality of anthracite.	Specific Gravity.	Carbon	Hydrogen.	Oxygen and Nitrogen.	Ash.	Name of observer.
Pennsylvania, America .	1.462	90.45	2.43	2.45	4.67	Regnault.
Wales, Swansea . . .	1.348	92.56	2.33	2.53	1.58	
Rolduc, near Aix-la Chapelle	1.367	91.98	3.92	3.16	0.94	
Mayenne, town & dep. Mire Baconnière . . .	1.343	91.45	4.18	2.12	2.25	
Swansea	1.270	90.58	3.60	4.10	1.72	Jacquelin.
Sablé, dep. de la Sarthe .	1.750	87.22	2.49	3.39	6.90	
Vizille, dep. de l'Isère . .	1.730	94.09	1.85	2.85	1.90	
Isère	1.650	94.00	1.49	3.58	4.00	

Regnault found 0.37, Jacquelin 0.58 to 2.85 nitrogen. The ash consists of silica, alumina, oxide of iron, and, according to more recent observations, also contains chlorides, which volatilizing during combustion, damage the metallic portions of the stove or grate.*

An attentive investigation into the nature of fosssil fuel cannot fail

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to the plan adopted in England (Thomson) into Splint, Cannel, Cherry, and Caking coal; Regnault arranged his according to their geological age; and Karsten followed an arrangement of which we shall again speak presently. The transverse lines in the columns of numbers, correspond with the respective divisions in a like order.

* A specimen of anthracite dust from a flue which we examined in 1847, afforded from 1 lb. avoirdupois, or 7000 grains; sulphate of lime, 12.3 grains; sulphate of ammonia, 285.5 grains; chlorhydrate of ammonia, 160.6 grains; and tarry matter, 20.4 grains. —**Am. Ed.**

in pointing out its gradual increase in carbon as compared with woody fibre, until at length both hydrogen and oxygen are completely removed. This circumstance becomes still more obvious, when the amount of ash is deducted, as in the following table.

Description of the substance.	Carbon.	Hydrogen	Oxygen.
Woody fibre	52.65	5.25	42.10
Peat from Vulcaire	60.44	5.96	33.60
Lignite from Cologne	66 96	5.27	27.76
Earthy brown coal from Dax	74.20	5.89	19.90
Coal from St. Colombe, secondary . . .	76.18	5.64	18.07
" " R. de Gier, Corbeyre, coal formation .	90.50	5.05	4.40
Anthracite, Mayenne, transition formation . .	92.85	3.96	3.19

In fact, all three ingredients have disappeared in certain proportions, whilst the carbon, which is always the preponderating element, is least affected.

[*American Coals.*—Of the several varieties of coal found in the United States, a tolerably correct understanding may be obtained, by consulting the following tables derived from "*A report to the Navy Department of the United States on American coals.*"*

As the present edition of this work is principally designed for circulation in the United States, we could not, perhaps, be justified in omitting to notice the results of the laborious and varied investigation of American coals undertaken by authority of the Government, and designed to furnish practical information as well for general purposes of the arts as for those of steam navigation. Several analyses of each sample of coal were also made in some instances, according to the organic method, for determining the ultimate constitution of the coals. The reductive powers of all were tested with the oxide of lead by the method of Berthier, and their practical usefulness in the blacksmith's forge, proved by applying given quantities to the manufacture of chain cables and performing other species of smith's work.

"The experiments on steam-generating power were performed in the Navy Yard at Washington City. The apparatus consisted of a double flue cylindrical boiler, thirty feet long and three and a half feet in diameter—the flues being ten inches in diameter. A cistern whose cubic contents were carefully measured, was placed above the boiler to maintain a proper supply of water, and by which the quantity of water evaporated during each experiment was determined. The boiler was furnished with two safety valves of the simplest form, with the weights acting directly upon them. These served to regulate the pressure of the steam generally, but it was measured by a manometer or mercurial guage, carefully graduated, communicating with the steam in the boiler, but under such circumstances as to be free from the influence of its temperature. The size of the grate and the area of the heating surfaces were all completely measured.

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* See Senate document No. 386, 28th Congress, 1st session.

The draft was determined by a syphon draft-guage and other means. A register of the barometric, thermometric, and hygrometric condition of the atmosphere was constantly kept. A thermometer was so disposed as to determine the temperature of the air as it entered the grate, after having been made, by the construction of the stack, to pass entirely around the two sides of the boiler and under the ash-pit and main fire-place. Other thermometers were so placed as to determine the temperature of the air and gases as they escaped into the chimney after combustion, that of the water in the supplying cistern, and that of the steam and water in the boiler. The coals were measured and weighed in charges, that is, in a box containing exactly two cubic feet. Care was taken to reduce them all to the size best adapted to their combustion. They were charged regularly, so as to keep them as nearly as possible in a uniform state on the grate. During the experiment a portion of each coal was carefully dried by means of an apparatus prepared for this purpose, to determine the amount of hygrometric moisture. The rate and manner of combustion were carefully observed, and the ashes, clinker, &c., weighed and preserved for subsequent analysis. The soot deposited on the sides of the flues and other passages was also collected, weighed, and submitted to a like chemical investigation.

"The air intended for the support of combustion entered an opening below the ash-pit, and passing thence through air chambers in a double wall on each side of the boiler, so as to absorb the heat radiated from this body, entered the fire by a passage from the back of the stack, directly under the flue below the boiler. After traversing the fire, the gases and other products of combustion passed under the whole length of the boiler, returned through it by the two *interior* flues before mentioned, and communicated with one of the flues leading directly to the chimney. This, however, was susceptible of being closed by a damper, in which case the gases, &c., passed, by another series of flues, entirely around and outside of the boiler below the level of the water line, and then escaped into the chimney. By this latter arrangement, so perfect was the absorption of the heat generated by the fuel, that the gases on entering the chimney were rarely more than 60° or 70° hotter than the steam in the boiler, and often the *difference* was much less.

"*One trial or set of observations generally occupied about twenty-four* hours. It was commenced by heating the water in the boiler to a certain temperature (usually 230°) by means of a weighed quantity of dry pine wood. During this period no steam was allowed to escape. The coal was then substituted, after withdrawing and weighing the unburnt wood, and the process continued with coal alone to the end. The ashes which the required quantity of wood would give having been determined by other experiments, were deducted from the whole amount of residue left.

"The weight of coal consumed at each trial was generally from 800 to 1200 pounds. Four trials were usually made upon each sample of coal. The mode of conducting the combustion was in some respects varied in the different trials, chiefly with a view of determining the influence of such changes or modifications upon the efficiency of the material. One important modification in operation, which was introduced in the experiments upon almost every species of coal, was the introduction of fresh atmospheric air to the gases immediately behind the grate. This was accomplished by placing in that part of the apparatus a perforated iron plate, through which the air from the ash-pit below could pass, and which could be closed by simply drawing over it another perforated iron plate."

The following table contains, in a condensed form, the most important results of the trials of evaporative power, with some of the marked characters of each coal as derived from the experiments.

It is proper to remark, that the coals assayed in these researches were either such as were found in commerce, or such as had been furnished by the proprietors thereof, under a request from the government that samples might be forwarded for trial. With a single exception, noted below, they are believed to have been obtained where active and extensive mining operations were carried on.

Designation of coals.		Specific gravity.	Weight per cubic foot, calculated from specific gravity.	Weight per cubic foot, by experiment.	Ratio of actual to calculated weight.	Cubic feet of space required to stow a ton.	Volatile combustible matter, in 100 parts.	Fixed carbon, in 100 parts.	Earthy matter, in 100 parts.	Ratio of fixed to volatile combustible matter.	Total weight in lbs. of coal consumed.	Pounds burned on a square foot of grate per hour.	Hours required to bring the boiler to steady action.	Cubic feet of water evaporated per hour during steady action.	Pounds of steam to 1 of coal from initial temperature.	Pounds of steam to 1 of coal from 212°.	Pounds of steam furnished by 1 cubic foot of coal.	Total waste in the state of ashes and clinker from 100 of coal.	Weight of clinker alone from 100 of coal.	Average weight, in lbs., of unburnt coke left on the grate after each experiment.	Parts of lead reduced from litharge by 1 of combustible matter of the coal.	Steam from 212° from 1 of combustible matter.
ıver Meadow, slope No. 3, .	Pa.	1·610	100·645	54·93	0·546	40·78	2·38	88·94	7·11	37·31	3944·5	6·69	3·87	12·57	8·20	9·21	505·5	11·96	1·01	112·4	32·41	10·462
ıver Meadow, slope No. 5, .	Pa.	1·551	96·93	56·19	0·580	39·86	2·66	91·47	5·15	25·36	4250·5	6·27	2·42	10·66	8·76	9·88	556·1	6·74	0·60	61·2	33·29	10·592
rest Improvement, ...	Pa.	1·477	92·31	53·66	0·581	41·75	3·07	90·75	4·41	29·75	3810·0	6·52	3·32	12·89	8·92	10·06	440·8	6·97	0·81	40·2	33·39	10·807
ıch Mountain, ...	Pa.	1·464	91·51	53·79	0·588	41·64	2·96	89·02	6·13	30·09	7371·9	6·69	3·54	14·04	8·96	10·11	545·7	6·97	3·03	26·6	33·49	10·871
high, ...	Pa.	1.590	99·39	55·32	0·557	40·50	5·28	89·15	5·56	16·87	3838·2	6·95	3·27	11·63	7·73	8·93	494·0	7·22	1·08	36·1	28·92	9·626
ckawana, ...	Pa.	1.421	88·84	48·89	0·550	45·82	3·91	87·74	6·35	23·13	4112·5	6·45	2·67	11·92	8·56	9·79	477·7	8·93	1·24	57·2	33·53	10·764
ken's Valley, ...	Pa.	1·389	86·82	48·56	0·559	46·13	6·88	83·84	9·25	12·34	2471·0	6·92	2·63	12·89	8·43	9·46	459·6	12·24	4·40	18·0	32·60	10·788
ıver Meadow, (navy yard,) .	Pa.	...	....	55·08	...	40·65	...	...	8·10	...	1897·3	4·63	5·08	9·42	7·86	9·08	500·0	8·10	1·40	107·1	....	9·881
tural Coke of Virginia, . . .	Va.	1·323	82·70	46·64	0·564	48·03	12·44	75·08	11·83	6·27	4209·0	8·15	1·74	12·56	7·47	8·47	395·3	18·46	5·31	60·9	32·49	10·389
ke of Midlothian coal, . . .	Va.	...	....	32·70	...	68·50	...	...	16.55	...	1037·0	9·64	2·00	16·50	7·40	8·63	282·6	16·54	10·51	53·2	....	10·343
ke of Neff's (Cumberland) coal,	Md.	...	....	31·57	...	70·95	...	...	13·34	...	994·2	8·43	1·17	14·91	7·85	9·00	284·0	13·34	3·55	43·7	....	10·381
xture, one-fifth Midlothian and our-fifths Beaver Meadow, .		...	....	54.29	...	41·26	...	...	8·88	...	2050·0	5·83	3·21	10·06	7·69	8·86	481·1	8·88	4·91	9·5	....	9·725
xture, one-fifth Cumberland and our-fifths Beaver Meadow, .		...	....	54.51	...	41·09	...	...	8·18	...	2074·0	7·98	2·25	12·81	7·97	9·18	498·5	8·18	3·09	16.0	....	9·997
ıw York and Maryland Mining Company's, ...	Md.	1·431	89·44	53 70	0·600	41·71	12·31	73·50	12·40	5·97	2127·7	6·28	1·33	12·79	8·65	9·78	524·8	12·71	5·43	10·1	30·33	11·208
ff's Cumberland, ...	Md.	1·337	83·28	54·29	0·652	41·26	12·67	74·53	10·34	5·88	4318·4	7·86	1·68	14·80	8·19	9·44	512·7	10·96	4·53	6·1	30·72	10·604
sby's "Coal-in-Store," . .	Md.	1·307	81·69	53·47	0·655	41·90	14·98	76·26	8·08	5·09	1158·0	6·04	1·75	12·73	8·88	10·02	535·6	8·38	1·33	18·2	32·69	10·935
kinson & Templeman's, . .	Md.	1·313	82·09	52·92	0·645	42·33	15·53	76·69	7·33	4·94	2318·2	7·33	0·99	15·70	9·47	10·70	566·2	7·96	2·12	5·1	30·06	11·624
sby & Smith's, ...	Md.	1·332	83·26	51·16	0·614	43·78	15·52	74·29	9·30	4·79	4474·5	8·02	1·52	14·97	8·69	9·96	511·1	9·69	3·04	5·3	33·01	11·034
mberland, (navy yard,) . . .	Md.	1·414	88 40	53·29	0·603	42·04	14·87	70·85	14·98	5·00	...	...	...	...	...	...	...	14·53	2·29	13·5	27·98	....
uphin and Susquehannah, . .	Pa.	1·443	90·19	50·54	0·560	44·32	13·82	74·24	11·49	5·37	2557·0	6·86	0·83	13·35	8·31	9·34	472·8	16·36	3·50	23·7	31·18	11·171*
ɔssburg, ...	Pa.	1·324	82·73	53·05	0·641	42·22	14·78	73·11	10·77	4·95	4295·0	7·77	0·84	15·67	8·64	9·72	515·9	11·20	3·40	13·7	32·54	10·956

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* The sample which gave this favorable result, was stated to be "*crop coal*,"—no regular mining operations having been carried on at the locality.—A still tter result might be reasonably anticipated from the coal regularly mined.

Table continued.

Designation of coals.	Specific gravity.	Weight per cubic foot, calculated from specific gravity.	Weight per cubic foot, by experiment.	Ratio of actual to calculated weight.	Cubic feet of space required to stow a ton.	Volatile combustible matter, in 100 parts.	Fixed carbon, in 100 parts.	Earthy matter, in 100 parts.	Ratio of fixed to volatile combustible matter.	Total weight of coal consumed.	Pounds burned on a square foot of grate per hour.	Hours required to bring the boiler to steady action.	Cubic feet of water evaporated per hour during steady action.	Pounds of steam to 1 lb. of coal from initial temperature.	Pounds of steam to 1 of coal from 212°.	Pounds of steam furnished by 1 cubic foot of coal.	Total waste in the state of ashes and clinker from 100 of coal.	Weight of clinker alone from 100 of coal.	Average weight, in lbs., of unburnt coke left on the grate after each experiment.	Parts of lead reduced from litharge by 1 of combustible matter of the coal.	Steam from 212° from 1 of combustible matter.
Lycoming Creek, Pa.	1·388	86·74	55·38	0·638	40·45	13·84	71·53	13·96	5·18	3073 2	6·33	1·72	12·13	7·92	8·91	493·3	16·92	3·26	46·2	32·89	10·724
Quin's Run, Pa.	1·331	83·22	50·34	0·605	44·50	17·97	72·79	8·41	4·05	1883·2	7·29	0·75	13·90	9·08	10·27	517·0	8·94	1·31	14·7	30·90	11·275
Karthaus, Pa.	1·284	80·22	52·54	0·655	42·63	19·53	73·77	7·00	4·11	3643·8	6·66	1·87	12·48	7·92	9·09	477·4	7·89	3·66	52·5	33·31	9·887
Cambria County, Pa.	1·407	87·94	53·46	0·608	41·90	20·52	69·37	9·15	3·66	3488·5	6·68	2·00	12·47	8·04	9·24	486·9	9·75	3·48	14·8	31·46	10·239
Barr's Deep Run, Va.	1·382	86·41	53·17	0·615	42·13	19·78	67·96	10·47	3·43	5072·7	7·60	1·52	13·42	7·84	9·02	478·7	11·07	4·78	6·4	28·01	10·142
Crouch & Snead's, Va.	1·451	90·71	53·59	0·591	41·80	24·38	59·98	14·28	2·50	3834·7	7·13	1·16	11·65	7·30	8·34	445·0	14·34	5·37	6·0	25·77	9·740
Midlothian, (900 feet shaft,) Va.	1·437	87·50	50·52	0·577	44·34	27·28	61·08	10·47	2·24	3417·5	8·68	1·38	14·51	7·50	8·58	433·7	10·70	6·47	5·9	26·99	9·611
Creek Company's Coal, Va.	1·319	82·48	46·50	0·564	48·17	32·47	60·30	8·57	2·03	3769·6	8·59	1·17	14·88	7·44	8·42	391·8	8·64	4·41	10·5	30·52	9·211
Clover Hill, Va.	1·285	80·36	45·49	0·566	49·25	32·21	56·83	10·13	1·79	3775·1	5·84	1·93	8·35	6·71	7·67	347·4	10·60	3·86	11·5	28·53	8·588
Chesterfield Mining Company's, Va.	1·289	80·57	45·55	0·565	49·18	32·63	58·79	8·63	1·92	3876·0	8·46	1·17	14·47	7·95	9·00	410·9	9·07	4·19	10·5	27·38	9·896
Midlothian, (average,) Va.	1·294	80·90	54·04	0·568	41·45	29·86	53·01	14·74	1·78	4506·4	6·68	1·52	10·09	7·30	8·29	448·5	14·83	8·82	6·4	29·03	9·741
Tippecanoe, Va.	1·346	84·14	45·10	0·536	49·67	34·54	54·62	9·37	1·60	4904·7	7·37	1·33	10·62	6·74	7·75	350·2	9·72	4·03	11·2	29·17	8·583
Midlothian, ("new shaft") Va.	1·325	82·82	47·90	0·581	46·76	35·77	56·40	9·44	1·68	2918·5	7·60	0·91	13·46	7·66	8·75	418·6	10·26	4·21	17·1	26·80	9·751
Midlothian, (screened,) Va.	1·283	80·21	45·72	0·570	48.99	34·70	54·06	9·66	1·57	4132·0	6·24	1·29	10·11	7·84	8·94	408·7	10·27	3·33	14·8	29·74	9·970
Midlothian, (navy yard,) Va.	1·390	86·86	54·47	0·627	41·13	29·12	56·11	14·14	1·95	1463·5	. . .	. .	. . .	. .	. . .	. . .	. . .	4·42	43·2	27·23	. . . .
Pictou, (from New York,) N.S.	1·318	82·35	53·55	0·650	41·83	27·83	56·98	13·39	2·11	4153·9	7·84	0·94	12·79	7·48	8·41	450·6	13·37	6·13	5·7	28·18	9·710
Sidney, N.S.	1·338	83·66	47·44	0·567	47·22	23·81	67·57	5·49	2·84	1601·1	8·31	1·18	13·85	7·01	7·99	378·9	6·01	2·24	5.9	29·15	8·497
Pictou, (Cunard's,) N.S.	1·325	82·83	49·25	0·595	45·48	25·97	60·74	12·51	2·59	1962·5	9·84	0·85	16·47	7·45	8·48	417·9	12·06	6·19	3·7	26·69	9·648
Liverpool, Eng.	1·262	78·89	47·88	0·607	46·78	39·96	54·90	4·62	1·51	3786·0	8·59	0·86	13·43	6·95	7·48	375·4	5·04	1·86	11·1	27·88	8·255
Newcastle, Eng.	1·257	78·54	50·82	0·647	44·08	35·83	57·00	5·40	1·60	4023·0	8·03	0.84	13·75	7·68	8·66	439·6	5·68	3·14	10·7	27·55	9·178
Scotch, Scotland.	1·519	94·95	51·09	0·538	43·84	39·19	48·81	9·34	1·26	3860·0	10·74	0·96	14·32	6·14	6·95	353·8	10·10	5·63	5·7	27·00	7·719
Pittsburgh, Pa.	1·252	78·37	46·81	0 598	47·85	36·76	54·93	7·07	2·01	208·4	. . .	. .	10·56	7·03	8·20	384·1	8·25	0·94	9·9	28·89	8·942
Cannelton, Ind.	1·273	79·54	47·65	0·599	47·01	33·99	58·44	4·97	1·72	2465·5	11·09	0·50	15·05	6·31	7·34	348·8	5·12	1·64	6·4	26·53	7·734
Dry Pine Wood,	. . .	. . .	21·01	. . .	106·62	. . .	. . .	0·307	. . .	2360·5	15·87	. .	13·86	4·06	4·69	98·6	0·307	0·00	0·0	. . .	4·707

From this synopsis it is easy to perceive that no one sample of coal can lay claim to pre-eminence over all others, when we take into view all their properties and uses; for this reason it will be proper, in studying their relative adaptedness, to compare them in the manner presented in the following classified view of twenty-five varieties of coal, derived from the preceding table, which may serve to indicate the practical value of the several *classes* of coals in five different respects.

Class of coals.	Names of samples.	Evaporative power of *equal weights* of coal.	Evaporative power of equal bulks of coal.	Freedom from tendency to clinker.	Rapidity of action in evaporating water.	Facility of ignition, or readiness with which steam is *got up*.	Sum of the relative values in the preceding columns.
Cumberland, (Md.) Free burning, bituminous.	Atkinson & Templeman's, .	1000	1000	282	828	505	3615
	Easby's coal in store, . .	936	946	451	658	286	3277
	Easby & Smith's, . . .	931	903	197	886	329	3246
	New York and Md. Mining Co.'s,	914	927	111	677	376	3005
	Neff's, ...	882	906	133	877	298	3096
	Averages, . . .	932	936	235	785	359	3248
Anthracites of Pennsylvania.	Beaver Meadow, slope 5, .	923	982	1000	722	207	3834
	Forest Improvement, (Schuylkill,)	940	955	741	790	150	3576
	Peach Mountain, (Schuylkill,) .	945	964	198	901	142	3150
	Lackawana, ...	915	844	484	779	187	3209
	Lehigh, ...	835	872	555	792	153	3207
	Averages, . . .	911	923	595	797	168	3395
Free burning bituminous coals of Pennsylvania.	Quin's Run, ...	960	913	458	726	667	3724
	Blossburg, ...	908	911	176	996	595	3586
	Dauphin and Susquehannah, .	873	835	171	766	602	3287
	Cambria County, . . .	863	860	172	867	260	3012
	Lycoming Creek, . . .	833	871	184	706	291	2885
	Averages, . . .	887	878	232	892	481	3299
Highly bituminous coals of Virginia.	Chesterfield Mining Company, .	841	726	143	1000	427	3137
	Midlothian, screened, . .	836	722	180	730	388	2856
	Creek Company's, . . .	787	692	136	981	299	2885
	Crouch & Snead's, . . .	779	786	112	635	431	2743
	Tippecanoe, ...	724	618	149	875	376	2742
	Averages, . . .	793	709	144	844	384	2872
Foreign bituminous coals.	Newcastle, Eng., . . .	809	776	191	827	595	3198
	Pictou, N. S., (Cunard's sample,)	792	738	97	928	588	3143
	Sidney, N. S., ...	747	669	276	764	424	2880
	Liverpool, Eng., . . .	733	663	323	857	581	3167
	Scotch, ...	649	625	107	847	521	2749
	Averages, . . .	746	694	197	844	526	3027
General scale of relative values formed from the averages of each class.	Maryland free burning coals, .	1000	1000	395	880	682	
	Pennsylvania anthracites, .	977	986	1000	893	319	
	Pennsylvania free burning bituminous, ...	951	938	390	1000	914	
	Virginia bituminous, . .	850	757	242	948	730	
	Foreign bituminous, . .	801	741	331	948	1000	

From the above annexed *general scale*, it appears that in evaporative power under *equal weights*, the Cumberland class surpasses the anthracites by about 2.3 per cent., and under *equal bulks*, by 1.4 per cent. They also surpass the foreign bituminous coals 20 per cent. when we compare equal weights, and 26 per cent. by equal bulks. In freedom from clinker, the anthracites stand pre-eminent; in rapid production of steam, when once in action, the Pennsylvania bituminous coals are somewhat superior to all others, and for rapidly *getting up* steam, the foreign bituminous coals are most effective.

Besides the trials of evaporative power and the various kinds of analyses already noticed, numerous analyses of the gases of the chimney were made during the progress of combustion, to ascertain the proportion of heat furnished to those gases, that is, which were not economized in the production of steam. A general view of the results of these trials is contained in the following table, exhibiting the per centage of volatile matter in the combustible part of several classes of coals, and the evaporative power of the same part, with the proportion which was expended respectively on the boiler and on the gases passing to the chimney.

Number of the class.	Kind of coal.	No. of samples of each kind entering into the comparison.	Volatile matter in 100 of *combustible ingredients* of each kind of coal.	Incombustible matter in 100 of coal.		Number of analyses of gases made to determine the quantity of heat absorbed by the products of combustion.	Evaporative power of 1 part by weight of *coal*.			Total evaporative power of one part by weight of *combustible matter* in each kind of coal.
				Ashes and clinker.	Moisture.		Applied to produce useful effect on the boiler.	Expended on the gaseous products of combustion.	Proportion per cent. absorbed by the gases.	
1.	**Pennsylvania anthracites,**	5	3.84	7.37	1.34	12	9.508	1.996	17.4	12.59
2.	**Natural coke of Virginia,**	1	13.75	18.46	2.81	5	8.662	1.517	15.2	12.92
3.	**Maryland free burning bituminous coals,**	5	15.80	9.94	1.25	12	9.894	1.738	15.0	13.09
4.	**Pennsylvania free burning bituminous coals,**	4	17.01	13.35	0.82	9	9.620	1.470	13.3	12.92
5.	**Coke of Virginia (Midlothian) coal,**	1	17.15	16.54	2.81	1	8.632	1.193	12.2	12.10
6.	**Foreign bituminous,** .	3	31.75	8.14	2.16	8	8.252	1.756	17.6	11.18
7.	**Virginia bituminous,** .	5	36.63	10.74	1.64	12	8.482	1.746	17.1	11.51
8.	**Cannel,**	2	39.37	7.61	2.80	5	7.219	1.501	17.2	9.73

The relation between the steam-generating and the chain-making power of several of those coals between which considerable differences in constitution are known to exist, will be abundantly evident from inspection of the following table.

For reasons above stated, and on account of the smallness of the quantity of coal used (60 lbs.), the individual samples could hardly be expected to present fewer or less important discrepancies than are to be found in the table.

Thus between the Scotch and the Liverpool, and between the latter and the New York and Maryland Mining Company's coal, this relation becomes apparent.

Relative heating powers of different bituminous coals, as tested in making chain cable, compared with their evaporative powers.

Designation of coals.	Pounds of steam at 212° produced by 1 pound of coal.	Size of links—diameter, in inches.	Number of links made by 60 pounds of coal.	Deduced number of links of 1⅜ inch in diameter by 60 pounds of coal.
Scotch	6.946	1⅜	10	10
Pictou (New York)	8.412	1⅜	11	11
Liverpool	7.842	1⅜	13	13
Midlothian (new shaft)	8.750	1⅜	14	14
Newcastle	8.656	1⅜	15	15
Atkinson & Templeman	10.699	1⅜	18	18
New York and Maryland Mining Company	10.259	1⅜	20	20
Crouch & Snead	8.345	1⅝	9	14
Creek Company	8.416	1⅝	9	14
Chesterfield Mining Company	8.998	1⅝	9	14
Dauphin and Susquehannah	9.340	1⅝	9	14
Blossburg	9.724	1⅝	10	15 5/9
Quin's Run	10.270	1⅝	11	17 1/9
Cannelton (Indiana)	7.340	1 5/16	5	11
Forks of Jenning's Run (Maryland)	—	1 5/16	8	18
Midlothian (900 feet shaft)	8.584	1 5/16	8	18
Neff's Cumberland	9.442	1 5/16	8	18
Atkinson & Templeman	10.699	1 5/16	8	18
Barr's Deep Run	9.018	1 5/16	9	20

A decided general confirmation of the relative heating power of the coals, as deduced from evaporation, is afforded by the comparisons in the second and fifth columns of the above table. Thus—

		Steam.	Links of chain.
Four samples, viz:	Scotch, Cannelton, Pictou, and Liverpool, on an average,	gave 7.635	11.25
Five samples, viz:	Crouch & Snead's Creek Company's Midlothian, (new shaft,) Chesterfield, and Dauphin and Sus'qhan.	gave 8.769	14.00
Four samples, viz:	Newcastle, Blossburg, Quin's Run, and Midlothian, (900 feet shaft,)	gave 9.308	16.41
Four samples, viz:	Neff's, Atkinson & Templeman's, Barr's, and New York and Maryland Mining Company's,	gave 9.871	19.00

It will be seen that three different sizes of chain were in progress of manufacture at the different periods at which these experiments were made. They have, however, been all reduced to the same size by a comparison with common standard samples of coal, which were used each on two sizes of chain.

The following table exhibits the principal results of the *organic* or *ultimate analysis* of coals, with comparisons of heating power calculated from those analyses, and compared with results of actual evaporation.

Table of Heating Power of Coals, calculated from Analysis, and practically obtained by Steaming Operations.

Designation of the coals.		Proximate Analysis.						Ultimate analysis.			By calculation, the *combustible matter* in 100 parts is found to be constituted of				Practical evaporative power.			
		Composition of the raw coal in 100 parts.						Grains of							Pounds of water from 212° to one of combustible matter.			
	Specific gravity.	Moisture expelled below 250° F.	Sulphur.	Volatile combustible matter.	Fixed Carbon.	Earthy matter.	Ratio of fixed to 1 of volatile combustible matter.	Dried coal assayed.	Carbonic acid collected.	Water collected.	Carbon.	Hydrogen.	Oxygen and Nitrogen.	Calculated evaporative power of the carbon alone in one of combustible matter, by Dulong's co-efficient, from water at 212°.	Evaporated from the boiler.	Vaporizable by the heat expended on the gaseous products of combustion.	Total of evaporative efficiency of one part of combustible matter, by experiment on a practical scale.	Difference between the calculated and the experimental efficiency of the combustible matter.
Summit Portage railroad, Cambria Co., Pennsylvania,	1.3617	0.700	1.500	18.195	64.245	15.360	3.535	7.26	20.62	3.23	91.955	5.867	2.178	11.522	10.238	1.312	11.550	—.028
Midlothian, "new shaft," Virginia,	1.3006	0.914	2.282	29.274	62.050	5.480	1.966	4.57	14.82	2.23	93.620	5.739	0 641	11.731	10.191	1.269	11.460	+.271
New Castle, England,	1.2567	1.461		28.312	68.377	1.850	2.415	6.46	19.56	3.21	84.157	5.626	10.218	10.545	9.178	1.720	10.898	—.353
Clover Hill, Virginia,	1 2887	1.277	0.514	28.409	65.425	4.375	2.268	6.05	17.68	2.58	83.393	4.958	11.649	10.445	8.588	1.949	10.537	—.082
Scotch,	1.2759	1.365		35.586	60.342	2.707	1.696	7.64	22.60	3.75	82.952	5.607	11.441	10.393	8.868	1.338	10.206	+.187
Caseyville, Kentucky, and Cannelton, Indiana,	1.3920	1.150		30.669	44.493	23.687	1.450	4.21	8.96	1.92	76.335	6.663	17.002	9.565	7.734	1.823	9.557	+.008
Averages	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	10.700	9.133	1.5685	10.701	+.003
Osage River, Mo. cannel.	1.2000	1.670	0.482	41.348	51.160	5.340	1.237	6.94	19.95	3.69	81.855	6.168	11.977	10.256				
Pure bitumen	1.1558	.000		72.438	24.799	2.761	0.342	8.16	22.60	5.73	77.679	8.023	14.298	9.464				

It appears that, on an average, these coals expended in evaporating water from the boiler 85.35, and on the products of their combustion 14.65 per cent. of their whole heating power. Both the *sum* and the *number* of differences between the practical and the calculated evaporative powers, affected by the positive sign, are seen in the last column to be the same as those affected by the negative sign.

Dulong's co-efficient for the heating power of pure carbon is 12906 parts of water heated 1° Fahr. by 1 part of carbon burned.

The data furnished by the preceding table afford the means of ascertaining the proportion of its carbon volatilized in the distillation of the *combustible matter* in each kind of coal.

The calculations prove that of its whole carbon-constituent, the per centage volatilized was as follows:

Cambria county coal	16.767
Midlothian, new shaft	29.195
New Castle	15.967
Clover Hill	16.847
Scotch Cannel	24.169
Caseyville, Ky., Channel	22.452
And that the average was	20.883

The *identity* of results obtained in the averages of the 15th and 18th columns should seem to demonstrate that the heating power of bituminous coals is proportionate to the *carbon* which they severally contain.

Composition and character of ashes from several varieties of American coals.

Characters and ingredients of ashes.	Sugarloaf Company's anthracite. Hazle creek, Pa.—1st specimen.	Sugarloaf anthracite—2d specimen.	Sugarloaf anthracite—3d specimen.	Buck Mountain anthracite.	Summit Coal Company's anthracite, head of Beaver creek—1st specimen.	Summit Company's anthracite—2d specimen.	Stevenson's Bluff anthracite, Beaver creek.	Salem vein anthracite, Pottsville.	Quin's Run bituminous coal.
Specific gravity of coal	1.591	1.574	1.550	1.559	1.613	1.594	1.612	1.569	1.372
Per centage of ashes in the coal	4.83	8.73	2.242	3.079	5.01	4.00	3.71	6.75	6.80
Color	light buff.	reddish white.	white.	reddish buff.	fawn.	reddish gray.	fawn.	brick red.	gray.
Silica in ashes, per cent.	53.603	45.105	43.68	45.60	54.50	50.25	50.05	50.00	76.00
Alumina	36.687	37.000	39.34	42.75	34.45	38.90	39.04	38.90	21.00
Peroxide of iron	5.590	13.000	8.22	9.43	7.50	8.75	8.75	8.00	2.60
Lime	2.857	1.380	5.76	1.41	2.25	0.85	1.56	2.10	
Magnesia	1.076	2.430	3.00	0.33	1.30	1.25	1.30	0.90	
Oxide of manganese	0.186								
Loss, per cent.	-	1.085	-	-	-	-	-	-	0.40
Sum	99.989	100.	100.	99.52	100.	100.	100.70	99.90	100.]

It would be a very erroneous idea to suppose that the combustion of wood, coal, &c., was an immediate, direct addition of atmospheric oxygen to their elements; on the contrary, the heat of the burning portion (*i. e.*, the surface of a log of wood), produces dry distillation of the internal parts nearest to it, which are in no connection with the air. When these have become the outer part, then they are first acted upon by oxygen. In short, it is not the wood *which we see burning, but the products of its decomposition by the agency of heat. The main points in this decomposition by mere heat in closed vessels,* (dry distillation,) are *shortly, the following.* From the moment in which the elements are forced by the heat to abandon their former state of equilibrium, the formation of new products is due to three causes; to the temperature, the degree of chemical affinity amongst the elements, increased by their being in the nascent state, and to their volatility. This latter is very considerable in hydrogen and oxygen, but altogether wanting in carbon; there is a tendency, therefore, in these to separate and pass off in the form of gas, but chemical affinity interferes and obliges both to unite, and form compounds partly with each other, partly together or singly with carbon. Amongst the combinations that are possible, those of course will result, whose elements under the circumstances, have the most powerful affinities for each other at the existing temperatures. Hydrogen and oxygen combine in the simplest and most stable manner to form water; the excess of hydrogen, which is common to all fuel, takes up as much carbon as the temperature admits of, forming light carburetted hydrogen and olefiant gas, whilst at the same time the united action of the two other elements upon the carbon, gives rise to a series of ternary compounds. The simultaneous production of all these bodies gifted with chemical affinities at a high temperature, induces fresh activity, and products of a subsequent action are the final result. In short, the nature of the process admits of the production of such an innumerable series of bodies as will never be exhausted by science, nearly as many as there are mathematical combinations, binary and ternary, depending upon the temperatures. Most of these are of constant occurrence, and some are of importance, and deserve notice. A fluid is obtained in addition to the gases, the lower stratum of which is an aqueous solution of products, amongst which *acetic acid* is the most prominent, the upper stratum is a fluid mixture of bodies analogous to the resins and ethereal oils, and very rich in hydrogen ; it is technically called *tar. Pyroxylic* or *wood spirit*, a kind of alcoholic compound, as well as the substances discovered by Reichenbach, *paraffine, picamar, creosote, kapnomar, pittacall,* and *naphthaline*, pyrogeneous resin and oil are all constituents of this liquid.

The less oxygen there is in fuel, and the more the hydrogen predominates, as is the case in coal, the more numerous are the products of decomposition, which this element forms with the carbon. However much the formation of products rich in carbon may be facilitated by a suitable temperature, in no case are we able with wood, still less with turf, brown or common coal, to compel the two other elements to combine with and eliminate the whole of the carbon; there always remains a certain quantity of solid carbon, depending in quantity upon the degree of heat applied. Wood, brown coal and turf exhibit, in the charcoal which remains, their primitive form and structure, so that year-rings and cells may be distinguished in the wood charcoal, and the kind of wood, from which it was produced, ascertained. Coal is affected differently, having a different elementary composition. Some kinds pass during the process of decomposition into a soft state, a kind of fusion, so that the bubbles of gas of the products of decomposition are evolved, as it were, from a paste. The carbon left by common bituminous coal is called *coke;* it is filled with cavities, is more or less dense, and has no resemblance whatever to the form of the original coal. When several pieces, or when powdered coal is submitted to dry distillation, the pieces cake together and form one solid lump of coke. Such coal is rich in hydrogen, and is called *caking coal.* Other kinds of coal are acted on in a similar manner to wood, and leave a coke of the same form without caking. When pulverized, they leave a powdery coke. This variety is called *sand-coal,* and is the richest in carbon. Between the two is the *sinter coal,* or that variety in which the coke from the single pieces of coal forms one entire mass without undergoing complete fusion. The natural moisture, as well as the oxygen present in the fuel, which during combustion produces water, frequently prevents the attainment of very high temperatures in the furnaces in cases where such is required.* For this reason, it has been the practice, from a very early period, to make use of dry distillation as a means of removing those constituents of the wood which absorb heat, or as a means of concentrating the heating power, and confining it to a smaller space. This is the object of *charring* wood, or of converting it into *charcoal,* which has since been extended to peat, brown coal, and particularly to coal itself, in which latter case the process is called *coking.* From the series of natural kinds of fuel we thus obtain a series of artificial ones, the production of which demands our particular attention. The production of charcoal and coke is in itself a separate operation, and distinct from those of which we shall treat hereafter, in which dry distillation of certain kinds of fuel is practised for obtaining tar and the gases simultaneously evolved.

On the Production of Charcoal.—On examining minutely the combustion of wood, *e. g.* by igniting the lower end of a chip of wood, two distinct periods will be observed. For as soon as the flame, which blazes at first in any one part, becomes weaker and is extinguished, the volatile products of decomposition, which inflame in the air, are no longer given off, and the process closes with the faint glimmering of the remaining charcoal. If the chip is inserted, when the flame is extinguished, in a narrow closed glass tube, the charcoal

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* The true cause why high temperatures cannot be attained in a furnace using bituminous coal, is, that large quantities of heat are rendered latent while converting its volatilizable materials from the solid into the elastic form. This loss is not adequately compensated by the subsequent burning of the gases.—Am. Ed.

cools without glimmering from want of air. It is even possible completely to char the chip, in the manner mentioned above, when the access of air is prevented from the beginning by heating the wood in a close vessel. The original mode of preparing charcoal on a large scale depends upon the former principle, without entirely excluding the latter. More recent methods involve the use of capacious close vessels. Whatever plan may be adopted, the carbon of the wood will always remain in the greatest quantity, when time is allowed for the oxygen to combine with hydrogen and form water. Experience has in fact proved that the slow process of charring is decidedly preferable; this may be seen from Karsten's experiments, by the side of which we place those of Stolze and Winkler. The following were the results obtained:

Species of wood employed.	Charcoal.*			
	By a quick process of charring.	By a slow process of charring.		
	Karsten.†		Stolze.†	Winkler.†
Young oak wood	16.54	25.60	26.1	22.8
Old " "	15.91	25.71		
Young red beech wood	14.87	25.87	24.6	17.8
Old " " "	14.15	26.15		
Young white beech "	13.12	25.22	23.8	
Old " " "	13.65	26.45		
Young alder wood	14.45	25.65		
Old " "	15.30	25.65		
Young birch wood	13.05	25.05	24.4	17.6
Poplar wood	—	—	23.8	17.7
Old birch wood	12.20	24.70	24.4	17.6
100 years old birch, well preserved	12.15	25.10		
Young deal, P. picea D	14.25	25.25	23.4	20.6
Old "	14.05	25.00		
Young fir, P. abies D	16.22	27.72	21.5	20.1
Old "	15.35	24·75		
Young pine wood, P. sylvester	15.52	26.07	23.7	
Old "	13.75	25.95		
Limetree wood	13.30	24.60	22.8	16.2
Ash wood	—	—	22.1	19.4
Willow wood	—	—	22.2	15.0

Winkler enclosed his specimens in crucibles surrounded with sawdust, and quickly heated them to redness. As a general result, the woods gave nearly a like amount of charcoal; and when the process was too rapid, only half the quantity.

Preparations of Charcoal under a movable covering. In heaps or mounds.—The method in question is essentially nothing more than

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* Mr. Bull obtained the same results with air-dried American woods, namely from 19 to 25 per cent., by igniting in crucibles angular pieces surrounded with charcoal powder. (See the above table of his results, page 24.)

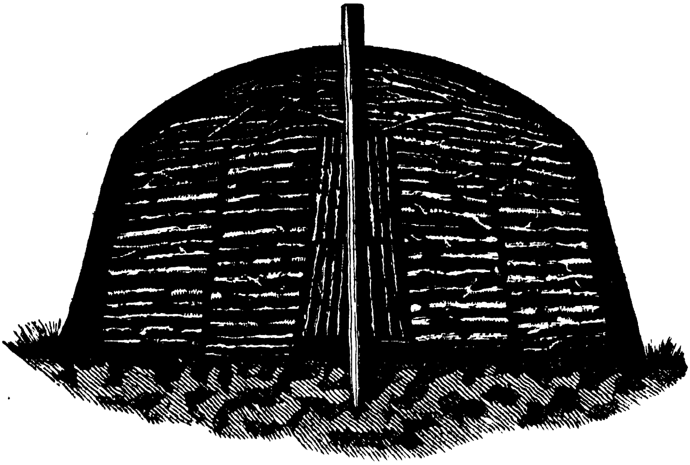
† The wood used by Karsten was dried in the air, that by Stolze 100° (= 212° F.) and that by Winkler in a dry room.

the combustion of a mass of wood under a movable covering, which enables the burner to regulate the admission of air and prevent any loss of charcoal by the action of its oxygen. The chief obstacles to a proper regulation of the process, and to a good result, are moisture and wet; the current of air is rendered irregular by sudden cooling, and by much wind.

A dry spot is cleared at the proper season of the year, which is during the summer months, sheltered from the wind (by a declivity or a wood); it must not be at too great a distance from the place where the wood is felled, that the expense of carriage may not be great. To make quite sure, and particularly if there is cause to distrust the dryness of the locality, it is well to cover the ground itself, or, after having first made a litter of shingles, planks or billets, with a layer of charcoal powder several inches in thickness. The construction of the heap is begun at the centre by erecting a stake as an axis, from which the heap is afterwards set on fire. This is either a strong post, around which the logs are arranged concentrically, taking the precaution to leave a free channel at the bottom from the stake to the periphery, that burning coals may be introduced, or three perpendicular logs are connected together with twigs, so as to leave a kind of open chimney. Whichever plan is adopted, the ignition always begins from the lower part of the stake.

Easily combustible pieces, *i. e.* partially charred wood from a former process, are placed round the stake, and round these the logs, which must be as nearly as possible of the same length, and so arranged one above the other in the form of a ring as to leave as small a space between them as possible. For this reason, all the split logs must have their sharp edges towards the stake, and the bark side outermost; all spaces occasioned by crooked wood must be carefully filled up with small wood, &c. The more slanting the logs are placed, the more loosely they will lie together, and *vice versâ;* on that account the external surface of the mound is made as steep as is consistent with the durability and the attachment of its external covering. It is also quite evident that many spaces must be left when the logs, as is sometimes the case, are laid horizontally and in a radiating manner round the stake in one or more concentric rings, because there will be too great a divergence amongst the outer ends of the logs forming the inner rings. A combination of both forms is practically the best, (Fig. 1,) and is constructed at first by making, round the stake, a steep and narrow mound, as a nucleus, and ranging the logs round this in the form of a ring pressing tightly the nucleus, so that its inclination determines the inclination of the whole heap. If all the logs be of the same length, the upper horizontal logs must approach nearer to each other, in proportion to the lessening diameter of the nucleus: thus the external surface becomes surrounded with a series of small steps, which serve a very useful purpose in supporting the covering. In all cases the upper part of the heap is covered with odd pieces of wood, billets, &c., until it assumes a rounded appearance. This covering is called the *cap*, the middle part of the heap, where in standing *mounds* the layers are changed in position, is called the *border*, or the *breast*, the base is called the *foot*.

Fig. 1.



The size of the mound depends upon circumstances, but must not exceed those dimensions which admit of a good regulation of the heat; heaps are seen of 10 feet in diameter, and even less, and they may extend to 20, 40, even 60 feet. It is obvious that the advantage of being less subject to cool is in favor of a large mound, as the surface is small compared with the space it occupies. Considered as hemispheres, the surfaces of mounds of 30 ft. and 60 ft. in diameter, will be the $\frac{1}{5}$th and $\frac{1}{10}$th of their cubical contents, therefore, in the greater one, only half the relative superficies. The heap must now, after having been *levelled*, *i. e.*, all the interstices filled up with small wood, be protected from the air and provided with a *covering*. Moist charcoal powder is best suited for this purpose, as it packs easily and closely together. Sand and earth are not so good; any of these, however, would fall into the interstices of the heap, if it were not first covered with a layer of turf, the earthy side outermost, with leaves, or even, in cases of necessity, with moss. This first covering, however, does not extend to the bottom, but is supported at a few inches from the foot by twigs, which are held by forks in the form of a ring against the heap, and are called its *armor*. The open part at the foot is left for the escape of aqueous vapor which is formed in the beginning; any opening in the cap, in the direction of the draught, would kindle the mound to an injurious extent. On the contrary, the covering, which is from 3 to 5 inches thick at the sides, is made thicker on the top. When the second covering of charcoal powder or sand has been made and pressed down, which is sometimes done at a later period, the whole is then set on fire; red hot coals are conveyed by means of the channel at the foot of the heap, or, on the other plan, from the top, to the stake, and the half-burnt pieces and chips about it are ignited as quickly as possible. When this is done, and the opening again closed up, the first period begins, namely, that in which moisture is expelled from the wood. This is called the *sweating process.*

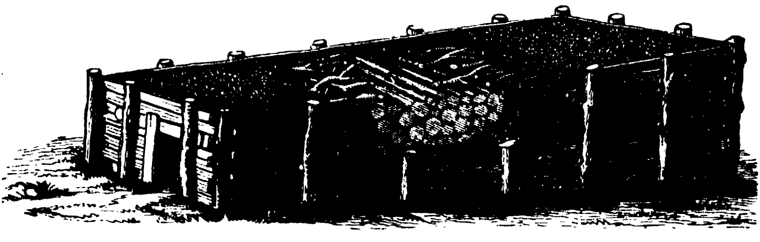
The most diligent attention is necessary, at this period, to prevent the heap being destroyed by explosion from a too rapid evolution of vapor. The duration of the sweating process is easily ascertained by the nature of the smoke, which passes up in a yellowish-gray cloud, and a portion of its vapors condense in the covering, causing it to become quite moist. As soon as the nature of the smoke changes, becoming gray and lighter, the open part below the armor is covered, and the second period of the process commences. But the state of the heap now needs repairs of an important kind; the wood of the stake has been gradually consumed, and cavities have been left; these cause a sinking in and falling together, which, producing larger inequalities, damage the covering and leave apertures for air to enter. By quickly removing the covering, the cap is left bare for a moment, and the wood in the neighborhood of the stake is broken up, and forced together by a long pole, the empty space filled up with fresh logs (*filling*), and the covering immediately replaced and stamped down. The combustion of a small portion promotes the dry distillation of the remainder, and the charring, properly so called, commences. The heap is now left to itself for several days, care being taken that openings are made at the foot, to allow the vapors of tar to pass out, and to supply the necessary amount of air, which, however, is partially effected by the porosity of the covering. The circumference of the heap now visibly diminishes, and attention must be paid to see whether this diminution is greater in some places than in others, or whether it presents a general want of uniformity. If such is the case, the charring has taken place chiefly in those parts, and a change of direction can be given to the process by increasing the thickness of covering in those parts, or making holes exactly opposite to them, which conduct the draught from them to other parts. With this process the labor of the charcoal burner would cease, if certain parts of the heap did not require additional care. For it is impossible to keep up the fire immediately below the covering, the wood in those parts is too much cooled, and the condensed vapors which collect there, resist the progress of the combustion. It is, therefore, necessary before the process is completed, (at a time when the wood in the interior is completely charred,) to carry the combustion to the very outside of the heap, by an increased access of air.

For this purpose, a second series of holes is quickly made in the breast, parallel with those in the foot, but at greater distances from each other. It is not necessary to make these holes higher up, as the draught naturally ascends into the cap. After a short time, the thick black smoke which at first ascends from these middle holes assumes the form of a thin blue cloud, the openings are then immediately closed, and fresh ones made about two feet lower down, when the same phenomena occur a second time. Very large heaps require a third series of holes, until close upon the lowest openings, fire partially issues forth instead of smoke. When this occurs simultaneously all round, the process is known to be successful. Wherever flames break out, they are immediately extinguished by moist charcoal powder, and in those places where they do not quickly appear, fresh holes are made to facilitate their production, until at length the whole heap is under cover, and the process complete.

The general appearance of the heap gives some clue as to the nature of the result; although in every case a great contraction has taken place, with careful management this is exceedingly uniform, whilst an inclined position, bulging and the like, prove a want of care. To break up the whole heap before it had cooled, would cause it to ignite and destroy the charcoal; and to wait until it had completely cooled, would involve a loss of time; the logs of charcoal are, therefore, drawn out separately. The burner lays bare an opening of tolerable size at the foot of the mass, draws out by means of a hook as much charcoal as time will permit before the air acts too strongly upon the opening, and then immediately closes it again; this is repeated round the whole mass, and the red hot charcoal which is drawn out, is extinguished by imbedding it in sand, charcoal powder, or by water; this operation is best performed at night, when the slightest spark is visible. The time required for charring varies with the size of the heap, from six to fourteen days; but four weeks are required when the diameter is thirty feet or more.

Another method of preparing charcoal, differing from the preceding in the mode of arrangement and management, but not in principle, is practised in some countries; *i. e.* in Wienerwald, it is called carbonization in heaps or piles (Haufenverkohlung). The wood is arranged in the form of a narrow, lengthened wedge, (Fig. 2,) the breadth of which is occupied by the blocks, and its length is generally from twenty to thirty feet. The thick end, which is likewise the hindermost as regards the course of the process, attains the height of seven to nine feet, the front thin end only two. Independent of the diminishing thickness (height) of the heap, the gentle slope of the spot gives it an inclination towards the front, so that the foot slopes upwards towards the back: what has already been said with reference to posi-

Fig. 2.



tion and covering, applies also in this case. The erection is commenced by driving posts all round the measured quadrangle, which in breadth and length must exceed that of the future pile; these posts must be higher towards the back, and correspond in every respect with the height of the pile. Having arranged the unhewn logs, eight feet in length, crossways upon a floor consisting of long poles placed lengthways, and thus formed the pile, a space six inches wide is left between the posts and the sides of the logs. This is for the reception of the covering, which otherwise could not be attached to the perpendicular sides.

Boards, shingles or other flat pieces of wood are set up inclining on the inside against the posts, and wet charcoal powder is stamped between these and the logs, until the whole side is covered. The thicker end generally terminates in a flat arch which sufficiently supports the covering without boards. When all the interstices have been filled up, the roof-shaped surface is supplied with a triple covering of twigs, leaves, and lastly of charcoal powder. On the two long sides a number of holes are previously made in the planks (not in the covering), and a larger one of the same kind in the front for the introduction of small wood for igniting, which is accomplished by thrusting red hot coals between the poles and the pile. When the fire has caught, which is seen by the smoke, the hole is closed up immediately; about fifteen inches from the ground, other holes 3 or 4 inches in diameter, are made in the front. The portion of the pile between these now begins to draw, whilst the adjoining part (higher up and thicker) is in the fomenting stage. If blue smoke is emitted from the openings, and the process is drawing to a close, the open spaces are closed, and fresh ones made at an increased height from the ground, and so on throughout the whole pile. In order to draw the fire down to the bottom, which is more difficult on account of the cooling and humidity, a few spaces are made immediately above the ground in that part, which is already nearly charred. When the process is advanced to about the distance of the length of the logs, the first portions of charcoal are drawn out. It is sometimes thought preferable to split the logs, and to place them longitudinally in a parallel direction with the sides of the pile, by which arrangement the carbonization is more easily diffused, and fewer openings are required. The preference given to charcoal prepared in this manner is not without foundation, as the charcoal is here drawn out as soon as it is perfectly charred.

General Remarks upon Heaps and Mounds.—The process of charring wood, which has been known for two thousand years,* belongs undoubtedly to that numerous class of inventions, which the correct practical discernment of former times has left little to modern theory to supply, beyond the rational explanation. Simple and ingenious as the process is, it has not been modified by any essential improvement. It is impossible to imagine a spot, where wood is felled, or to which it is brought by flooding, or by wooden sledges, which does not offer the simple requisites for the erection of a coaling heap; and this cir-

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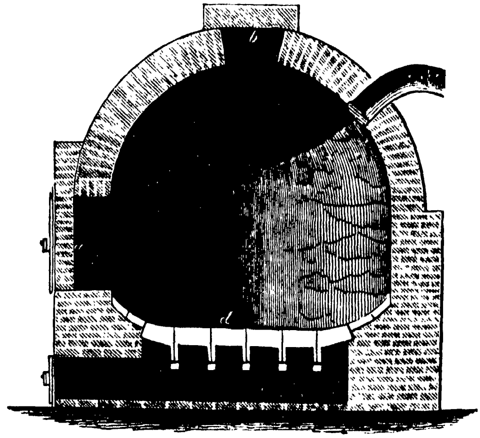
* It is described by Theop. Erosius, who lived 300 years A. C., and by Pliny.

cumstance is of importance, as the cost of carriage upon wood so far exceeds that upon charcoal. Moreover, as has already been remarked, wood diminishes in bulk during charring, as much as from 20 to 25 p. c., so that a heap comprising 3600 C. F., on being charred, becomes 2250 C. F., and a space or hollow of 750 C. F., would be left, into which the air having access would destroy and waste a portion of the wood. But this cavity is not actually produced, because the flexible covering gives with the wood and obviates any injury from such a cause. No arrangement could so surely, effectually, and easily regulate the access of air, upon which the main point in the operation depends, as the movable covering. Each thrust of the pole is like opening a stop-cock, each shovel full of earth like closing another. Lastly, the fire can be brought to act upon all parts of the mass of wood, however extensive it may be, from the peculiar nature of the procedure. The object of the charcoal burner, is to char by dry distillation the great portion of the wood at the expense of the smaller portion, which, in being consumed, affords him the requisite heat. A certain portion of the contents of the heap must be considered as the necessary fuel with which the burner effects his purpose. Whilst the admitted air partially consumes the one log, the adjoining one is exposed to the heat which it evolves, undergoes dry distillation, and is itself afterwards, for a short time, exposed to the action of atmospheric oxygen. The ability of the workman consists in observing accurately the time when the air should be prevented having access to the wood, and the neighboring parts are undergoing spontaneous decomposition. This part of the operation is very much facilitated by forcing the vapors, contrary to their natural course, to take a downward, instead of an upward direction, and this retards the process, whilst it enables the workman clearly to discern what changes are taking place, and at the same time affords him leisure for taking the necessary precautions. Lastly, it is worthy of notice, that the fire beginning in the middle of the heap, gradually proceeds to the circumference, and thus the nucleus of the heap, which is the first to be completely charred, is protected by an enclosure of burning wood impermeable to air, from the destructive influence of oxygen. As a great drawback to these positive advantages, there is one imperfection equally indisputable, which has given rise to a number of propositions for improving the process; it is the actual loss of all available secondary products, namely tar and pyroligneous acid. The sale of these is very much dependent upon the nature of the country, and is often exceedingly small, and yet various methods have been tried, though not always with success, for collecting them. Collecting these products from the mound generally does more damage than they are worth. Some have proposed to form the covering of slaked lime, in order at all events to preserve the acetic acid as acetate of lime; others, that it should consist of portable hurdles covered with clay, which being supplied with tubes, might carry off the vapors to condensing vessels. This, however, would be robbing the covering of its most useful quality, *i. e.* its flexibility. The long masses or piles are better suited for condensing arrangements, and the best proposition is, to place a tube in the coating at the thicker end which shall conduct the vapors to a vessel containing water. When it is not necessary that the spot chosen for the heap should be changed, and follow the course of the woodman, where the wood, as in mountainous districts, can always be brought to the same spot by sledges or otherwise; then the base of the heap may be built in the form of a flat funnel, the lowest part of which, the middle, is connected with a channel leading to a pit at the side, in which tar and pyroligneous acid may be collected.

Charring in Furnaces.—The endeavor to obtain all the products simultaneously, and the hope of a greater amount of charcoal, probably first led to the substitution of fixed apparatus, either of brickwork or of iron *charcoal furnaces*, in place of the covered heaps. Some are calculated, as were the heaps, to produce the temperature necessary for charring, by the combustion, with little access of air, of a portion of the wood enclosed within them; they are furnaces, the sides of which form a fixed covering for the heap. In others, that portion of the wood destined to produce the heat, is entirely separated from that to be charred; the latter is placed inside, the former outside, the furnace.

A correct view of the matter has proved, that the gases and vapors evolved from a block of wood, in as much as they are the products of dry distillation, and unconsumed, are actually themselves fuel, all of which is unavoidably lost in the heaps; when these, therefore, are evolved plentifully, the operation should be brought to a close as quickly as possible.

Fig. 3.



In the furnace represented at Fig. 3, the air has access through the bars. It is filled by the aperture *a*, and afterwards by *b*, in the arch, the charcoal is drawn out only at *a*. All the openings are bricked up during the operation. By means of a tightly fitting door to the ash pit, the draught is regulated. The air is allowed access until the walls of the furnace have attained a heat sufficient to complete the carbonization, the doors are then completely closed, and earth thrown against them, when thick smoky vapors of tar make their appearance.

In Russia, Sweden, and according to Kavanko, in China, carbonization is usually effected in pits, the sides of which are made to form the furnace. The pit is usually situated on the side of a hill, and in the shape of an inverted cone; at the side is a tar vessel, which is connected with the sole of the furnace by an inclined tube. The top of the pit, after having filled it with finely cleft wood, is closed with a common covering of earth, through holes in which a draught is produced. The furnace proposed by de la Chabeaussière is nothing more than a carefully constructed pit, which is worked upon the same principles, and which, like the preceding, is more adapted for the production of tar than of charcoal. The form being the same, a draught is produced from below by means of a number of channels, which pass down the sides of the furnace, and open at the sides above the sole. The whole is covered above by an iron hood, in such a manner, that the conducting pipe for the tar opens a few inches below it. In consequence of too much cooling, a quantity of wood remains but only half charred.

The furnaces in which carbonization is conducted by means of a series of holes (space holes) made in the wall, are different from the above. They contain from 7 to 8 stacks (Stecken)[*] of wood, are made quadrangular, that the wood may be more closely packed, and are slightly arched at the top. The lowest series of holes is on the same level with the sole, the next 18 inches higher, and the remainder at distances of 3 feet from each other. When the wood is introduced, and it must be packed as closely together as possible, a channel is made above the sole, corresponding with the door, which is the means of getting at it, and by which the whole is ignited. By a pipe from the upper part of the furnace, the vapors are carried off. Distinct apertures are adapted for charging the furnace, and drawing out the charcoal. When the process has begun in the furnace, and a certain temperature has been attained, the space holes are closed, one after the other, with clay plugs as the process progresses, and when it is nearly finished, the whole furnace is covered with clay. The charcoal must not be taken out until the furnace is completely cold; for before that occurs, and it requires two or three weeks to cool, the air on entering would consume a large proportion of the red hot charcoal. The second kind of furnace, which is heated by fire from without, admits of all the products being completely collected, an advantage which is only counterbalanced by the necessity of employing small quantities of wood at a time; for it is clear, that the bad conducting power of wood and charcoal must offer an insurmountable obstacle to the penetration of heat from without, into the interior of a larger furnace, and that its full action cannot there be exerted.

The Production of Tar.—This kind of furnace is exceedingly appropriate, when charcoal is not the chief product required, but when the object in view is the production of tar. Coniferous woods have been found to produce the largest amount of tar, on account of the highly hydrogenized resins, and the turpentine with which they are

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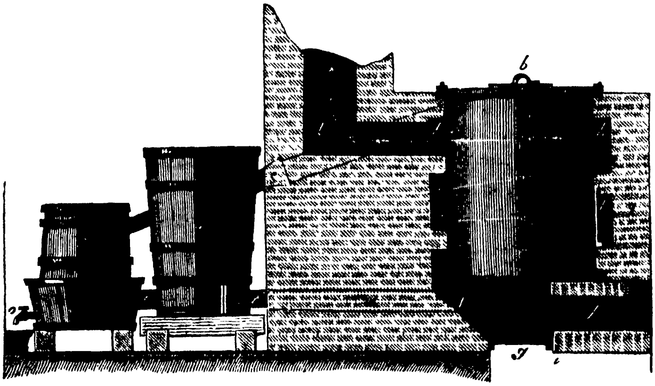
[*] Say 8 to 9 cords the Stecken, or stack, = 6 ft. by 6 ft. by 3½ ft. These being Prussian feet, the stack will correspond to 137.57 cubic feet English or 1.07 cord of wood.—AM. ED.

impregnated; those parts which contain the most resin are, therefore, chosen. The tar, or pitch furnaces, which are generally constructed of clay on the spot in the forest, consist of two hollow arched cylinders, one within the other; the inner one, destined to receive the resinous logs, extends with the aperture in its dome somewhat beyond the outer one, which, leaving an annular space of a few inches, rises close up to the dome. The space between both is appropriated to the fire, to support which, a few holes are left. The sole of the inner space deepens in the shape of a funnel, and ends in a tube, leading through the intermediate space and the external cylinder to the tar cistern. When the furnace is charged with wood, the aperture is closed and fire is made in the annular space as long as tar distils over below. The thick fluid swimming uppermost in the condensing vessels, which at first is yellowish brown and at last blackish brown, is the tar, a solution of pyrogenous resin in volatile oils and acetic acid. If it is separated from the lower watery layer, and distilled by itself, a mixture of these latter is obtained, pine-tar oil, and the resins remain as ship's tar, or *pitch.* According to Stolze, the foliaceous woods produce from 9 to 10, the coniferous woods 13 to 14 per cent. of tar. A very good arrangement for obtaining both charcoal and tar is shown in Fig. 4. The space in which the wood is to be charred, is an iron box, (walled spaces require too much fuel to heat them,) that will contain one, or at most, two cords; it is placed over a grate in such a manner that the flame shall pass in a spiral manner round the sides and then pass up the chimney; *b* is the door for filling; the tube *c* carries off all the volatile products, first through the cooler *d*, whence the condensed products are conveyed to the receiver by the tube *e*, whilst by another tube *f* the gases pass to their destination, the fire-hearth. When the fire produced by the combustion of twigs at *g* has raised the box to a red heat, the first vapors which appear carry with them combustible gases; as soon as these appear in increased quantity, the cock at *v*

Fig. 4.



is opened, and they are admitted to the fire, which they now entirely support without any stoking. After about sixteen hours, the fire is extinguished by shutting off the gases, the whole is allowed to cool, and the charcoal taken out. It has already been mentioned, that furnaces, like the one here described, when compared with heaps, can only char small quantities at once; trials have been made to overcome this difficulty by constructing larger boxes, and supplying them with heating pipes, so that the heat might be applied not only at the surface, but to many parts in the centre. If the heating is conducted in such a manner that the flame contains little or no excess of oxygen, the pipes may then be dispensed with, and at the same time a saving of fuel effected, inasmuch as the oxygen is always excluded. The construction of the furnaces introduced by Schwartz into Sweden, is founded upon this principle; they are large, close, walled spaces, into which on the one side, the hot gases (flame) are introduced from a hearth built for the purpose, and from the other issues the tar-pipe. The thinnest and most combustible logs are placed in this, as in the other furnaces, at the bottom, where the charring is effected with the greatest difficulty. The expectations raised by this arrangement, as compared with the mounds, have not been realized in practice. It will be found more economical to substitute for the flame expressly prepared for the purpose, that which issues in a useless manner from some furnace employed for other objects; and this has actually been done in some places. Thus, the flame from iron smelting furnaces has been employed with success for the purpose of carbonization in furnaces, several of which may be placed round the mouth of the iron furnace. Supposing them all to be filled with wood, the flame is conducted through a sliding door into the first, until the heat is sufficient to complete the charring; its door is then closed, and the flame is conducted to the next, and so on. Before the last is completely charred, the first has in the mean time been recharged.

The Produce.—The produce in charcoal is apparently, at first sight, very variable. The experiments undertaken on a large scale by Junker, at the instigation of Berthier, at the smelting works in Plauen, are, of all others, calculated to afford trustworthy results. The following woods, all thirty-two years old, were first weighed, and then charred in similar heaps of 5 klafters* each. The weight of the charcoal was ascertained immediately after its preparation, before it had had time to absorb aqueous vapor. Unfortunately, however, the quantity of water in the wood was not previously ascertained. The following results were obtained:

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* Klafter, the Bavarian term for Stecken, = 6 ft. by 6 ft. 3½ ft.

Species of wood.	Charcoal.	Half-charred wood.
	per cent.	per cent.
Green red beech, cut in May, 1832 . . .	19.7	0.6
Pealed " " " . . .	23.0	0.3
Dry " and oak, 2 years old . .	24.0	0.3
Dry oak, 2 years old, pealed . . .	25.7	0.34
Green oak, cut in May, 1832 . . .	22.4	0.3
" pealed " . . .	21.2	
" unpealed " . . .	18.8	1.0
Equal parts of unpealed red beech and oak, cut Jan., 1831, and carbonized in August, 1831 . .	23.4	0.5
Green red beech, unpealed, charred immediately .	12.9	0.3
Green oak, immediately charred . . .	13.5	0.4

The first five experiments were made in August, and consequently at a favorable season; the last five in January, when the weather is unfavorable. The mean produce of all together, is 20 per cent.; furnaces produce 23 to 27 per cent. of the wood used. But in order to draw a fair comparison, $\frac{1}{5}$th must be added to the whole quantity of wood, as that is about the quantity required for heating the furnaces, so that the 27 parts of charcoal are the produce of 120 parts of wood, or 22 per cent. of the wood, being not much more than the average quantity produced in mounds. On the other hand, expenses must be incurred for the erection and repair of the furnaces, which very much exceed what is required for attendance on the mounds. Without reference to the different methods described, amongst which none deserves decided preference, it cannot be denied that they all produce no more than $\frac{2}{5}$ths of the whole amount of carbon contained in the wood, so that there can be no doubt as to the deficiency of all the processes. The wood, in the state in which it is employed, contains 20 per cent. of hygroscopic moisture, 40 per cent. of hydrogen and oxygen, and 40 per cent. of carbon. This is consumed during the process, partly, 1, to evaporate the water formed with that already in the wood; 2, to form, with portions of the other elements, tar and pyroligneous acid, &c.; 3, to evaporate these; 4, to produce a red heat throughout the mass of charcoal; and 5, to supply the constant loss of heat: that which remains after a supply has been furnished for these different objects, is the whole produce in charcoal. If we suppose the whole hydrogen united with oxygen, without taking up any carbon, we shall have $40 + 20 = 60$ per cent. of water to evaporate; this, as will be shown below, will require 5½ per cent. of charcoal; of the remaining 34.5 per cent., 0.6 will be consumed in bringing the whole to a red heat, and from 1 to 2 per cent. will necessarily be uselessly burnt. Any method by which we could obtain the remaining 32 per cent. of charcoal, must force the hydrogen to unite entirely with oxygen, without exerting any affinity for carbon; and as this would be contrary to the laws of chemical combination, science affords us no hope of ever attaining it. According to Stolze's experiments, the carbon contained in the tar and acetic acid amounts to 11 per cent. of that contained in the wood. Statements, like those of Kavanko, according to which the Chinese obtain from 30 to 35 per cent. of charcoal from fresh wood, or the entire amount of carbon, are absurd.

Weight of the Charcoal.—The charcoal obtained from different kinds of wood is not pure carbon; for by heating it a second time, a residue of volatile matters, amounting to 7 per cent., may be driven off. Besides this, it differs in other respects; that from the soft woods is much more porous than hard wood charcoal; *i. e.*, 1 cubic foot of soft wood charcoal weighs considerably less than a cubic foot of that from hard wood; a circumstance that materially affects smelting processes. According to Hassenfratz, who has made the most accurate experiments, the specific gravities of different kinds of charcoal are the following: alder 0.134, birch 0.203, white beech 0.183, oak 0.155, red beech 0.187, red fir 0.176, lime 1.06. A correct notion of the weight of a given mass of charcoal, and the relative weights of different kinds could be obtained, if, in being heaped up together, it did not leave innumerable spaces, the amount of which cannot be determined. The following statements are the mean of a great number of observations made upon a large scale, interstices included: 1 cubic foot of beech-wood charcoal (split wood) weighs from 8 to 9 lbs.; the same wood charcoal (brushwood) 7 to 7.5; charcoal of split oak wood 7 to 8 lbs.; of brushwood 6 to 6.5; of the softer kinds of wood 4.5 to 5.5 lbs.; pine wood 5.5 to 7 lbs. One property of wood-charcoal is very remarkable, and deserves notice, viz., its property of condensing gases; charcoal will often condense 90 times its volume of ammoniacal gas, and 10 times its volume of the permanent gases, nitrogen, oxygen, &c. Fresh charcoal exposed to the air quickly loses its easy inflammability; it gains, however, indisputably in heating power, on which account seasoned charcoal is always preferred in the arts. The cause of this fact is not known; it cannot be explained by the absorption of water and air alone. Common charcoal gains 5.7 and 8, and exposed for a longer time, from 10 to 20 per cent. of its original weight.

Of Charbon Roux (*Rothkohle*).—It has already been stated, in other words, that the object of charring wood is to increase the amount of combustible matter per volume. Thus, a cubic foot of beech wood = 20 lbs., contains, after the abstraction of its hydrogen and oxygen, nearly 9 lbs. of combustible matter; a cubic foot of beech charcoal, on the contrary, contains nothing else, and weighs 12 lbs. We have, therefore, increased its combustible matter ⅓ per cubic foot, and yet it is by no means asserted that the carbonization must be completed, as is the case in charcoal from heaps, in order to obtain the desired result. Berthier pointed out this fact some years back, and it has now been proved in a series of interesting experiments by Sauvages. He charred in the same furnace, one after the other, 5 equal parts of air-dried wood, and interrupted the process each time at a different interval, in order to examine the products of the various degrees of carbonization as to their loss of weight and bulk, and their amount of combustible matter. He found that:

100 lbs. wood charred for	3 hours.	4 hours.	5 hours.	5½ hours.	6½ hours.	Mound charcoal.
weighed . . .	65.4 lbs.	53 lbs.	47 lbs.	41.5 lbs.	39.1 lbs.	17.2 lbs.
and 100 C. F. measured	86 C. F.	76 C. F.	58 C. F.	55 C. F.	52 C. F.	33 C. F.

lastly, they contained of combustible matter:

1	C. F. wood	908	parts by weight.
1	" " charred during 3 hours	883	" "
1	" " " " 4 "	904	" "
1	" " " " 5 "	1133	" "
1	" " " " 5½ "	1091	" "
1	" " " " 6½ "	1136	" "
1	" mound charcoal . . .	1069	" "

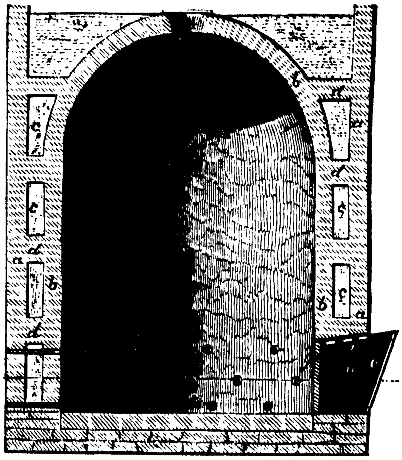
It is evident, from this table, that the amount of combustible matter in equal volumes of charred wood, does not increase even after exposure to heat for 5½ hours, that a continuation of the heat occasions an absolute loss, and that it must be advantageous to stop the process before the formation of mound charcoal is effected, a practice which is already becoming general. Wood of this kind, not completely charred, but only to that point when it contains the maximum quantity of combustible matter per volume, is called *red charcoal* (charbon roux). In France and Belgium, where this new kind of charcoal is in use, it is prepared by a kind of heap carbonization, which does not entirely depend upon the same principle. The heap is more in the shape of a pile, lengthened out, and erected over a channel formed in the ground and covered with iron slabs. The heated gases of a fire, situated at one end, are forced by the motion of a ventilator to pass along the channel, and from thence through a crevice or longitudinal slit, extending the whole length of the iron slab, to permeate the whole mass of the wood, which, thus heated, undergoes dry distillation. On the outside, the heap is covered with a layer of earth, through which the gases are allowed to escape at those parts to which it is desirable to direct the heat, whilst all is covered up, where the opposite object is to be gained. The operation is, therefore, regulated in the same manner as in the mounds with movable coverings. Experience and practice must teach the workman how to apply the principle of mound carbonization to the furnace charring of Schwartz, so as to obtain the greatest possible uniformity in the product. The introduction of red charcoal into a country is of importance, as it effects a great saving in the consumption of wood, the scarcity of which is always on the increase. The greatest difficulty attendant upon the practical employment of this charcoal, is that of obtaining it perfectly uniform in chemical composition, as upon this point its action depends. If this is variable, the furnace man must remain in total ignorance of the right quantity of fuel to be used.

[At the iron works at West Stockbridge, Mass., a part of the charcoal is prepared in ovens holding each 60 cords of wood. Their dimensions are 36 feet long, 12 feet wide and 18 to 20 feet high. This quantity of wood yields 3500 bushels of red charcoal, which, computed on the Winchester bushel of 2150 cubic inches, give the bulk of charcoal 67 per cent. that of the wood employed.]

Of the Preparation of Peat Charcoal.—The charring of peat is very much facilitated by two circumstances. The rectangular form of the peat bricks admits of their being piled up together without leaving those interstices, which is such a great objection in the wood mound, and the lesser combustibility of peat charcoal renders such minute attention to the process unnecessary, and admits, with advantage, of the construction of heaps very much less in circumference. These consist generally of 700 to 1000 bricks; they are from 6 to 7 feet in diameter, and 4 feet high. Around the stake, which is driven into a dry place, the peat-bricks are arranged endwise in concentric series, forming circular layers, of which four, five, or six, with an internal decreasing diameter, are placed one above the other, with this precaution, however, that in all four directions air-channels or passages, of the width of a brick, are left in the direction of the radius, by means of which the heat is afterwards regulated; otherwise the peat heap would be too closely packed to allow any passage of air through its interstices. At the foot of the stake some dry wood is placed for ignition; the heap is covered with an inner coating of moss and leaves, and with an outer one of earth or charcoal dust, leaving only the middle part of the hood round the stake uncovered, for the purpose of setting fire to the heap by one of the passages. By opening and shutting these channels, the combustion is conducted in all directions until flame breaks forth from the opening in the hood, which is then closed. The completion of the charring is then effected by apertures all round, beginning at the hood and proceeding foot by foot to the base. The appearance of the smoke issuing from these apertures is here also the indication of the stage and state of the operation. The nature (age) of the peat, its consequent density, &c., must direct the burner. A mound, of the circumference stated, produced from not quite air-dried peat, 24 per cent. of the weight and 27 of the bulk; from air-dried, 27 per cent. in weight and 32½ in volume; from freshly dug Pfungstadt peat, 30 per cent. in weight and 29 in bulk; from excellent peat, quite dry, 35½ of the weight and 49 per cent. of the bulk. In the district of Siegen very good peat produced 23 per cent. of the weight and 40 per cent. of the bulk. Experiments upon a small scale generally afford a still larger produce, sometimes as much as 40 per cent. of the weight. Much difficulty is attached to the drawing and quenching the peat charcoal, which are undertaken when the mound has cooled during a certain time, for the charcoal easily crumbles to powder and is then useless.

In Furnaces.—The use of furnaces affords no increase of produce, but a safer regulation of the fire, and is more applicable to peat, as that substance is always obtained upon the same spot, and it is not necessary, as in the forest, to follow the clearing or to transport the material. In the manufactory of arms at Oberndorf in Wirtemberg, there are charring furnaces which have stood the test of ten years' experience, and have been approved; such a one is represented in Fig. 5. It is in the form of an upright cylinder, closed at the top by a circular arch, 9 feet in height, and 5½ feet in diameter, containing 189 C. F. The furnace itself *b* is surrounded by a second wall *aa*, in such a manner as to leave a space *cc*, which is filled up to the dome with sand as a bad conductor of heat. Both walls are of brick, each one singly is 15 inches thick, as is the space *cc*, so that the entire thickness of the walls is 45 inches. *dd* are stones, placed longitudinally and perpendicularly, to give greater solidity to the walls. Above the sole of the furnace are three rows of draught holes, pieces of old gun barrels walled in, which can be closed with bottle stoppers. The door for drawing out the charcoal can be closed by the cast iron slab *f;* the iron support of the door projects slightly forward, and can be closed in the front by a board *e*, and the space *m* then filled with sand from *g*. On charging, a channel is left in the axis of the furnace, for igniting the contents. In the beginning, the charging aperture *i*, and the lower draught holes, are left open, and as soon as the peat appears white hot, they are closed, and the upper ones opened. When all smoke has ceased, all the apertures must be closed, or filled with sand, and a layer of sand placed over *i* about one foot in thickness; this occurs in about forty to forty-eight hours, and then the furnace is left during six or seven days to cool.

Fig. 5.



That no interruption may occur, ten such furnaces are worked at the same time. Peat charcoal, as far as heating power is concerned, ranks amongst the best kinds of fuel; it possesses, however, at the same time, properties which render it unfit for many purposes. If 100 lbs. of peat leave 21 lbs. of ash, and produce 47 lbs. of charcoal, these 47 lbs. of peat charcoal will contain 21 lbs. of ash, *i. e.* 45 p. c., which affect the processes in which it is employed, *e. g.* forging; partly on account of its quantity, and partly by entering into fusion, and acting chemically upon the bodies to be heated. As most kinds of peat are rich in ash, this must be augmented to such an extent in the charcoal, as to render the greater number of them unfit for carbonization. Another great objection to peat charcoal, is its loose, brittle character, which causes it soon to fall to pieces, and become useless.

In high smelting furnaces the pressure of the layers of ore suffices to crush it; its application is, therefore, confined to open boilers and forge fires. This want of firmness has been found to render this charcoal quite unfit for removal, and the carbonization must be effected on the spot where the charcoal is to be used.

Charring of Brown Coal.—Of all kinds of fuel, brown coal is least adapted for carbonization, although it is decomposed with as much ease as wood, and the charcoal which it produces is not so easily inflammable. As regards the amount of ash, what has been said of peat, applies to brown coal, but even the best kinds of brown coal are not easily charred, for, during the action of heat, the single layers, concentric rings, &c., which are scarcely perceptible in the fresh specimens, split off, and a compact piece of brown coal becomes thus completely separated into small fragments, or is so split about, as not to bear carriage. In experiments with lignite from the Hessenbrücker Hammer (in the Wetterau), 15½ p. c. by weight, and 32 p. c. by volume were obtained by carbonization in heaps. This quantity is too small to pay for the cost of manufacture.* In the neighborhood of Cassel, where circumstances are more favorable, the carbonization in mounds is actually carried out, but only upon a small scale.

Experiments made with brown coal upon a small scale, in which the coal was heated in close crucibles, until no more vapors were evolved, gave the following results:

	100 parts.	Charcoal %		100 parts.	Charcoal %
	Earthy coal from Dar .	49.1	Bohemian.	Lignite from Neundorf . .	38.4
	“ “ Bouch. d. R.	41.1		“ “ Coulang . . .	38.1
	“ “ Basses-Alpes.	48.5		“ “ Jahnsdorf . .	32.8
	Lignite from Greece . .	38.9		“ “ Paredal 1 . .	39.6
	“ “ Cologne . .	36.1		“ “ “ 2 . .	40.7
	“ “ Iceland . .	57.5		“ “ “ 3 . .	42.0
Left side of the Rhine near Düren.	“ “ Raddergrube	41.6		“ “ Antoni-Zeche .	40.0
	“ “ “	49.7		“ “ Wellonitzer Br.	35.9
	“ “ Gr. Urwelt .	44.3		“ “ Nemtschauer Br.	34.7
	“ “ “	43.9		“ “ Hartenberg 1 .	37.2
	“ “ “	51.3		“ “ “ 2 .	34.6
	“ “ Friesdorf .	28.2		“ “ Kanden . . .	37.5
	“ “ “	48.2		Pitch coal from Grünlat . .	37.2
	“ “ “	46.8		Earthy coal fr. Hartenberg 1.	42.1
	Earthy “ Uttweiler .	68.2		“ “ “ 2.	48.4
	“ “ Raddergrube	48.3		“ “ “ 3.	36.8
	“ “ “	46.4		“ “ “ 4.	39.0
Right side near Bonn.	Lignite from Pützchen .	46.4		Pitch “ “ 1.	43.9
	“ “ “	44.7		“ “ “ 2.	40.3
	“ “ “	51.0		Earthy coal from Soaz . .	46.4
	“ “ Stöszchen .	29.1		Pitch coal from Reichenau .	38.1
	“ “ “	40.6		“ “ “	29.3
	“ “ Orsberg . .	62.8		“ “ Altsattel . .	40.3
	“ “ “	68.4		“ “ “	35.0
Bohemia.	“ “ Auzig. . .	40.1	Bavarian Oberpfalz	Earthy coal from Verau . .	35.6
	“ “ “	40.0		Lignite “	46.0
	“ “ Hegendorf .	41.2			

In England, a cwt. of coal costs about 8½*d.*, one cwt. of charred coal about 5*s.* 10*d*

Carbonization of Pit Coal. General Principles.—The charcoal which is left as the residue after the action of heat upon pit coal, is commonly called coke. It has been already mentioned at p. 32, in what manner the different kinds of coal are acted upon, and produce various kinds of coke. Caking coal softens during decomposition, and leaves charcoal with more or less distinct traces of fusion. As in this kind of fuel, the oxygen does not predominate, and it is the hydrogen, which at a high temperature carries off the carbon, it was supposed that the property of caking was due to the predominance of the latter over the former. It is no doubt true that 12.5 parts of hydrogen can combine with as much carbon as 100 parts of oxygen, but the predominance of the hydrogen over the oxygen, is not sufficient to explain the manner in which the coal is acted upon by heat, as the following examples taken from Regnault's analyses will prove, in which analyses, particular care was taken to describe the nature of the coke. The formulæ represent the relation of the equivalents calculated from the analyses.

		Relation of H to O.
Anthracite from Balduc, sand coal . . .	= 80 C+ 44 H+ O	44 : 1
Coal from Blanzy, sinter coal . . .	= 80 C+ 64 H+6 O	10.7 : 1
Cannel coal from Lancashire, sinter coal . .	= 80 C+ 64 H+3 O	21 : 1
Coal from Mons (flenû) caking coal . .	= 80 C+ 120 H+5 O	24 : 1
Coal from Grand Croix (maréchal) highly caking .	= 80 C+ 56 H+3 O	18.7 : 1

It will be seen that the property of caking generally increases with the quantity of the latter two elements, particularly with that of the hydrogen. Anthracite, consisting almost entirely of carbon, may be viewed as a kind of natural coke resulting from the process of coal formation. Although the hydrogen is on the increase in all the rest, in proportion as they soften in the fire, yet in the last, which possesses this property in the highest degree, the reverse is the case, its hydrogen amounting to only half the quantity contained in the caking coal from Mons.

It is remarkable that the same should be the case with the younger coal of Obernkirchen, which is also of a highly caking character. It also produces a porous, friable coke, and has the composition 80 C+ 52 H + 3 O or O : H = 1 : 17. An explanation of this property of the coal can, therefore, only be expected from an investigation of the arrangement of its elementary molecules, that is from its constitution, a subject upon which science has yet to throw more light.

Desulphurization.—The production of coke is undertaken with the same general object in view, as the production of wood charcoal; but it is desirable, for many purposes, to free the coal from sulphur. In this sense the production of coke is also called the desulphurization. For purposes connected with the arts coke must be compact, in large pieces not liable to crumple and form dust, and it must possess a certain degree of solidity, so as to stand pressure in smelting furnaces without being crushed. Both qualities must be considered in the choice of the material selected for its production. Sand coal must be discarded on the first ground, and too highly caking coal on the second; the latter crumbles, because the holes or cells are too large, and the walls of these holes or cells are too easily compressed.* Experience, however, has shown that the softness of coke is dependent upon the mode of its production, and that this may be remedied accordingly. If, for instance, coke is prepared under the pressure of a heavy covering, the blisters which form in the softened coal are pressed together, after the escape of the gases which caused them, and a denser coke is produced. In order to obtain good coke, caking coal, which approaches sinter coal in composition, should be selected.

As coke is much less inflammable and only burns well with a good draught, but is soon extinguished in furnaces with little draught and in the open air, and as the coal is always furnished on the same spot, fewer precautionary measures are requisite, and the operation of coking is more easily and better effected in a stationary apparatus.

In Heaps.—The oldest and still very common method is that of mounds or heaps, in which the operation, however, is not conducted in the same manner as in the wood heaps. No covering is employed, but carbonization is commenced with free access of air, and a coating of dust is first applied when the coke has already been produced, and the attention of the burner is required to prevent its further consumption. The coking station is always the same, and becomes sufficiently covered of itself with charcoal debris. In order to prepare more coke at once, long heaps have been substituted for the original circular mounds; the length of these is of no consequence, and according to circumstances and the consumption of coke, they may sometimes extend 200 feet. A string is stretched along the coke station, in order to point out the axis of the heap in the direction of which large pieces of coal are made to lean against each in the beginning, so that a longitudinal channel (ignition passage) is formed through which the string passes. It is of consequence to notice the natural stratification of the coals; they must always be placed upright (as compared with the direction of the layers), and with their fractured surfaces at right angles to the axis of the heap. Parallel with the first series of coal, is placed a second, and then a third, and so on; but the pieces constantly diminish in size, until the station measures six feet on both sides. Upon this substructure the heap is then made without particular care in the arrangement, the largest pieces below and the smallest above, until it has reached about two feet. To facilitate the ignition, stakes are rammed in at distances of two feet from each other throughout the whole length of the heap, and project from the top. When they have been taken out, spaces are left into which burning coal is introduced. The fire thus spreads at once from more than a hundred places through the passage of ignition.

As soon as the burner observes the thick smoke and flame cease at any part, or that any part becomes covered with ash, he endeavors

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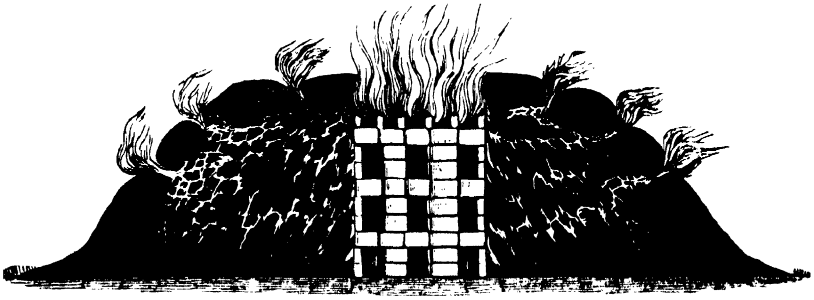
* But much depends also on the rate of coking, whether a dense and compact or a loose and friable coke shall be obtained.—Am. Ed.

immediately to stop the progress of the fire by covering it with powdered charcoal, and repeats this throughout until the whole is covered in, and the heat is then left two or three days to cool. The covering on the side exposed to the wind should be thicker, according to the quantity of wind. When the fire is nearly extinguished, which is the case after as many more days, the coke is drawn. This mode of procedure is simple, but not very economical; the extension of the fire proceeds from without (properly above) towards the interior and downwards, so that the upper coal is already coke at a time when the inner part of the heap is only heating, and requires air, which consequently must not be excluded by a covering, although it is requisite to protect the outer coke. Whilst the inner portion, therefore, is becoming coke, the outer portion which is already coke is being consumed, without a possibility of preventing it. A somewhat different method practised, for example, at the Clyde iron works in Scotland, completely obviates this difficulty.

Fig. 6.



In Mounds.—Fig. 6 represents such a mound; it is round and treated in the same manner as those employed for wood charcoal. A conical brick chimney three or four feet high is erected upon the coke station, three feet wide at the base; but whilst building a brick is left out from time to time, so that throughout the whole structure a number of apertures *A A* remain, by means of which the inner part of the channel remains in connection with the heap of coal surrounding it. The heaviest pieces of coal are placed nearest the chimney and gradually diminish in size towards the outside, by which arrangement the mound assumes a round shape; care is likewise taken in constructing the mound to leave free channels or spaces from the apertures *A A* to the circumference. The inclination of the mound must not be too great, that the covering of ashes (cinders) with which it is enclosed may have a sufficient support. The mound represented in the figure is about twenty feet in diameter, and four and a half feet high, so that with its covering it exceeds the height of the chimney by a few inches. The ignition is effected by the chimney, into which burning coals are thrown, which gradually communicate the flames to the mound through *A A*, beginning, therefore, from the bottom and the middle, which is of importance. Spaces are made at the foot of the mound to admit of air passing through, and escaping by the chimney. Gradually at the end of four or five days the surface becomes red hot as may be seen through the covering, the mouth of the chimney is then covered with an iron plate, and the spaces are closed for about three days, when the coke is drawn. In other parts, where the same sort of mound is used, the process is conducted in a different manner, and resembles that practised with the heaps first described. The mound has then no covering, and the chimney is covered immediately after ignition with an iron slab. The flame then penetrates the mound, fed by the air which has everywhere free access. As soon as the flame ceases at any spot, it is covered with cinders, and so on until the whole is covered. The heat which has now been attained, is sufficient to drive off the last portions of vapor and tar, which pass out from the re-opened mouth of the chimney. When these are no longer evolved, it is again closed and the mound allowed to cool. One advantage over the carbonization in open heaps is still preserved, and that is, that the process proceeds from the interior towards the exterior, which is not the case in the heaps.

In Furnaces.—The use of furnaces is considered in many countries more profitable. All the furnaces destined solely for the production of coke, (and not of tar and gas, for which see gas illumination,) are worked with access of air, and never by a separate fire from without. One of the most commonly used, is depicted at Fig. 7, and its horizontal section at Fig. 8; both represent a coke furnace used at the Tyne iron works and elsewhere. The drawing represents four furnaces, which are so arranged as to save brick-work and retain the

Fig. 7.

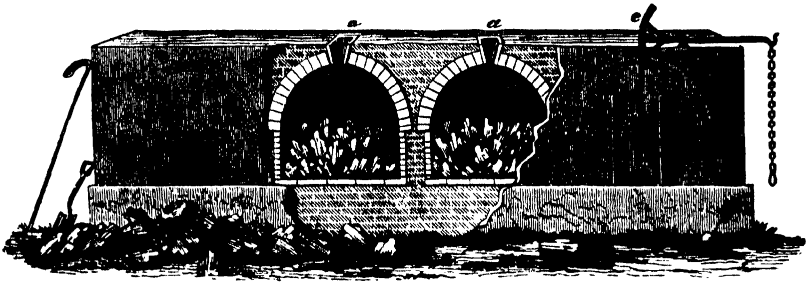
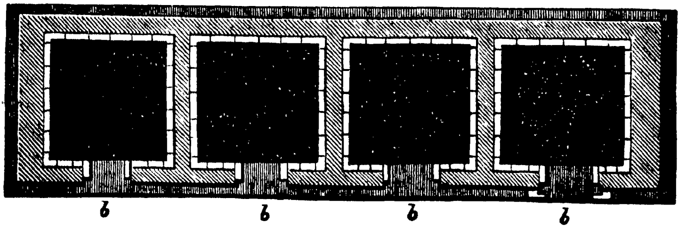


Fig. 8.



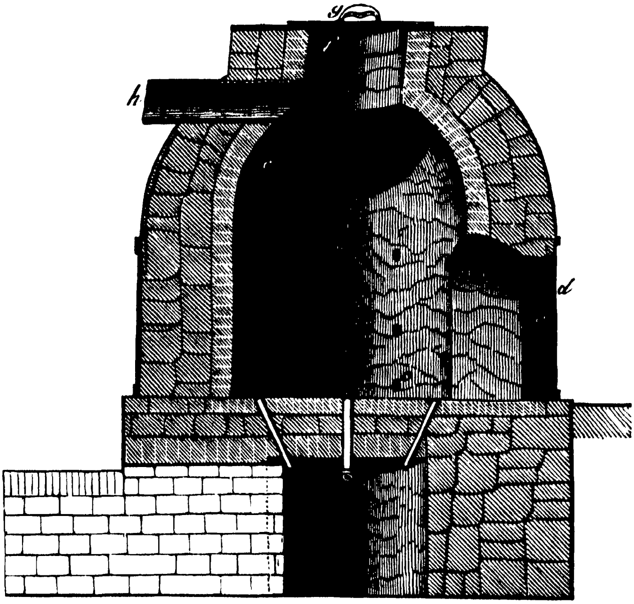
heat. Each single furnace is a square space, arched at the top, is constructed of brick, ten feet deep, twelve feet wide, so as to contain 120 square feet of coal, and ten feet high. The whole thickness of the wall is two feet, including the internal lining of fire stone. No grate is requisite, but in the centre of the arch *a*, an aperture is made 2½ feet wide, and another *b b* at the bottom of the front wall, for the introduction of the coal, and which can be closed by a door three feet square. The aperture *a* is supplied with an iron ring, the opening *b* with an iron casing which forms a groove *c*, in which the door slides. This door consists of an iron frame, filled with brick work, which is movable in *c*, and is suspended at *d*, the lever *e* with its chain *f* serves to move it. In the brick work of the door, are a number of draught openings *g g*; these, however, are often wanting, and then the case of the door does not fit exactly, but is loosely set in bricks, so that sufficient air has access. The first furnace in the drawing has a door of a less convenient construction.

The working of these furnaces continues day and night without interruption, except when repairs become necessary, and the first operation is the charging. By the open door *b b*, two tons = 40 cwts. of coal, is introduced into the furnace, which quantity just reaches to the base of the arch, (leaving, therefore, space for swelling,) and is spread out by rakes. As soon as the charging-door is closed, the coal catches fire, and a thick smoke issues from the aperture in the arch, which is only closed towards the end of the process. It must be remembered, that the furnace, which is constantly at work, was only deprived of its charge of coke the moment before, and received consequently, the new charge whilst in a red-hot state; it is, therefore, the heat of the walls which ignites the coal on all sides; this heat, however, would be insufficient to char the whole mass of the coal; but the operation is urged on by air rushing in from the apertures *gg*, igniting the vapors arising from the coal, and thus raising the temperature of the interior to the required pitch. At the expiration of three hours, the intensity of the heat is so great, that the lower opening, *gg*, must be closed, in order to moderate the access of air, which constantly enters at *g g*, and passes off at *a*. In twenty-four hours, from the time of beginning, on the second morning, according to the usual process, the upper draught-holes are plastered over, and the furnace remains for twelve hours with the mouth *a* open, during which time the remainder of the gases and vapors are driven out of the coal by the existing heat, and pass off in flame. When this ceases, *a* is closed with a slab of iron, or with stones, which are covered externally with sand, in order, during the next 12 hours to moderate the heat. The whole time expended, from the charge being placed in the furnace to the time the coke is drawn, is 48 hours; it is evident that the furnace must then still be red-hot; but the slight combustibility of coke admits of the door being now opened, the coke raked out into iron wheelbarrows, quenched with water, and carried away. The furnace is then charged again as quickly as possible, and the process repeated.

Whilst the contents of one furnace are being drawn off, the other is at work, and so on, that the labor may be equally divided.

In most coal countries, large quantities of tar are obtained in the production of coal-gas for illumination, and the secondary products of the coking process are, consequently, not collected. In Silesia, on the contrary, the industrial relations of the country are so distinctly in favor of collecting the tar, that that point can by no means be neglected. In Gleiwitz, for example, the arrangement represented in Fig. 9, has been recently employed. The furnaces there are cylindrical, arched over with a hood, about 8 feet high, and built of bricks. They are charged by the opening *a*, which is afterwards bricked up with dry bricks, and closed on the outside by an iron door *d*, the crevices in which are filled with clay; *f* is the mouth of the furnace, with an appropriate cast-iron door *g*. The air has access (for here, as in the former case, no external fire is applied) by the apertures *c c c*, which are ranged one above the other in rows, reaching to the hood. The lowest of these are in the sole of the furnace itself, which thus becomes a kind of grate, and is hollow beneath. It is as well, however, if not better, to make the sole of massive brickwork, so that the draught-holes occupy the sides, beginning at the same level. The tar vapors and gases are conducted during the operation, through the tube *h* in the side of the hood to a cistern, which condenses and collects the former, allowing the latter to escape. During the cold season the tube *h* leads directly to this cistern; but in

Fig. 9.

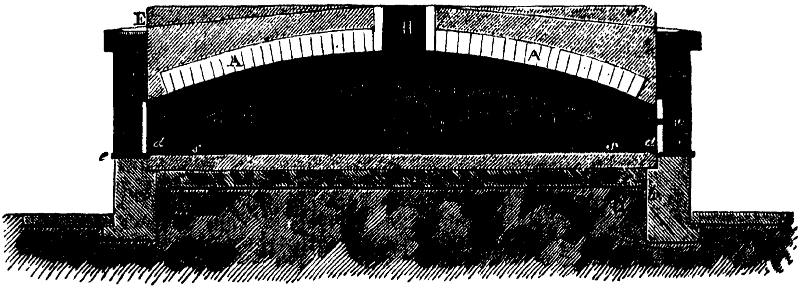


the summer it is carried in a zig-zag manner through a water-tank, for the purpose of aiding the condensation.

In the first instance, large lumps of coal are introduced at *a*, leaving, however, a small space for the insertion of burning coals, then smaller pieces at *f*, in all about 35 to 40 cwts. When the first have taken fire, the two larger apertures, and the upper rows of draught-holes *c c* are closed, and the lower row only is left open. As soon as the fire, as seen through these openings, assumes a reddish-yellow color, the holes are closed, that the second row may be opened, and so on. The first row is closed after 10 hours, the second is allowed to remain open for the same time, the third row 16 hours, and the last, or uppermost, 3 hours, after the closing of which, the furnace is left for 12 hours before the coke is drawn. With four of these furnaces, eight or nine burnings are made weekly in Gleiwitz. The coal which is used there is of a slightly caking character, without being very poor in hydrogen. As the average of several months, the cwt. produces 74 parts by volume, 53 per cent. by weight of coke, and about 5¼ gallons of tar. The same coal, charred in heaps, produces only 47 per cent by weight of coke, which is much more porous and less dense, so that, compared with furnace coke, a like bulk weighs 1,3 times less.

The refuse coal from the pits, coal-dust,* &c., which, in itself, is of very little value, can be turned to good purpose if it is of a caking character; for the single pieces, in becoming soft, adhere together and compose as solid a coke as the large coal. A trial has been made in St. Etienne, by stamping moist coal-dust into wooden boxes, which can easily be taken to pieces and are furnished with pegs on the inside, to form small mounds, with corresponding draught-channels, which are ignited after the removal of the mould. Too much loss, however, and manual labor have caused this mode of procedure to be supplanted by the use of closed furnaces, of which, the one represented at Fig. 10, being that used at Rive de Gier, on the Loire, is a good illustration. The construction is the same in principle as the common baking-oven; namely, a flat arched space, with an even sole without grate, which,

Fig. 10.



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* For a recent application of refuse coal to the manufacture of a patent fuel, see Appendix.

heated by the previous operation, ignites the charge which follows just in the same manner as was the case with the previously described furnace. The sole of the furnace *s s* is oval-shaped, 11½ feet wide, and 23 feet long, composed of a mass of clay 6 inches in thickness, which is spread out and stamped upon a layer of small stones, *t t*, through the interstices of which its moisture can escape. The foundation contains in the centre an empty space *D D*, which being filled with earth or rubbish, forms the more immediate support of the sole. In the two small sides of the furnace, are the working apertures *d d* opposite each other, 2.8 feet wide, and 2 feet high, each of which is surrounded by a frame of cast-iron fixed in the wall, in which the sliding-door *P* moves up or down. The latter is a kind of flat iron box, filled with brickwork, and turned with the door side to the interior of the oven, in order the better to withstand the heat. In the middle of the door is a small aperture *o*, through which the workman can observe the progress of the operation. The greatest distance between the arch and the sole is in the middle, and amounts to 4 feet; a small chimney *H* is there erected 1.6 feet in diameter, and 1.8 feet high. In the interior of the furnace, at *H* and *A*, the brickwork is composed of fireproof materials, and clay is used instead of mortar; outside are common stones, covered with a layer of mortar, which has been sifted previously together with sand; *e* are thresholds before the doors, for drawing the coke out with rakes, and are of stone or iron.

As soon as the coke from the previous process has been removed, the furnace is again charged, without delay, with coal-dust, which must be kept moist, that it may easily cake together. If the coal cakes very much, the mass spread over the sole of the furnace must not exceed 8 inches in height; if it is less liable to cake, the depth of the charge may be 10 inches: it must be uniformly spread out, and the doors then closed, with the exception of a narrow slit at the bottom for the introduction of air. The furnace will contain from 60 to 70 cubic feet of coal. When the heat of the furnace begins to act upon the coal, which is quickly the case, aqueous vapor, sulphur, and combustible gases are copiously evolved. It has been found advantageous to prolong this stage of the process as much as possible, in order to secure a large product of coke, and for this reason also, it is well to wet the coal-dust. Properly conducted, this part of the operation should occupy two hours, the slight draught being only just sufficient to carry off the vapors; the evolution of vapor then rapidly diminishes, and the combustible gases passing off in greater quantity suddenly ignite, with a kind of explosion; the yellow smoke then ceases for a moment to be succeeded by a black cloud. At this stage, the mass of coal is at a low cherry red heat, and it becomes necessary to increase the draught in order to drive off the whole of the vapors and volatile matter. To effect this, the door is raised about 3 inches: the fire immediately draws up, and a dusky, sooty flame issues from the chimney. After three quarters of an hour this becomes clearer and white, the heat is then uniform over the whole mass of coal, which begins to split and crack, and must not be disturbed. In three quarters of an hour more, these fissures have extended to the very sole of the furnace, and when the whole is at full red heat the door is closed, and the crevices filled with clay. The heat now generated is sufficient to complete the carbonization, and to drive off the last portions of volatile matter. For a time the flame still flickers, becoming whiter and whiter, at a considerable distance above the chimney, but gradually diminishes, threatening to die away altogether, because the evolution of gas from the interior has entirely ceased. If more time were lost, the air would, at last, enter by the chimney as the pressure diminishes, for which reason the cover is advanced more and more over the chimney, and at length completely closes it. That no heat may be lost, the coke is now removed as quickly as possible: the doors are opened without delay, the mass of coke broken up with staves, and raked into the barrows, sprinkled with water, partly to quench the fire more quickly, and partly to decompose the remaining sulphur compounds, the presence of which are recognized by the odor* of the aqueous vapors arising from the glowing coke. The furnace then receives a fresh charge, and the same process continues uninterruptedly. Each operation requires about 24 hours.†

Produce.—The method just described affords a larger produce than any other process of carbonization. The annual average, from observations made at Rive de Gier, was 69 per cent. coke; with inferior coal and less care, they always obtain not less than 60 to 65 per cent.; whilst coal and pit-dust in the mound, only yield 45 to 50 per cent.; and in the heap, rich coal yields 40 to 45 per cent. Coal containing little hydrogen, of course, produces more, and indeed about ⅓. General experience has shown that the furnace produces denser coke than the mound; and this, again, coke more dense than the heap; and yet the coals in the two latter cases scarcely yield their own volume, whilst in the furnaces this increases in the ratio of 10 : 12. On the other hand, the smelters find the coke from heaps and mounds much more free from sulphur than that from the furnaces, which is generally, although not necessarily, the result of those processes having been used, which in other respects afford so many practical advantages.

Nature of the Coke.—The product of this operation forms first a connected mass, but on cooling, splits into a number of more or less similar pieces, sometimes in the form of basaltic columns, sometimes as irregular lumps with warty excrescences. Its structure is *porous*, or finely *vesicular:* only highly caking coal forms large vesicles; in the first variety the color is a light iron gray with a silky lustre; in the other it is blackish gray, and its lustre is fatty. A play of colors is said only to occur in coke that is rich in sulphur; it is by no means a desirable property. For the most part, the individual portions of the fibre-coal may be distinguished here and there in the mass itself; by carriage and heaping together, these portions split off, and cause

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[*] Of sulphuretted hydrogen and sulphurous acid.

[†] For additional matter concerning coke, see Appendix.

a waste of a certain per centage. Coke, like charcoal, attracts moisture from the air, in damp weather as much as 30 per cent. In general it is better not to keep the coke too long, as exposure to the weather causes it to become soft and crumble.

Relative Value of Fuel.—Common every-day experience is sufficient to show that different kinds of fuel are by no means capable of producing a like amount of heat. It therefore becomes interesting and important to learn the methods which science has adopted for ascertaining the maximum effect of the different kinds of fuel. The results obtained from these researches are called the *theoretical effect.* For ascertaining this, the knowledge of two things is indispensable; namely, the *quantity of heat* which a certain amount of fuel is capable of producing, and the *time* which is required for effecting that object. These two points furnish the idea of what is called *heating power.* The *value of the fuel* depends upon its *heating power*, and its price at the time of consumption; it varies, therefore, in different localities, and can only be relatively fixed.

Strictly speaking, the determination of the first point (the quantity of heat) is impossible, as heat cannot be weighed or measured; the quantity of heat, therefore, which a body produces during combustion, cannot *itself* be ascertained, but for practical purposes a knowledge of the *absolute* quantity is not required; it is sufficient to know how much the quantity of heat produced by one kind of fuel exceeds or falls short of that produced by another, the actual quantities produced by each, being left undetermined. In short, a knowledge of the relative quantities of heat is all that is required, and for obtaining this, science offers several means. All researches of this kind, and undertaken with this object, must only be considered as relative. The more ancient, purely physical experiments, undertaken by the most distinguished men of science, were all conducted upon the same principle, that of causing the whole quantity of heat (actually unknown) which a burning substance or fuel emits, to act upon a third body, in order to compare the action which the different kinds respectively have upon it. The apparatus by which this is effected, is the well-known calorimeter. Lavoisier and Laplace caused the heat in this instrument to act upon ice, and measured the heat by the quantity of ice that was melted. At a later period, Count Rumford, to whom we are indebted for many experiments upon fuel, used water instead of ice, and measured the quantity of heat, by the increase of temperature in a given quantity of water. Both methods of determination are in fact the same, if we remember that the same quantity of heat which will melt 1 lb. of ice at 32°, is just sufficient, according to Lavoisier and Laplace, to raise the temperature of as much water (1 lb.) 135° F. (75° C.); or what is the same thing, to raise 0,75* lbs. of water 180° F. (100° C.) When it is further taken into consideration, that according to Clement and Desormes, an

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* This number they obtained as the mean of two determinations, which were 73 and 76. From the more recent and accurate experiments of de la Prevostaye and Desain, as well as from those of Regnault, it appears that this number must be raised to 79.

equal weight of aqueous vapor, whatever may be its temperature and tension, is always formed from one and the same amount of heat, and consequently always contains the same quantity; and, moreover, that the quantity of heat which water at 212° absorbs (latent heat) in a manner no longer indicated by the thermometer, in order to be converted into vapor, would, according to Clement and Desormes be 5,5, according to Rumford 5,67, and by more recent experiments 5,72 times, sufficient to heat the same weight of water from 32° to 212°, it becomes easy to calculate how much water would be converted into vapor by the heat that is required to melt 1 lb. of ice. Thus the latent heat of vapor* (1030°), divided by the heat absorbed by melting ice (142°), give 7,25; and conversely $142 \div 1030 = 0.136$ lbs. vaporized by the "heat of fluidity" of 1 lb. of ice.

Rumford's experiments on wood led to the following results:

One pound of the following kinds of wood when burnt will heat:	Pounds of water from 32° to 212°.	One pound of the following kinds of wood when burnt will heat:	Pounds of water from 32° to 212°.
1. Limetree wood.		6. Sycamore wood.	
Dry wood, 4 years old	34.707	Strongly dried in an oven	36.117
" " slightly dried	38.833	7. Wood of mountain ash.	
" " strongly dried	40.131	Strongly dried in an oven	36.130
2. Beech wood.		Dried brown	32,337
Dry wood 4 or 5 years old	33.798	8. Wood of bird cherry.	
" " strongly dried	36.476	Dried wood	33.339
3. Elm wood.		Strongly dried in an oven	36.904
Wood rather damp	28.147	Dried brown	34.736
" dried, 4 or 5 years old	30.205	9. Fir wood (deal).	
" strongly dried	34.083	Ordinary dry wood	30.322
" dried brown	30.900	Well dried in the air, in shavings	34.000
4. Oak wood.		Well dried in an oven, in shavings	37,379
Common fire-wood, in small shavings	26.272	Well dried brown, in shavings	33.358
The same in thicker shavings	25.590	Well dried, in thick shavings	28.695
" " thick shavings	24.748	10. Poplar wood.	
" " dried in the air	29.210	Wood dried in the ordinary manner	34.601
Very dry wood, in thin shavings	29.838	Wood strongly dried in an oven	37.161
" " thicker "	26.227	11. Hornbeam.	
5. Ash wood.		Dried wood (ordinary)	31.704
Common dry wood	30.666		
The same dried in air, shavings	33.720		
The same, shavings dried in an oven	35.449		

A most remarkable connection between the quantities of heat evolved, and the chemical process of combustion, was first pointed out by Welter in the calorimetrical experiments of Laplace, Lavoisier, Despretz, Rumford, and others, and gave rise to a new and more convenient method of determining the heating power. He found, namely, that those quantities of a combustible body which require an

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* By our own experiments, the latent heat of the vapor of water is 1030° Fah. (See Report on the "Strength of materials for steam-boiler," pp. 44–5.)—Am. Ed.

equal amount of oxygen for combustion, evolve also equal quantities of heat, as is shown by the following examples:

1 pound	will heat pounds of water from 32° to 212°	1 pound of oxygen in consuming	will heat pounds of water from 32° to 212°.
Hydrogen . .	236.4 Despretz	0.125 pounds	2.955
Charcoal . .	78.15 "	0.375 "	2.931
Quite dry wood .	43.141 Rumford	0.724 "	3.093

In the greater number of combustible bodies, the differences are not greater than might be anticipated from the difficulties attending all calorimetrical researches, whilst in others, as phosphorus, iron, &c., they are twice as great. Thus far Welter drew the conclusion, that the oxygen required for the combustion of a body being in the same relation, and as the quantity of heat evolved, it could reasonably be made the measure of the heating power. In fact, we are led *a priori*, to this supposition, if we consider, that on the one hand, the heat evolved must bear some relation to the mass of the body burnt; on the other hand, however, that oxygen may just as well be considered the combustible portion, as the body with which it combines (the fuel). When, therefore, oxygen burns by means of carbon, wood, hydrogen, &c., the heat which is evolved must increase with the quantity of it that is consumed; the supposition of Welter has not, however, obtained any positive proof. Nevertheless, Berthier has founded a practical process upon it, to determine by one experiment the quantity of oxygen requisite for combustion, and thus the heating power of the combustible. It consists in heating to redness a weighed quantity of the combustible with a large excess of pure litharge until the combustible is completely consumed by the oxygen of the oxide of lead as it would be by that of the air. Every equivalent of oxygen that is used, leaves an equivalent of reduced metallic lead. We have, therefore, only to weigh the metallic lead in order to discover the amount of oxygen consumed and the heating power, always supposing, that the object in view is merely a comparison of the relative powers of the different kinds of fuel. If, however, it is required to ascertain the quantity of water heated up to 212° F., it becomes necessary to refer to the known calorimetric power of a single combustible body. Carbon is usually chosen, which is then made the standard of comparison. Now 1 part of pure carbon requires 2,666 parts of oxygen, which taken from litharge, leave 34,5 parts of metallic lead; the same quantity of carbon, according to Despretz, is sufficient to heat 78,15 parts of water from 32° to 212°; so that each part of lead that is reduced by an experiment with any kind of fuel, *corresponds to* $\frac{78{,}15}{34{,}5} = 2{,}265$ *parts of water, which will be raised by its means from 32° to 212°.* **An elementary analysis, in which any substance is completely consumed—its carbon being converted into carbonic acid and its hydrogen into water—is a means of calcu-**

lating with greater accuracy the requisite quantity of oxygen for combustion and the consequent heating power.* As 1 part of carbon takes up 2,666, and 1 part of hydrogen takes treble that quantity, namely 8 parts of oxygen, we have only to deduct from the sum of both, the quantity actually present in the combustible, in order to ascertain the quantity furnished from without, and that becomes the measure of the heating power; *e. g.*, in oak-wood there are: 0,4943 parts carbon, and 0,0607 hydrogen, which would give

$$0{,}4943 \times 2{,}666 + 0{,}0607 \times 8 = 1{,}318 + 0{,}485 = 1{,}803.$$

If the oxygen in the oak-wood, viz. 0,445, is deducted from that quantity, we obtain 1,803—0,445 = 1,358 as the amount of oxygen required, corresponding to 17,57 of lead or 39,8 of water, which would be heated to 212° by 1 part of oak-wood. All the elementary analyses cited above, are therefore so many determinations of heating powers, and are here placed by the side of direct experiments made upon Berthier's plan, partly by himself, partly by Winkler, Karmarsch, and others.

I. DIFFERENT KINDS OF WOOD.

Species of Wood.	Dried in the ordinary manner. Berthier.		Containing 9 0/0 water. Winkler.		Perfectly dried. Schödler and Petersen.			
	Pounds of lead reduced by 1 lb. of wood.	Pounds of water which a pound can heat from 32° to 212°.	Pounds of lead reduced by 1 lb. of wood.	Pounds of water heated by 1 lb. from 32° to 212°.	Pounds of oxygen required for the complete combustion of 1 lb.	Pounds of water consequently heated from 32° to 212°.	Quantity of air at 60° required to consume completely 1 lb.	
							in lbs. av.	in C. F. English. (13.2 C. F. = 1 lb.)
1 part Oak wood	12.5	28.3	14.05	31.82	1.358	39.82	5.83	77.0
" Ash "			14.96	33.89	1.356	39.76	5.82	76.9
" Sycamore "	13.1	29.7	14.16	32.07	1.394	40.85	5.98	79.0
" Beech "	13.7	31.0	14.00	31.71	1.346	39.44	5.78	76.4
" Birch "	14.0	31.7	14.08	31.90	1.356	39.73	5.82	76.9
" Elm "			14.50	32.84	1.418	41.55	6 08	80.3
" Poplar "			13.04	29.54	1.390	40.72	5.96	78.8
" Lime tree "			14.48	32.80	1.429	41.87	6.13	81.0
" Willow "			13.10	29.67	1.352	39.61	5.80	76.6
" Fir "	14.5	32.8	13.86	31.39	1.408	41.25	6.04	79.8
" Pine "	13.7	31.0	13.88	31.44	1.392	40.82	5.98	79.0
" Scotch fir "			13.27	30.06	1.393	40.85	5.98	79.0
" Hornbeam "	12.5	28.3						
" Alder "	13.7	31.0						
" Larch "					1.408	41.25	6.04	79.8

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* *Practical experiments upon a large scale, as well as elementary analysis, have shown that the determinations made with litharge are liable to a constant error, and are always* (about $\frac{1}{9}$th) short of the truth. [See below (p. 86), Table of experiments on American coals, litharge reduction and ultimate analysis, compared with evaporative power.—**Am. Ed.**]

II. CHARCOAL.

Pounds of lead reduced by one lb of charcoal according to Berthier.			Pounds of water heated from 32° to 212° by 1 lb. of charcoal.	Pounds of lead reduced by one lb. of charcoal.	Pounds of water heated from 32° to 212° by 1 lb. of charcoal.	Required for perfect combustion
				Winkler.		
Commercial	Poplar charcoal	30.60	On an average 68.	33,56	On an average 75.7	On an average 146 C. F. air at 60°.
	Sycamore "	30.60		33,23		
	Ash "	29.60		33,23		
	Asp "	29.5				
Enclosed in bottles immediately after being made.	Fir "	32.3	On an average 72.	33,51		
	Alder "	32.4				
	Birch "	31.4		33.71		
	Oak "	31.3		33.74		
	Beech "			33.57		
	Elm "			33.26		
	Lime tree "			32.79		
	Willow "			33.49		
	Pine "			33.53		
	Scotch fir "			33.62		

III. VARIETIES OF PEAT.

Locality.	Berthier.		Locality.	Winkler.	
	Pounds of lead reduced by 1 lb of peat.	Pounds of water heated from 32° to 212° by 1 lb. of peat.		Pounds of lead reduced by 1 lb. of peat.	Pounds of water heated from 32° to 212° by 1 lb. of peat.
Peat from Troyes .	8.0	18.1	Among 24 sorts from the Hartz mountains, the worst gave	11.9	26.9
" Ham, dép. de la Somme .	12.3	27.9	" " the best.	18.8	42.6
" Bussy, dép. de la Marne .	13.0	29.2		Griffith.	
" Framont, dép. des Vosges	15.4	34.9	From Allen in Ireland		
" Ischoux, dép. des Landes	15.3	34.6	" " upper	27.7	62.7
" Königsbrunn,			" " lower	25.0	56.6
Wirtemberg	14.3	32.4	" pressed peat	13.7	28.0

Karmarsch found, in an extended examination of more that 100 varieties of Hanoverian peat, a considerable difference amongst the individual kinds, which could not be definitely traced to their age or other properties, but with reference to age, the following mean values were obtained:

1. Recent peat.
   a. Yellow grass peat evaporated per lb. 1.78 lbs. of water, and
   b. Brown and black peat, 2.03 lbs. of water.
2. Old peat.
   a. Earthy peat, 1.98 lbs., and

b. Pitch peat, 2.08 lbs. of water. In general, the quantity of water vaporized by 1 lb., ranged between 24½ oz. with the worst, and 36¾ oz. with the best kind.

IV. PEAT CHARCOAL.

Source.	Berthier.		Source.	Berthier.	
	Pounds of lead reduced by 1 lb. of charcoal.	Pounds of water heated from 32° to 212° by 1 lb. of charcoal.		Pounds of lead reduced by 1 lb. of charcoal.	Pounds of water heated from 32° to 212° by 1 lb. of charcoal.
Crouy-sur-Ourcq. depart. Seine and Marne	17.7	40.1	Essone, much used in Paris . . .	22.4	50.7
— Ham . . .	18.4	41.7	Framont, and peat from Champ du feu	26.0	58.9

V. BROWN COAL.

Locality.	Berthier.		Locality.	Berthier.	
	Pounds of lead reduced from the oxide by 1 lb. of coal.	Pounds of water heated from 32° to 212° by 1 lb. of coal.		Pounds of lead reduced from the oxide by 1 lb. of coal	Pounds of water heated from 32° to 212° by 1 lb. of coal.
Gemeinde Dauphin, Basses Alpes . .	25.3	57.3	St. Lon, Basses Pyrenees	20.3	46.0
St. Martin de Vaud, Canton de Vaud .	22.6	51.2	Val-Pineau, D. Sarthe	19.25	43.6
Minerme, dep. de l'Aude	22.8	51.6	Common German .	18.40	41.7
Gardanne, Bouches du Rhône . . .	22.0	49.8	Edon, dep. de la Charante	17.0	38.5
Fuveau	21.0	47.6	Alpheus, Greece . .	16.3	36.9
Enfant Dort . . .	21.0	47.6	Triphilis " . .	16.3	36.9
Koep Fuarch, Lake of Zurich . . .	20.7	46.9	Kumi " . .	15.8	38.8
			Elbogen, Bohemia .	18.2	41.2
	Kühnert.			Regnault.	
Brown coal from Meiszner . . .	20.1	58.9	Earthy coal from Dax	21.38	62.6
Pitch coal from Meiszner	15.9	46.6	" fr. Bouches du Rhône	18.89	55.3
" Ringkuhl .	16.9	49 5	' Lower Alps	16.69	48.9
" Habichtswald	16.0	46.9	" Greece . .	17.84	52.3
Glance coal from Ringkuhl . . .	19.3	56.5	" Cologne . .	18.24	53.4
Pitch coal from Habichtswald . . .	19.0	43.6	" Usnach . .	15.90	46.6
Lowest stratum Ringkuhl	19.0	43.6		Varrentrapp.	
Mid. stra. Ringkuhl .	19.0	43.9	Helmstedt, Prinz Wilhelm's mines . .	20.17	59.1
Stillberger coal . .	14.1	41.3	" other mines	21.83	63.9
Lignite from Meiszner	14.7	43.1	Schöningen, Gr. Treue	18.76	54.9
" Laubach	17.5	51.3	" other mines	18.60	54.5

VI. MINERAL COAL.

Locality and kind of coal.	Berthier.		
	lbs. of lead reduced by 1 lb. of coal.	lbs. of water heated from 32° to 212° by 1 lb. of coal.	According to the analyses, page 28.
a. Caking coal.			
Coal from Dowlais in Wales	31.8	72.0	
Glamorgan	31.2	70.7	
Eschwiller, near Aix-la-Chapelle	31.0	70.2	69.7
Lippe-Schaumburg	30.9	70.0	80.0
Newcastle	30.9	70.0	71.5
Carmeau near Alby	30.1	68.2	
Rive de Gier, Grand Croix	29.6	67.0	78.0
Mons, Bouleau-Fontaine-Madame	29.0	65.7	
Cannel coal, Wigan	28.3	64.1	76.0
Mons, Grand Gaillet	28.1	63.6	
Rochebelle, near Alais	27.6	62.5	79.7
Mons, nvll. Alliance pit	27.4	62.1	
Bonchamp, Haute Saône	27.3	61.8	
Bessèges, Aveyron	27.0	61.1	
St. Pierre la Cour, near Mayenne	27.0	61.1	
Epinac, Saône and Loire	26.8	60.7	72.8
From Oviedo in Asturia	26.1	59.1	
Treuil mine, near St. Etienne	25.4	57.5	
Bellestat, Aude, so called Jayet	24.4	55.2	
Jayet (unknown locality)	23.3	52.8	
b. Sinter coal.			
Cherry coal, Derbyshire	27.2	61.6	
Soft coal "	26.3	59.5	
Oviedo in Asturia	26.1	59.1	
Cannel coal from Glasgow	24.9	56.4	
St. Georges di Lavencas, Aveyron	24.0	54.5	
Cannel coal from Lancashire	23.5	53.2	
Ombrowa, Silesia	21.2	48.0	
Salin, Jura	21.0	47.5	
Vazas, Slavonia	19.4	43.9	
c. Sand coal.			
Durham	31.6	71.6	
Rolduc, near Aix-la-Chapelle	31.0	70.2	80
Zinsweyer, near Offenberg	22.2	50.3	

VII. COKE.

Species of coke.	Berthier.	
	lbs. of lead reduced by 1 lb of coke.	lbs. of water heated from 32° to 212° by 1 lb. of coke.
A la Garre, from coal of St. Etienne	28.5	65.6
From coal of Bessèges	28.4	64.3
" " Rive de Gier	26.0	58.9
Gas coke from Paris	22.2	50.3

	Excess of hydrogen.		Excess of hydrogen.		Excess of hydrogen.		Excess of hydrogen.
Oak-wood . .	5.08	Beech wood .	6.50	Poplar-wood	8.20	Deal . . .	9.50
Ash	5.05	Birch . . .	7.50	Lime-wood	13.90	Pine wood .	8.80
Maple . . .	8.30	Elm . . .	10.00	Willow . .	7.00	Scotch-fir .	7.70
						Larch . .	8.60

This excess of hydrogen, on heating the wood, will give rise to the formation of gaseous hydro-carbons, and as these carry away a considerable portion of carbon, the residue of charcoal will be diminished. It is principally these gases and vapors which burn so readily, and produce the flame. The lighter kinds of wood are, therefore, chemically characterized by a larger excess of hydrogen, which causes the first stage of their combustion (*combustion with flame*) to be augmented at the expense of the second—the *incandescence of the charcoal;* they consequently generally burn with greater facility, or, what is the same thing, they *evolve their heat in a shorter space of time* than the hard woods; this property may very properly be called that of *greater combustibility.*

The time required for combustion, and consequently for the evolution of heat, is also dependent upon the state of division, or the size of the logs, charcoal lumps, or peat bricks, &c., in which they are exposed to the fire. A certain weight of wood, for example, exposed in fine shavings, will come vastly more in contact with the consuming air, than when it is in the form of a single compact piece. In the former case, many more portions of the wood would burn simultaneously than in the latter, and the evolution of heat would be over in a comparatively small space of time. Whilst the compact lump is slowly consumed, and is capable of keeping the surrounding parts (the sides of the furnace) at a moderate temperature for hours, the shavings would for a few minutes bring it to a red heat. This circumstance is practically of much importance. As surely as the combustibility (the quantity which is consumed within a given time) is increased at first by division, so surely, if that division be carried beyond a certain limit, does it act in an opposite manner, until the combustibility is completely destroyed. Charcoal powder, saw-dust, crushed coal of the best quality, powdered peat, &c., cease to be combustible bodies, because, whatever kind of grate may be used, the small particles lie so close together as to leave no space for the access of air; in this state, they are valueless. Caking coal only, can be converted from this state into compact coke, and made available. Fuel that falls to pieces when exposed to heat without caking again, is also subject to this evil. Pulverulent waste from peat, wood-charcoal, and pit-coal, is sometimes made available by mixing it with as much softened clay as is necessary to make it cohere, forming it into bricks, drying, and selling it as an inferior fuel, under the name of briquettes, or *combustible bricks.* The pit refuse from caking-coal may be employed in the same manner, as a means of effecting cohesion. One part of smithy-refuse from St. Etienne, is capable of forming a compact coke with from 2 to 3 parts of brown-coal; each shovelfull of this mixture thrown upon the fire, forms in a few minutes a compact lump, which burns as well as large coal.*

Concluding Remarks.—As combinations of organic origin, the kinds of fuel which have here been described, are not very simple in constitution, and therefore offer but slight resistance to external modifying causes, *i. e.*, they are easily decomposable bodies. Chemical combinations generally can only exist within the limits of certain temperatures, these limits being greater for simple than for complex bodies. The varieties of fuel are not volatile; the chemical equilibrium amongst their elements is destroyed on an increase of temperature long before their volatilization can be effected. The decomposition caused by heat, is nothing more than an overthrow of the existing arrangement of the elements, as, for instance, in wood, and an immediate re-arrangement with the formation of new compounds capable of existing at the higher temperature. The nature of the products is, therefore, mainly dependent upon the latter; at different temperatures of decomposition, these cannot be the same; and they must vary in quantity still more than in quality; but the result will be essentially different, according as air (oxygen) takes part in, or is excluded from, the process. In the former case, the products are immediately subjected to the energetic chemical action of oxygen, and forced to part with their elements; combustion results, therefore, as a secondary process. In the latter case, where decomposition by heat is effected without access of air, we have what is called in chemistry, dry distillation, in which operation the products can be conveniently collected and studied, and this demands particular attention, because upon it are founded important transformations of certain species of fuel.

From all that has been said about the nature of fuel, it is evident that the "invention" of any new kind must be absurd; any such can only be a preparation of refuse coal of some kind, which, nevertheless, may be better fitted for some uses than the natural material. If the advantages of the so-called Carboleine, lately discovered by Weschnaekoff, (a mixture of small coal, and probably refuse fat,) and so highly extolled, prove to be well-grounded, its higher price, as compared with pit-coal, will be fully compensated by its more concentrated heating power, and prove of advantage to steam navigation.

All the experiments which have been adduced, give the comparative quantities of heat which can possibly be obtained from the fuel, ex-

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* The objection stated in the text to the use of fuel in a state of powder, has been completely removed in practice in glass works, boiler fires, &c., by covering the surface of the grates with lumps of sandstone, limestone, &c., thereby preventing the powder falling through the grates, and spreading the supply of air through the particles of the fuel lying on these lumps.—T. R.

Anthracite dust is extensively used under steam boilers and for other useful purposes, its combustion being kept up by forcing air through it with a powerful fan blast. It has also been converted into combustible bricks with coal tar from gas works, and used in locomotives.—Am. Ed.

pressed in quantities of water heated, or of steam generated. They, therefore, express the greatest amount of heat which these can afford. If the quantity of heat actually obtained in practice, and made available, according to the present state of our arts and manufactures, be placed in comparison with this, we shall find that it is exceedingly small. A considerable portion of the heat, therefore, which is dormant in the fuel, is either not evolved in practice, or is lost, and not made available. Both cases occur; but that we may better perceive the sources of this loss, it will first be necessary to obtain a knowledge of the principles upon which the application of heat depends.

Of the Application of Heat.—The application of fuel to practical purposes is called heating, and the object of it is to evolve the heat from the fuel as completely as possible in suitable arrangements (stoves, fires, &c.), and to conduct it, without loss, to the purpose it is intended to serve. This latter is either purely industrial, in as much as the heat evolved is made to aid the conversion of raw material into the objects we stand in need of—all fusing, melting, boiling, roasting, forging operations belong here—or it is one of daily occurrence, namely, the heating of those spaces which we inhabit during the cold season, *the heating of dwellings.* As the other cases will be more fully treated of in describing the various arts and manufactures, we shall first consider the heating of rooms exclusively.

The chief object of heating is, to maintain, by means of fuel, the air contained in the room at a temperature required by our physical wants, and to preserve its temperature above that of the cold air without. It happens, however, that the power of air to transfer or conduct the heat which it has received through its mass, is very small, and any quantity of air would be heated with difficulty and very slowly, if a current were not produced in it at the beginning, which must be considered the chief disseminator of the heat. The layer of air immediately in connection with the heated medium, (the sides of the stove,) undergoes, as soon as its temperature is raised, an increase of volume, and consequent diminution of weight; it is, therefore, immediately forced from its position by colder air, and is compelled to betake itself to the higher regions. The previously colder air undergoes the same motion, and so on, until, at length, the whole quantity of air in the room, in the course of this current, has come into contact with the heated surface. The velocity of such a current is, therefore, dependent upon the extent of the heating surface in general, and upon the difference of temperature between it and the heated room, or, what is the same thing, between the surface of the stove and the cold air; it is not, however, in direct proportion with it, but is in the ratio of the square root. If the air in the room, for example, is 59° Fah., and the surface of the stove at one time 176°, and at another 112°, the current in the latter case will be $\sqrt{\frac{176-59}{212-59}} = \frac{1}{1.1}$ more rapid. Lastly, as heat from any source is communicated radiation, as well as by conduction, the more distant layers of air become warmed in this manner, and carried up by the current. In this manner, the heating of rooms would be a very easy matter, and would be effected quickly, and at small cost of fuel, if several circumstances did not occur which cannot be avoided, and by which a constant withdrawal of heat, and loss of heated air, are going on. First, the walls of the room, the windows, and doors, will constantly take up heat, and evolve it again externally; secondly, the air in the interior being warmer and lighter, will not be in equilibrium with the external air; all crevices, therefore, in windows and doors, and particularly the opening of these, will allow cold air to stream in from below, whilst hot air passes out above; lastly, it is absolutely necessary that the air which has passed through the lungs and the skin should be replaced, in other words, that rooms should be ventilated. According to Munke's estimate, the loss, after deducting what is necessary for ventilation, amounts in 12 hours to 5 times, and according to another estimate, to 6 times the quantity of heat that is required to heat the air of a room of ordinary dimensions, 36° Fah. In individual cases, this quantity must always vary, and be expressly determined. This loss is partly compensated by the vital heat of the persons present in the room, as also by the lamps and candles which are burnt; but it is certain, that the greater part of the fuel is not consumed for the purpose of heating the air of the room, but in order to make up for the constant loss which we have noticed. Proper arrangements, for instance, double windows and doors, which enclose a stagnating layer of air, materially lessen the loss of heat. During the time that a door is open, the warm air will stream out from above, and the cold will enter from below; and this will take place the more rapidly, the greater the difference of temperature between the two.

Hence it is very advantageous to allow the doors to open upon warmed ante-rooms. It must, of course, be understood, that no statements can be generally applicable to all localities. The amount of loss may, however, be empirically found in every case, by ascertaining how much the temperature of a room sinks in a given time after the extinction of the fire. Heating the air in the manner described, is always effected by one arrangement, in which the combustion of the fuel, and the conduction of heat are combined. The manifold forms and shapes which are given to these arrangements, do not prevent our distinguishing three distinct parts: the space in which the combustion takes place; the space in which the heat exerts its influence, and, lastly, the chimney, which is partly necessary to create the draught of air, and partly to carry off the products of combustion. The two primary conditions which every arrangement must satisfy, are, the maintenance of a temperature capable of consuming the material, and the supply of air (oxygen) necessary for combustion. A want of either the one or the other, is invariably attended with imperfect combustion, and consequent defective evolution of heat, a circumstance which can never be altogether remedied in practice.

The air that is required for combustion is sometimes supplied, as in metallurgic processes, by machines for that purpose; but in most cases, as in room-stoves, kitchen-ranges, boiler-furnaces, &c., the heat itself is used as a means of supplying the fire-place with air; this is done by *chimneys*, which are essentially nothing more than a channel leading to a certain height above the fire-place, the diameter of which, whatever may be its form, must correspond, within certain limits, with the size of the fire, and communicate freely, above and below, with the air. The column of air which occupies the interior of the chimney, is kept in equilibrium by a column of equal magnitude without; a state of things which ceases, however, as soon as the fire begins to warm the internal column, expanding it, and rendering it lighter. The equilibrium is then destroyed, the external air enters the space left vacant by the ascending inner column, is again heated in its turn, and gives place to another quantity of cold air, and so on; in short, a draught is created which lasts during the whole time of combustion. The superior gravity of the external air increases and diminishes with the height of the chimney, and its temperature. We know that air is expanded $\frac{1}{274}$th of its volume for every additional 1° C. of temperature, or $\frac{1}{493}$d part by every degree Fahrenheit;[*] in a channel of equable diameter, this may be measured directly by the height. If h represent the height of the chimney, t the difference of temperature between the external and internal column of air, we have $h - \frac{h\,t}{493} = h\left(1 - \frac{t}{493}\right) = h'$, as the height of the internal column of air, supposing it to have the temperature of that without. The former is, therefore, shorter than the other by $h - h'$, or $h - h\left(1 - \frac{t}{493}\right) = \frac{h\,t}{493}$ a difference of height through which this must pass in order to enter the chimney. The velocity which it has acquired at the end of its descent, is just that with which the air in the chimney is moving, and according to the law of falling bodies, just double that of the acceleration gained during the descent.[†] For the present case, in which $s = \frac{h\,t}{493}$, we have therefore, $c = 2\sqrt{g\,\frac{h\,t}{493}}$ as the velocity which must obtain according to theory. The formula, however, is based upon assumed conditions, which are never actually present in practice, and experience has shown that the real velocity in a chimney, on account of irregularity in the walls, and retarded flow of air through grate and fuel, as well as on account of the altered chemical nature of the latter, &c., remains so far behind the theoretical calculations, that the latter cannot be made use of to ascertain its real value.

These circumstances may partly be made the subject of calculation,

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[*] This is according to the determinations of Rudberg, Regnault & Magnus.—AM. ED.

[†] If g represent the space which is traversed by a body falling freely in a second, (16.1 ft. English) t the duration of the descent in seconds, s the space passed through in the time t, and c the acquired velocity, we obtain $c = 2\,gt$. And because the space traversed is proportional to the square of the time occupied, or $s = gt^2$, it follows that

$$t = \sqrt{\frac{s}{g}}, \text{ and hence } c = 2\,g\sqrt{\frac{s}{g}} = 2\sqrt{gs}.$$

so far at least as is necessary to understand the mode of their action. The friction which the current of air suffers against the inner sides of the chimney, is an obstacle of some importance; the force of the current coming in contact with the rough sides, is partially broken, and this must increase with the number of the irregularities; *i. e.*, with the height of the chimney and the force with which the reverberation occurs, or with the velocity of the current, and depends, lastly, upon the nature of the material composing the chimney. Common brickwork covered with mortar, offers much more resistance than cast or sheet iron. A narrow chimney, under the same circumstances, will act more unfavorably than a wide one, as in the latter the greater portion of the column of air will pass through the centre of the chimney, and not touch the sides. In a very narrow channel, every particle of air will come in contact with the side. The friction, therefore, generally decreases with the increase in diameter. The actual velocity of the current has been found considerably under what it should be, according to calculation, even when those influences which have been mentioned, and the amount of which has been determined by experiment, are taken into consideration. This is explained by adventitious circumstances, as the want of regularity in supplying fuel, accumulation of soot, stoppage of the grate by ash, &c., which always occur more or less in practical manipulation.

As the increase of diameter and of temperature in the chimney are means of partially decreasing the friction, it becomes interesting to know how far these can be practically applied. It is clear, from what has already been said, that the disadvantages accompanying the heightening of the chimney may be avoided by widening at the same time; but calculation proves that this must cease when the height of the (round) chimney exceeds the diameter 30 or 40 times, therefore, very soon. By an ingenious contrivance, these narrow limits have been exceeded. The contrivance is this; the mouth of the chimney remaining of the same size, the remainder of its length is very much widened; thus the necessary quantity of air passes through the grate and the fuel with the same velocity as before—and this is the real object of the draught—but spreads itself out afterwards in the wider channel, flowing, consequently, with less velocity and proportionally diminished friction. Calculation shows the greatest advantage to be obtained, when the mouth is ¼th the width of the chimney; for it is obvious, that, with an increase of width, the mass of brickwork, and with it the amount of cooling which it occasions, must also increase. There will, therefore, be one point, where the advantage of diminished friction will be counterbalanced by the disadvantage of cooling. The principle upon which the construction of chimneys is based, supposes the draught to increase in proportion as the temperature of the interior exceeds that of the outer atmosphere; this, however, occurs in a less proportion (in the ratio of the square root) than the increase of temperature; so that above 482° Fah., no increase of draught is obtained, when the height of the chimney is 20 times its breadth. When one portion of the chimney is horizontal, no great difference in its action is observable, if the entire height is not diminished by it; but the friction and cooling effect are somewhat increased. All contractions above the mouth must, however, be carefully avoided. Lastly, it is worthy of remark, that the wind generally exerts a retarding influence, which is difficult to overcome; this can only be effected by heightening the chimney and increasing the draught, or by adapting some arrangement to the mouth so as to prevent the pressure of the wind from acting below a certain height.

The most important part of the fire-place is the support for the fuel, inasmuch as this is open to afford access for the air; it is called the grate. The spaces between the bars of the grate should be wide enough to allow the ash to fall through, and at the same time narrow enough to keep back the coal; they form together the entrance to the chimney. The form of the bars and their distance from each other have, consequently, a considerable influence upon the draught. The section of the bars must be such as to allow the spaces to be wider on the lower side; and strictly, they should together form an opening which is to the diameter of the chimney as 1 to 4, such a relation having been shown to be practically the best. But a great part of the surface of the grate must always be stopped and rendered ineffective by the fuel upon it; the amount of this obstacle will vary with the kind of fuel, and can only be estimated by experience. In fact, the number of spaces must be at least 4 times that calculated from the section of the chimney, and therefore collectively they must have the same area of opening as the latter in order to work well, and their number must also depend upon the quantity of material which the fire-place is intended to consume at one time. The greater the heating power of the fuel, the wider may be the grate, and vice versâ. The grate may be altogether dispensed with when wood is used, and holes in the door may be substituted for it. The shape of the grate is of less importance; but when it aids the uniform sinking of the fuel, when it is deepened or basket-shaped, &c., it may materially assist the process of combustion.

Of heating arrangements in general.—In order thoroughly to understand the principles of applying heat, it is necessary to remember that the heat evolved from fuel is disseminated to surrounding bodies in two ways, by *radiation* and by *immediate contact.* Peclet has examined these points, with the aid of a very ingenious apparatus. He surrounded fuel, contained in a round wire basket, with a ring-shaped vessel, in such a manner that the quantity of water contained in the latter could only be heated by radiation from the surface of the globular basket. By comparing the size of the radiating surface with the quantity and the temperature of the heated water, it was found that the radiated heat from wood was $\frac{1}{4}$, from wood charcoal $\frac{1}{2}$, from coal about as much, and from peat and peat-charcoal $\frac{1}{12}$ of the whole amount of heat evolved. The radiant heat is therefore nearly always the smaller quantity, and on that account, the arrangements in which it is only employed for heating the air of dwellings, are not advantageous. Nevertheless these, which are called fire-places or hearths, and belong to the most ancient modes of heating dwellings, are still the most common in many countries. The chimney opens as usual into the room, and at the lower part, a few feet from the floor, it widens, forming a recess, at the bottom of which is a kind of basket or grate for the fuel, fixed in such a manner that the fire burns unenclosed in the room, but the smoke passes off by the chimney. The air, therefore, flows from the room to the fire, becomes heated and passes off—and this constitutes the great evil—directly into the chimney, without having an opportunity of parting with its heat for any useful purpose. In addition to this, the quantity of air cannot be regulated in an open fire, and a considerable portion of the warmed air of the room is uselessly carried away by the draught. The only way in which the fire can warm the air, is consequently by radiation. All the improvements made by Rumford and others upon open grates, tend, therefore, to facilitate radiation towards the room, to make use of the escaping air as much as possible without injuring the draught, and lastly, to regulate the draught. With this object in view, the grate is brought forward as much as possible from the wall of the chimney, and the sides of the recess are so formed, that their inner surface, acting like the reflector of a lamp, shall collect the rays of heat, and reflect them into the room; moreover, the size of the recess has been lessened and fitted with dampers to avoid a loss of heat, and yet the loss is still very much greater than in the other arrangements. The last-mentioned object has given rise to a new method of heating, which combines the advantages of an open fire with those of a stove, and has, consequently, been called the stove fire-place. A stove of this kind, invented by Desarnod, stands forward isolated in the room, and instead of being immediately connected with the wall of the room, has an iron plate at the back, above which, through a slit, the smoke passes off, and after circulating, is carried to the chimney. The room is then warmed, not only by radiation, but also by the immediate contact of the air of the room with the heated iron plate and the tube in which the smoke circulates. The thorough circulation, occasioned by an open fire, as well as the agreeableness of seeing the fire, which is certainly great, are reasons in favor of continuing this mode of heating in countries where the winters are not too severe, and the summers not too hot to allow of its adoption.*

Of Stoves.—The arrangement by which combustion takes place in the room, but, with the exception of the grate, in a closed space, and by which the heat evolved is communicated first to the sides of the enclosing space, and from these to the air of the room, comprises the different kinds of *chamber stoves.* Whilst in an open fire, the heat is communicated immediately from it, and no hot chamber is really present; this generally forms the most important part of the stove, and is of considerable extent. The communication between the

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* The Appendix will contain a description of some of the most recent improvements in fire-grates.

chimney and the hot chamber is generally effected by means of sheet-iron pipes, which are no unimportant part of the stove. In the greater number of dwelling-houses the chimneys are made so wide, that a man may ascend them for the purpose of sweeping; the chimney thus exceeding the proper dimensions, ceases almost entirely to cause a draught, and only serves to carry off the smoke; the draught must, therefore, be effected by the smoke-pipe. This pipe ascending in the room, and surrounded by the air, may be viewed as a continuation of the hot chamber, and very much adds to the effect produced by the latter. In addition to the requisitions made upon a hot air chamber (page 89), stoves in particular require that the heating chamber should be correctly proportioned to the quantity of fuel, which must depend upon the size of the room, the loss of heat that will occur, and upon the ventilation. The heating chamber must have surface enough to communicate the heat which it receives in a given time, and in such quantity as will compensate for the loss of heat from known causes, supposing the quantity of fuel used to be in the right proportion. The materials which are used for the construction of stoves, are cast iron, sheet iron, bricks and mortar. It thus becomes necessary to know the relative degree of facility with which they communicate the heat they receive; for we know, from daily experience, that iron conducts and communicates heat much more readily than clay. This power of communicating depends, indeed, upon two things, and in the first place, upon the power of conduction, which, according to Despretz, is nearly 33 times less in clay than in iron.* But the heat has to be communicated not only from particle to particle throughout the material of the chamber, but also from its surface to the air, which occurs partly by contact and partly by radiation, the different surfaces acting in very different manners in this respect. By both methods together, this communication of heat from the surface to the air is, according to Peclet, in sheet iron 1.21 times, and in cast iron twice as rapid as in clay; so that, under similar circumstances, the iron will in the same time give off $33 \times 2 = 66$ times, and sheet iron $33 \times 1.21 = 39.93$ times as much heat as clay. In order, then, to obtain the same effect from a surface of clay, it must be 39.93 times larger than one of sheet iron, and 66 times one of cast iron. Iron stoves, therefore, heat and cool quickly, clay stoves the reverse. The object in view must always decide to which the preference should be given. When the fuel is consumed with that degree of rapidity which is requisite to the evolution of the entire amount of heat, this is given off with far greater intensity than is appropriate for the heating of dwellings, which should have a uniform temperature; *i. e.* for this purpose a complete but very slow evolution is required, that the air of the room may, as nearly as possible, be kept at a temperature of 20° C. (68° F.) It will easily be under-

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* Peclet has corroborated this statement by recent experiments, according to which, plates of 1 square metre surface, and 1 mm. thick, at a temperature of 1° C., allow heat to pass through in the relation of clay to iron as $0.24 : 7.95 = 1 : 33,1$.

stood that iron is not the most appropriate material for this purpose, as it disseminates its heat as quickly as it receives it. Clay, for the contrary reason, is decidedly preferable; with whatever degree of rapidity heat may be communicated to it from within, it always gives it out much more slowly and gradually. Inasmuch as more heat is amassed by clay than is at first given out, a kind of accumulation is made, which is as advantageous as it is agreeable in regulating the combustion. In Germany, a distinction is made between the common iron *Leitung-stove*, which from its cheapness, durability, and the facility with which it can be manufactured on a large scale, is commonly used, and the so-called *Massen-stove*,* in which the heating is not effected through the walls of clay, or iron pipes, or both together, but the heat accumulated during combustion by a solid mass of stone is gradually given out from it when the fire has been extinguished. From the given quantity of air (= A) which the stove must hourly heat (to t°) to make up for the loss by cooling and ventilation, the requisite amount of clay surface may easily be calculated. The mean weight of 1 cubic foot of clay is 125 lbs.; 1 cubic foot of air, at 60° F., weighs 0.07575 lbs.; therefore, 1650 times less than an equal bulk of clay, and the same amount of heat produces the same rise of temperature in like masses of both bodies. The specific heat of air and of clay are nearly $\frac{1}{4}$th that of water. The heat, therefore, required to raise 1650 cubic feet of air to the desired temperature, or t° above the outer air, will be sufficient to produce the same effect in 1 cubic foot of clay. The latter, however, becomes by the action of the fire, much hotter, and warms the air of the room by cooling gradually from a maximum temperature $= T^\circ$ to a temperature t'°, which is still sensibly higher than t°. The heat evolved during cooling will warm a greater body of air to t° in the ratio of $t^\circ : (T - t')^\circ$, whence we obtain $Q = \frac{A\,t^\circ}{(T - t')^\circ\,1650}$, as the volume of clay corresponding to the body of air to be heated. In the greater part of Germany, Leitung-stoves are employed, but in the North (Sweden and Russia,) the Massen-stove is preferred, and is sometimes used as a bed.

Heating by means of channels or flues.—Another mode of applying heat, and the most ancient mode, having been used by the Romans for heating their baths and still common in hot-houses, &c., is that by means of flues. The hot gases and smoke produced in a grate placed below, and on the outside of the space to be heated, are conducted through a system of channels under the floor, where they part with their heat and then escape by the chimney. Unfortunately, this mode of applying heat, certainly the best adapted for dwellings, can only be managed in the lowest floor of the house, and even there with difficulty. Of course, in heating by means of flues, care must be taken to allow no heat to be conducted away below, by lining the

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* The distinction between the German *Leitungsöfen* and *Massenöfen* is simply this, that the former is made of metallic materials, and the latter of clay, bricks, or of what are known as "Dutch tiles."

lower part of the flue with rubbish or non-conducting substance. Heating by flues only differs from that by stoves, inasmuch as they are in different positions as regards the room; as the fire in the latter is below, the conducting pipes or flues may be brought under the floor, from whence the heat is better circulated throughout the room. In one respect only, the two fires or stoves differ distinctly from each other; the stove, viz: to which flues are adapted, should itself conduct away as little heat as possible, all being reserved for dissemination by the flues.

Heating by means of Hot Air.—In cases, where, for the sake of elegance, safety (in prisons, &c.), or from want of space, the stove is better removed from the room, the necessary quantity of air can be heated in another part of the building, and conducted by pipes into the different rooms. This method has very improperly been called *heating by hot air*—a name which applies equally to every mode of heating rooms. It is evident that the air already in the apartment must be able to make room for the current of warm air. Either no particular attention is paid to this, and the air is allowed to escape by crevices in windows, by opening doors, &c., or the portion which has been used and become cold is conducted back to the stove, again heated, and then performs a second circulation; or lastly, the air of the room is conducted to the stove, not, however, to be warmed again, but for the supply of oxygen to the fuel in the interior of the stove. The second case combines the great evil of imperfect ventilation, which can only take place by casual openings of windows or doors, with a certain economy of warmed air; but this is only apparent, for the more perfectly the room is closed, the sooner it will be necessary to remove the vitiated air, and supply its place by a fresh quantity. The last method causes a saving, by supplying warm air to the fire from the room, instead of cold air from without. If 1 lb. of air-dried wood requires 5 lbs. = 66 cubic feet of air at 32° for combustion, and when, moreover, according to Rumford, 26 lbs. of water will be heated by it to 212°, or $4 \times 26 = 104$ lbs. of air to 212°, or $\frac{180 \times 104}{68-32} = 520$ lbs. of air to 68°; then the temperature of 68° (instead of 32°) at which, in the present case, by way of example, the air is furnished to the fire, will correspond to a consumption of $\frac{1 \times 5}{520}$ = nearly 0,01 lb. of wood, which must consequently be saved.

This saving of 1 per cent., or something more, when the temperature exceeds 68°, is too small to warrant any particular arrangement; hence, practically, it is better to unite the two latter modes. The air which has then circulated for some time, may be allowed access to the hearth, and be replaced by air from without, the heating of which will then cost just as much as has been saved by employing the other for feeding the fire. Supposing that proper change of air can be effected in a room by means of doors and windows, the first method will necessarily be highly advantageous; the air streaming in will force out that already in the room, and thus produce a state of things in which the tendency of the external air to force its way through the crevices will cease completely, and with it all the disadvantages and evils which attend it. It is quite certain that the loss occasioned by supplying the fire with cold air is counterbalanced by the advantage gained. For buildings in which the rooms are irregularly heated, sometimes more of them and sometimes fewer at once, the method of heating by hot air is not desirable, because the proper relationship between the dimensions of the stove and the supply of hot air, is thus destroyed. In other respects, a great saving is connected with it, for the number of stoves is diminished to one, and the fuel in that one is more completely used than if it were distributed amongst several stoves; lastly, the advantage of a uniform, equable heat given off from the floor, fully compensates for any loss of heat occasioned by the transit through the flues.

[*Heating by Flues from Anthracite Furnaces.*—The general introduction of anthracite into domestic use in the Atlantic states has given rise to a variety of arrangements for heating private dwellings, in such a manner as to dispense with open fires. So far as the editor of this work is aware, the first plan for this purpose was devised and applied in his own family, about the year 1824–25, when a large house was heated by means of a furnace in the cellar, surrounded by an air-chamber of brick work, and having its gaseous products of combustion carried first through a double cylindrical drum on the first floor, then through a pipe to the third floor, where it passed a second simple drum, and thence out through an aperture in the upper part of the building. In an apparatus subsequently constructed for the same purpose, the position of the furnace was similar, but the fire was also employed for culinary operations as well as for heating the air of apartments. The description and publication of the plan of effecting the great saving of fuel, labor, furniture and health, which this mode of using anthracite had been found to produce, appear to have given a considerable impulse to the adoption of that as the chief fuel in all the Atlantic cities, and to have led to the devising of numerous modifications in the details of apparatus, none of which, however, seems to possess any thing essentially different in principle from the one originally constructed. The following general views are abstracted from a description of the plan* published after a full experience of seven or eight years had tested its usefulness:—

"The expensiveness of fuel renders it desirable to arrange houses so as at once to limit its consumption, and to secure an ample supply of wholesome air. The latter requisite is too often sacrificed to the mere elevation of temperature. Not only is the composition of the air allowed to be deteriorated by frequent respiration, but its hygrometric state is sometimes such as to operate most injuriously on the system. Nature, in general, supplies our lungs with air capable of receiving from them some portion of moisture; if this portion be

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* See Silliman's American Journal of Science and Arts, No. 2, vol. xxiii., Jan. 1833.—Am. Ed.

either too great or too small, the lungs, and eventually the whole body, will suffer either from the excess or the deficiency. To regulate this quantity is one part of our own duty, and is accomplished by supplying water for evaporation in the air-chamber.

"The general plan consists in placing in the basement story, or in the cellar, (as the case may be,) a single furnace capable of effecting the combustion of as much fuel as will be required to heat all parts of the house. Where anthracite is employed, this arrangement is, perhaps, more desirable than where any other fuel is used, because the labor of attendance is then reduced to an amount utterly insignificant, compared with the expense of fuel, and extremely small compared with what it would be with other combustibles.

"The furnace is either of cast or rolled iron, the latter being preferable on account of its lightness and pliability; the former, for its resistance to corrosion and for cheapness of material. A stove or furnace, formed of either of these materials, is placed in the basement or cellar, and surrounded, except in front, with any substance suitable for forming a chamber to receive air at the bottom, which, after ascending around, and over the surface of the iron, passes up through openings in the floor, or through flues in the walls of the house, or through chimneys formerly used to convey the products of combustion. The front part of the furnace is made to join the enclosure, allowing access to the fire, but not admitting a communication with the hot air-chamber.

"The air to supply the combustion is taken either from the apartment immediately around the furnace, or, what is preferable, is conducted to the grate through a trunk descending from the floor of one of the upper heated apartments. In the latter case, it serves to carry down the colder parts of the air of the room in proportion as the warm air rises from the furnace to take its place.

"By the arrangement above described, the fire is left open, and at liberty to be used for culinary purposes, while the back of the stove or furnace is employed to heat air for supplying parlors, chambers and passages.

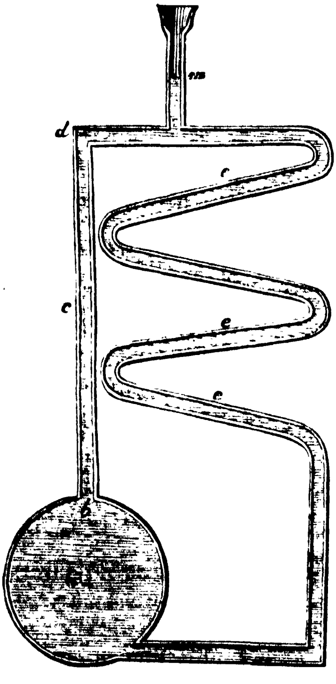
"The air to be used for this latter purpose is derived from a source not subject to any species of contamination. It is generally advisable to receive it through a conducting tube from the open air, and to keep it separate from that which supplies the combustion.

"Pipes of conduit are employed when several stories, not connected by an ample stair-case, are to be kept at uniform temperatures, but the opening or closing of doors is often sufficient to regulate the heat. It has been found by experience, that when once admitted into the lower apartment, the warm air soon makes its way into every open apartment in the house.

"By the adoption of this plan wide chimneys are rendered useless; occupying a great space, they carry off the hot air which is sent up from the furnace. And yet they do not perform well the service of ventilation, since their apertures are below the proper level for that purpose."]

Of Heating by Water.—From what has already been stated, the principle upon which the method of heating by air is founded, is this: that the heat communicated to the air by a central fire, is carried with it to the various places, rooms, &c., to be heated. Instead of directly warming the air, in many cases an intermediate body, water, is employed, which receives its heat in like manner from the central fire, and on being conducted to the different parts of the building, again emits it. The water, therefore, only serves to convey the warmth, and from its great specific heat is peculiarly adapted for that purpose. According to Delaroche and Berard, the quantities of heat in equal weights of water and air at the same temperature, are in the ratio of 374.6 : 100; or the heat which is liberated when water cools down 100°, is sufficient to raise the temperature of 3.74 times as much air to the same amount. Here we have, therefore, an analogous case to that of clay; the heat which is required by a given quantity of air can be retained in a much less quantity of water, and thus, as it were, become accumulated. This is the case to a much greater extent when water in the form of vapor, is made the purveyor of heat; for in passing into the state of gas (vapor), water absorbs 5.72 times as much heat as is required to heat it from 32° to 212°, and this quantity of heat produces no increased temperature in the steam, it cannot be recognized by the thermometer, and becomes first apparent when the vapor is again condensed. Consequently, 1 lb. of vapor at 212°, will, in condensing to form boiling water, give off sufficient heat to raise the temperature of 5.72 lbs. of water, or 3.746 × 5.72 = 21.4 lbs. of air to 212°, or 107 lbs. to 68°. Both modes of applying water are in use, the one is called *heating by water*, the other *heating by steam*.

Fig. 11.



The warm water must necessarily be renewed in proportion to the amount of heat required by the room, and to avoid the trouble of constantly changing the water, it must circulate in such a manner, that the cold water shall flow off and be constantly replaced by a fresh supply of warm water. Fig. 11 shows the principle of the circulation. The heat applied to the vessel *a* at the bottom will be first communicated to the lower layers of water; these will become expanded and specifically lighter, and must consequently rise to the higher parts of the vessel; at first, therefore, to *b*, from thence into the tube *c*, and at length to *d*. In proportion as these rise, however, cold water must flow downwards in *e*, if no vacuum is to be formed; and this constant motion is kept up as long as any difference of temperature exists in the different parts of the apparatus, and never ceases, if the warm water is cooled in its course and the difference of temperature thus rendered constant. It is obvious that *a* may be an open vessel, into which the ends of the tube dip like a syphon, but then much heat will be lost. The heat itself is, therefore, the motive power for circulation, which is so much the more rapid, the less cooling and other obstacles are placed in the way of the ascending current. In England, where water heat has been much introduced by Perkins, closed boilers are used, which can be heated after the manner of steam-boilers, or the pipes themselves, without any boiler, are carried through the stove in several revolutions. The dimensions of the fire and the conducting pipe must be so proportioned, *i. e.*, the cooling must take place so rapidly, that no steam can be formed. To avoid all danger from explosion, which unforeseen production of vapor by over-heating might possibly occasion, safety-valves must be introduced, and compensating pieces, to prevent the bursting of tubes by the expansion and contraction of the metallic masses. The latter is guarded against by connecting the ends of the pipes with a stuffing-box, instead of with screws, thus combining moveability with a water-tight connection. There must also be tubes at the top of the conducting pipes, as at *m*, for the escape of air, which is evolved from the hot water.

The quantity of water, which is to be conveyed per minute from the apparatus to the space to be heated, can be determined in the following manner. If A represents the air in cubic feet, t° warmer than the external air, which is lost every minute and must be replaced; and if 1 cubic foot of water is 837 times as heavy as 1 cubic foot of air, then A cubic feet of air correspond in weight, with $\frac{A}{837}$ cubic feet of water; but the heat which raised the temperature of A to t°, is only capable of raising the ¼th part of this $\frac{A}{837}$ or more correctly $\frac{A}{3.746 \times 837}$, to the same temperature; in other words $\frac{A}{3.746 \times 837}$ cubic feet of water in cooling t° will raise exactly A cubic feet of air to the same extent. But the water in the pipes has a temperature of nearly 212°, and gives off from 100 to 125° of this, or cools $(T-t')^\circ$, therefore, as much less water will be required as $(T-t')^\circ$ is higher than t°, namely:

$$\frac{A\,t^\circ}{3.746 \times 837(T-t'^\circ)} = \frac{A\,t^\circ}{3135.4(T-t')^\circ} = Q \text{ cubic feet} = Q\ 62{,}5$$

lbs. of water per minute. To accommodate the conducting pipe to the production of such an effect it is necessary to know the velocity with which water moves in pipes. The determination of this is the same in principle as that of the draught in chimneys, only that the friction of the water is somewhat different from that of the air. The velocity, together with Q, gives the diameter of the pipes, and the latter the dimensions of the fire. The ascending pipe is protected as much as possible from cooling by badly conducting substances, and is not bent, the descending pipe on the contrary is furnished with every facility for communicating heat to the air of the room. When the heat is to be communicated over a very extensive space, the water becomes too cold in the last rooms; it is well in that case to supply each half of the space with a separate set of pipes.

Steam acts more energetically than water, and less of it is consequently required. As 12.3 cubic feet of air at 32° make 1 lb., then A cubic feet in the former equation will weigh $\frac{A}{12.3}$ lbs., and will be heated by the condensation of $\frac{A}{12.3 \times 3.746 \times 5.72}$ lbs. of steam of 212° to form boiling water (of 212°), and consequently by $\frac{A\, t^{\circ}}{12.3 \times 3.746 \times 5.72 \times 180} = Q$ lbs. of steam to t° higher than the temperature of the external air. The pipes destined to carry the vapor to the place for condensation, are chosen of narrow bore (about 1.5 inch), and to avoid all condensation during the transit, are surrounded with a thick covering of list or other woollen cloth; the condensing pipes are at least four times as wide, made of copper or cast iron, and must be so arranged that the air can escape when the steam is admitted, or this would otherwise very much retard its dissemination. These tubes should generally be rough and not polished, and the copper tubes should be painted or stained in a manner to give them the appearance and the properties peculiar to cast iron. To allow for the expansion in length, the same plan may be adopted as in the water pipes, or simply a bent piece of flexible metal may be inserted into the course of the tube, which by bending to a greater or less degree compensates for the expansion. It is not extraordinary that different bodies should condense steam in a very unequal manner according to the nature of their surfaces; Clement found that at a temperature of 59° in the surrounding air, 1 square foot of surface of a horizontal cast iron tube, could condense 0.234 lbs. of vapor, of a bright copper tube 0.184 lbs., and of a blackened copper tube 0.213 lbs., a quantity, which is somewhat increased by a perpendicular position of the tubes.

However this apparatus may be modified, care must always be taken that the condensed water can flow off; this is best done by a set of pipes on purpose, which convey it back to the boiler. Occasionally a quantity of water is expressly left in the pipes after the circulation, that the after-action (as in the clay stoves) may be obtained. In case of any sudden, unexpected, powerful condensation which would draw the water up from the boiler, there must be a valve, which opens downwards, somewhere at that part where the vapor enters. Heating by means of air, on account of the larger dimensions of the pipes, occasions greater loss, than the two last modes, which, however, are accompanied by imperfect ventilation. In heating by water the apparatus is simpler, the temperature is more easily regulated, and the heat is not so suddenly evolved as from vapor or steam, which latter, however, can be used for much greater distances and heights than would be compatible with the pressure of columns of water. It is obvious that in either case the heating pipes may be made of any shape, ornamental as columns or as stoves, and will then act in a similar manner to stoves.

Of the Actual (*practical*) *Effect of Fuel.*—It has already been noticed above, that the actual effect of fuel in practice is very much below what it should be according to theory. The causes of this are partly casual and external, partly, however, they retain to the nature of the process, and are consequently unavoidable. Of the latter, the maintenance of a draught in the chimney is not the least in importance, and to accomplish it, a portion of the heat evolved must always be sacrificed.

According to p. 81, 1 lb. of dry wood requires on an average 5.94, or in round numbers 6 lbs. of air of 32° (=73.8 cubic feet): suppose this to escape with a temperature of 302° Fah. into the chimney, the quantity of heat contained in it will be just as great as that (in 1 lb. of air at $6 \times 270 = 1620$ or) in 9 lbs. of air at 212°, and consequently in $\frac{9}{3.746} = 2{,}4$ lbs. of water at 212°. According to Schoedler and Petersen, 1 lb. of dry wood will heat on an average 40.6 lbs. of water to 212°, the action of the chimney causes a loss of $\frac{2.4}{40.6} = 0.06$, or 6 p. c., and will increase with the temperature of the escaping air.

The combustion in well constructed stoves is always more or less imperfect. In consequence of too great a withdrawal of heat by the walls of the fire-place, or too great access of air—at least twice as much as is required by theory—and from an occasional temporary stoppage of the grate, and consequent deficiency of oxygen, a portion of the fuel has not the opportunity of uniting with oxygen and evolving heat. It has, therefore, no alternative, but to resolve itself under the agency of the heat into volatile, or non-volatile products, which are mechanically carried off by the draught to the remoter parts of the chimney, where they pass off as *smoke.* The smoke has retained in its constituents the property of uniting with oxygen (burning), and thus of evolving a quantity of heat equivalent to that portion which is lost. The combustion in the fire-place, as above stated (p. 88), is thus partially reduced to a process of "dry distillation;" in fact, instead of the vapor of water, carbonic acid and nitrogen (from the air) alone, we find these gases constantly passing off mixed with smoke, which collects as *dry soot.* The so-called smoke-consuming arrangements in stoves are intended, although they effect it but very imperfectly, to complete the combustion afterwards, by bringing the smoke into contact with a stream of hot air.* Even the condensable portions of the smoke absorb heat (latent) in being converted into vapor, and still

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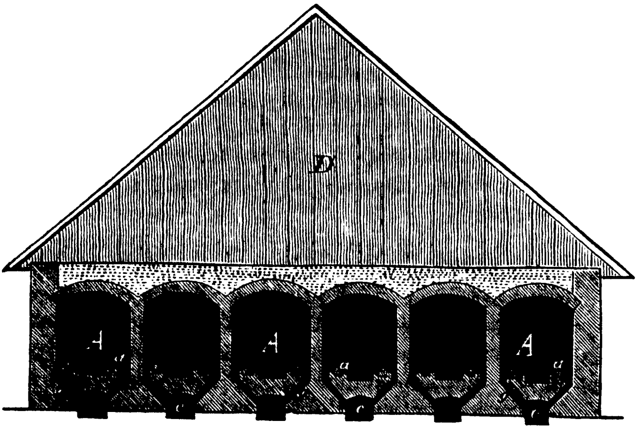
* For an account of the contrivances for the prevention of smoke, see Appendix.

more, the water formed during combustion, which heat for the most part is lost. The loss, however, that is occasioned by the hygroscopic water, from which fuel is seldom freed (never for use in dwelling rooms) is much greater. This loss is of a two-fold nature, first because the water detracts from the mass, 1 cwt. of wood, for instance, only containing 80 lbs. of actual fuel, and then because the water absorbs so much heat in being converted into vapor. For this reason Rumford's experiments (with common wood) give a less result than those calculated from the analyses (with dry wood); it must not, however, be forgotten that the heat of the vaporized hygroscopic water, in as much as it is condensed, is not lost in the calorimeter, as it is in practice. Its influence is easily calculated. Wood in the common state, therefore, air dried, contains about $\frac{1}{5}$th water, and only $\frac{4}{5}$ths of actual fuel; of the 40.6 lbs. of water, which 1 lb. of dry wood heats to 212°, $\frac{40.6}{5} = 8.1$ lbs. are left cold; besides every $\frac{1}{5}$th lb. absorbs as much heat as corresponds with $\frac{1}{5} \times 5.72 = 1.14$ lb. of water at 212°. Altogether, therefore, the moisture in the wood causes a loss of heat = $\frac{\text{[illegible]}}{40.6}$ = [illegible] p.c.

This clearly explains the economy of dry fuel. For common every day purposes it is too costly to dry the wood by artificial means, and generally not practicable; for certain technical purposes, however, dry wood only can be employed, and the arrangements, in which the desiccation is effected upon a large scale, are very advantageous for fuel, which is obtained at one constant locality, like peat, &c., as the worthless refuse of the pits may be used for heating the kiln. Fig. 12 represents a section of a drying kiln for fuel, first introduced in the

Fig. 12.



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* For computations on the amount of heat expended upon the moisture generated in burning, on that of the fuel itself, on the gases passing to the chimney, and on the contents of the boiler, see Report on American Coals, pp. 561 to 581—Am. Ed.

French glass houses. The whole space covered by a single roof is a long quadrangle, and contains six arched passages *A A A*, 60 feet in length, 6 feet broad, and 5 feet high, which may be viewed as separate stoves, each having its own fire *c c c*. Each fire extends underneath the whole length of the arch *A A*, and terminates at both ends in a grate, from whence the disengaged heat is conducted to the middle, but also freely escapes along the whole length into the space *A* by the several channels cut in the sides *g g*. Theses double channels are at greater distances from each other in the neighborhood of the grates (at the ends therefore), but are more closely approached towards the middle, that the heat may be more equably disseminated. The fires *c c c* are arched over for a short distance, above the two grates, and further on, covered with slabs of iron, and in the middle with sheet iron. Above this triple covering is a railway *a a a a* upon which iron barrows move, and into these the fuel to be dried is placed, and kept in the stove. The plates of iron, and the sheet iron are intended only to keep off the fire, that the contents of the barrows may not inflame; every barrow contains about two measures of wood (Stecken.) Each passage A holds nine barrows and these are dried in thirty-six hours.

In contradiction to the foregoing remarks, the action of water upon burning fuel has been considered advantageous, and not without some reason. But a distinction must be made as to whether the water is brought into contact with the fuel in the gaseous or liquid state. It appears from the experiments of Bunsen and Fyfe, that red hot coal and aqueous vapor mutually decompose each other into hydrogen and carbonic oxide gases (and some carbonic acid), both of which, if sufficient oxygen be present, burn with the evolution of a white heat to form water and carbonic acid;* the numerous observations showed further, that the increased quantity of heat evolved, was more than could be calculated upon from the consumption of fuel for producing the vapor. If, therefore, sufficient air be present with the vapor to burn the gases which are formed, the vapor will be of service and produce with the greater amount of heat, a more lively flame. The moment, however, that the vapor exceeds the proper proportion, and the access of air is thus diminished, the temperature sinks, so as even to extinguish the fire.

The best plan is to place a vessel with water under the grate, so that the heat radiating downwards may cause evaporation without cost. In steam-engines the vapor which has been used is conducted at once to the fire, instead of being condensed. An addition of water to the fuel causes so great a depression of temperature in being converted into vapor, that the decomposition of the aqueous vapor can no longer be effected. Such a practice, which is not unfrequent amongst consumers of coal, should therefore be avoided, for in addition to this,

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* 1 part of coal, burning, surrounded by vapor, first to carbonic oxide and then to carbonic acid, heats 78.15 of water from 32° to 212°; 0.1666 parts of hydrogen are liberated at the same time, which in burning, heat 39.5 parts more water. The advantage gained, therefore, is $= \frac{39.5}{78.15 + 39.5} = \frac{1}{3}$, supposing the combustion of coal in aqueous vapor to be attended by the same heating phenomena as in the air.

practical experiments, instituted by the Frankfort society for the improvement of arts and manufactures, have proved the practice to be indisputably bad. A moderate moistening of small coal has, however, one advantage, that of preventing its falling through the bars of the grate and creating dust, for when moistened, it cakes together and becomes more solid. It is still better to add about $\frac{1}{5}$th of moist clay for the same purpose, which being disseminated throughout the mass of the coal, gives more abundant access to the air, and the heat taken up, is given out again (in the manner of the "massen" stoves) more slowly, and consequently with more advantage. The experiments made by the society above-named, showed that small coal mixed with clay, was even better than small coal alone.

When moist wood is heaped up in one place, where there is no proper draught of air, in a short time a chemical change occurs, which is accompanied by the almost entire destruction of its combustibility, and therefore requires special notice. It is well known that the dead wood in the centre of old trees (where moisture, but no air has access), becomes changed into a white, soft, phosphorescent substance, which, when ignited, burns slowly, like wood that has been converted into humus, without any flame in the same way as amadou, and with a very slight evolution of heat. Nevertheless, in this mouldering process the weight of the wood has undergone greater change than the relative proportions of the elements. A specimen contained, for instance, 47 per cent. carbon, and with 6 per cent. hydrogen only 45.3 per cent. oxygen; an excess, therefore, of that element above the quantity contained in fresh wood, which would tend rather to increase the inflammability of the substance. It is highly probable that the hydrogen existing in it, is already combined in the form of water, a supposition which the properties of the substance fully bear out. In the same manner a mouldering process takes possession of firewood under the circumstances named, and decreases its value as it destroys its combustibility and inflammability. The wood is then said to be *decayed*.

However interesting it may be to know the heating power of combustibles, obtained by good experiments, as pointing out the highest attainable point for practical operations, yet their numerical values are so modified and changed from what they originally were, by the concurrence of all the circumstances enumerated, that the effects of the different kinds of fuel, in the present state of our arrangements for combustion, cannot be always correctly estimated by these data. The relative value also of the theoretical calorific power can no longer be traced in practice and *vice versâ*. Lime-tree wood, for instance, should produce the greatest effect according to theory, although this is by no means actually the case. Hence, an answer to the important question respecting the relative effects of different kinds of fuel in ordinary fire-places has been obtained by direct practical experiments upon a large scale. Of course, such experiments will only be applicable with exactness to the kind of firing with which they were undertaken. Some of the most trustworthy observations will here follow.

the vapor were conducted through the fire for every 100 lbs. that were liberated. If these are deducted, we obtain instead of 10.97, 10.53 as the real effect produced, which would still be 37 per cent. more than the maximum of that coal by itself. Further experience may corroborate these statements.

The Hessian Society for the promotion of arts and manufactures has experimentally examined the effective value of wood, peat, and coal, burnt under different well arranged boilers. It was found, by a series of experiments upon six such fires, that 1 lb. of split beech wood, which had been felled two years previously to use, converted on an average, 2.075 lbs. of water at 32° into vapor; 1 lb. of peat evaporated 1.992, and 1 lb. of coal refuse 5.201 lbs. of water. For common purposes, fuel is generally bought and consumed by measure, but their relative values may be easily computed,* by ascertaining the weight of a given bulk.

[In addition to the foregoing facts, relative to the heating power of fuel, it is proper to state that Mr. Bull, in the paper already cited (p. 24), also gave comparative experiments on several varieties of bituminous coal, anthracite and charcoal. Dr. Samuel L. Dana, at Lowell, Mass., has likewise carried on an extensive series of practical researches, on the relative heating power of different coals, with special reference to improvements in the construction of furnaces and boilers.

These will be found at large, in a work by the editor of this treatise, entitled "Notes on Anthracite Iron," and also an abstract of them in the Second Bulletin of the National Institution, p. 165. The following results, taken from the last mentioned publication, will convey an idea of the relative efficiency of the different forms of boilers used in these trials.

Comparisons of results, deduced from the experiments of Dr. Samuel L. Dana, of Lowell, Massachusetts.

1. *In plain Cylindrical Boilers, twenty feet long, thirty inches in diameter.*

Sydney coarse bituminous coal, 7.18; 208 pounds per hour burned.
Philadelphia pea coal, 8.60; 180 pounds per hour, on an average.
Philadelphia pea coal, mean of 10 days running, 9.48; 100 pounds per hour burned.

2. *In Cylindrical Boilers, twenty feet long, forty-five inches in diameter.*

Coarse Sydney coal, 6.04; 300 pounds burned per hour.
Anthracite dust ½, Sydney slack ½, 7.40; 233 pounds burned per hour.
Anthracite dust ¾, Sydney bituminous slack ¼, 7.51; 228⅓ pounds burned per hour.
Best peach mountain anthracite, 8.00; 243 pounds burned per hour.

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* Referring to the table at p. 43–4, it will be easy to ascertain how much evaporative power each variety of coal there exhibited, contains per cubic foot, both as it exists in the mine, and as it is found in a marketable state in commerce.—**Am. Ed.**

Peach mountain anthracite, 8.43; 240½ pounds burned per hour.
Beaver meadow anthracite, 8.89; 196 pounds burned per hour.
Coarse Lackawanna anthracite, 9.17; 249 pounds burned per hour.

3. *In three Cylindrical Boilers, thirty-six feet long, twenty-four inches in diameter.*

Anthracite, coarse, 10.60; 179 pounds burned per hour.
Anthracite, coarse, 11.59; 151 pounds burned per hour.

4. *In four Cylindrical Boilers set on Mr. A. A. Hayes's plan, each twenty feet long, and twenty-four inches in diameter.*

Sydney coal, screened from dust, 5.83; 250 pounds burned per hour.
Sydney slack alone, 8.64; 148⅓ pounds burned per hour.
Philadelphia pea coal alone, 9.06; 117 pounds burned per hour.
Boston anthracite dust ¾, Sydney slack ¼, 9.60; 108 pounds burned per hour.
Lackawanna nut anthracite, 9.77; 106 pounds burned per hour.
Anthracite dust 3 parts, Sydney slack 1 part, 10.24; 141.5 pounds burned per hour.
Lackawanna egg, 10,28; 147.3 pounds burned per hour.
Anthracite dust ¼, Sydney slack ½, 11.13; 112.5 pounds burned per hour.
Anthracite dust ¾, Sydney slack ¼, 11.36; 67.1 pounds burned per hour.
Anthracite dust ½, Sydney slack ¼, 11.37; 107 pounds burned per hour.
Philadelphia pea coal ¾, Sydney slack ¼, 11.48; 100 pounds burned per hour.
Lackawanna egg anthracite, 11.55; 109 pounds burned per hour.
Anthracite dust ½, Sydney slack ½, 12.52; 87½ pounds burned per hour.

5. *In a Tubular Boiler, thirty-six feet long, twelve tubes, each three inches in diameter.*

Coarse Lackawanna anthracite, 11.96; 85.8 pounds burned per hour.

6. *In a Cornish Boiler of the usual construction, thirty-six feet long, six feet exterior, and three feet ten inches interior diameter.*

Coarse Sydney bituminous coal, 6.32; 233⅓ pounds burned per hour.
Coarse Lackawanna anthracite, 7.75; 155.4 pounds burned per hour.

7. *In an improved Cornish Boiler, with three simple cylindrical boilers inserted in the interior Flue.*

Coarse anthracite, kind uncertain, 10.90; 171.6 pounds burned per hour.
Pea anthracite 3 parts, bituminous slack 1 part, 12.08; 136.6 pounds burned per hour.
Lackawanna anthracite, ordinary size, 12.98; 145 pounds burned per hour.

Beaver meadow anthracite, ordinary size, 13.41; 122 pounds burned per hour.

The following results have been obtained in this country, in a locomotive boiler of the common form:

Schuylkill anthracite, 9.51; 57.3 pounds burned per hour.
Wood, 4.71; 112.6 pounds burned per hour.

Mr. Thomas Wicksteed has published a set of results obtained in England in Cornish boilers, using various sorts of fuel, which are here reduced to the standard of 212°, to render them comparable with the preceding and following sets.

Blythe Maine Northumberland bituminous coal, 7,44.
Derbyshire bituminous coal, 7.64.
Large Newcastle coal, average 8.64.
Derbyshire ½, small Newcastle ½, 8.69.
Welsh ½, Newcastle ½, 8.86.
Gas coke ½, small Newcastle ½, 8.91.
Gas coke alone, 8.92.
Average Welsh, 8.98.
Average small Newcastle, 9.01.
Best small Newcastle, 9.38.
Anthracite, 10.17.
Best Welsh coal, 10.71.]

II.—OF ILLUMINATION AND LIGHTING MATERIALS.

General Principles.—The possibility of producing artificial illumination, as opposed to the light of day, depends upon the well-known and easily-observed fact, that the action of high degrees of heat upon bodies which are not volatile, is always attended with the *evolution of light.*

So different, however, is this phenomenon in bodies of unlike nature, that with a temperature, at which solid bodies, like iron, emit a vivid white light, gases are scarcely visibly incandescent. There is, therefore, another influential circumstance besides temperature to be attended to, and that is the *density* of the luminous body; little is, consequently, to be expected from gases alone as the means of illumination; and, in reality, light is always produced by *solid* bodies, which, in giving off heat, or what is practically the same, by a simultaneous process of combustion, are brought to a state of incandescence. In artificial light there is consequently always *burning matter* which produces *heat*, and *incandescent* (solid) *matter*, which, in consequence of the heat, evolves *light.* The two modes which thus present themselves are both made use of in the arts.

Sometimes, when expense is not an object, this light is required of the very highest intensity, more intense even than that of the sun. If, for example, microscopic objects under a high magnifying power are to be sufficiently illuminated, the light for that purpose is evolved from a piece of chalk (lime), heated to the most intense white heat either with a Hare's oxyhydrogen blowpipe, or in a flame kept up by a blast of common air. Here, then, without reference to expense, the principles adduced have been distinctly followed. Indeed, the choice at one and the same time of the hottest of flames, and of one of the most fire-proof substances, like lime, combines all the requisites for the evolution of the most intense light. In this case, which is one of the modes alluded to, and by far the most rare method of producing artificial illumination, the incandescent and luminous body is brought, from without, into the sphere of combustion whence the heat proceeds; by the second essentially different method, the combustion itself eliminates the solid body, which, at the moment of its separation, takes the position of the lime in the former example, namely, is made incandescent, and becomes luminous in proportion to the degree of heat evolved. Inasmuch as all practical methods of illumination are founded upon this principle, an explanation of it only, and of the mode of applying it, will be all that is required here.

Chemistry makes known to us numerous bodies, which, during combustion, become luminous with the evolution or formation of solid compounds; but many considerations must be attended to as regards their applicability for illumination. Phosphorus and zinc, for instance, burn with a brilliant light: the one, because the phosphoric acid formed during combustion remains for a few moments within the sphere of combustion, and becomes incandescent, the other, because the oxide of zinc plays the same part. Neither of the two, independent of other reasons, would fulfil the requisitions of common illumination, because the products of combustion, oxide of zinc or phosphoric acid, are neither of them volatile, and collect in an injurious manner in the immediate neighborhood. It is, therefore, absolutely necessary that the products of the combustion of the illuminating materials, in order not to interfere with the course of the process, should themselves escape from the immediate vicinity, or should be volatile. The evolution of carbon which passes off when burnt in the form of gas, (carbonic oxide or acid,) is common to the flames of coal gas, candles and lamps. The combustion of the carburetted hydrogens is peculiarly adapted to give a clear view of this subject. If carburetted hydrogen is ignited whilst issuing into the air, both its elementary constituents become the prey of oxygen; but not both at the same time, for the hydrogen is much the more combustible of the two. The phenomena, therefore, succeed each other in such a manner, that the hydrogen is first consumed as a gas, by itself, with an almost imperceptible light, but a powerful evolution of heat, which causes the carbon, simultaneously eliminated, to become incandescent and consequently luminous. *In the next moment, however, the incandescent floating carbon is brought to the edge of the flame, where there is abundance of air to consume it, and its place is occupied immediately by another portion of solid carbon.* If carburetted hydrogen is mixed with chlorine, the same occurs, but the first act ends the process; on ignition, the hydrogen burns to hydrochloric acid, and the carbon sinks down in the form of powder or soot. In the air, the soot is burnt a few seconds after its production; this, chlorine could not accomplish. The illuminating power of different carburetted hydrogens varies considerably. Fire damp contains 1 part by weight of hydrogen to 3 of carbon; 1 part of hydrogen requires 8; 1 part of carbon, 2.666 parts of oxygen for combustion. Supposing the oxygen of the air, which takes an active part in combustion, to combine with both simultaneously, then—as 8 parts of oxygen consume 1 part of hydrogen—just 8 parts of oxygen would unite with the carbon, and consume 3 parts, or exactly the whole quantity. In olefiant gas, there is 1 part hydrogen to 6 parts carbon; therefore, under the same supposition, 1 part hydrogen and 3 parts carbon will be consumed together, whilst as much carbon, or 3 parts will be set free. Although in reality the hydrogen is always consumed first, yet it is obvious, that olefiant gas is capable, under similar circumstances, of supplying more carbon to the flame, and consequently of producing more light. Oil of turpentine contains 8, the oil from coal-tar (naphtha) nearly 10 parts of carbon to 1 of hydrogen. Most bodies of organic origin that are decomposed by heat, give rise, amongst other products, to gases and vapors which are indebted to the presence of one or other of the hydro-carbons, for their property of burning with a luminous flame. If these consist of olefiant gas, or of some hydro-carbons that are richer in carbon, the flame is more luminous; if fire-damp or similar compounds compose their chief bulk, the flame is much less powerful. The former are generally the product of bodies rich in carbon. It has already been seen that wood (= 50 per cent. carbon + 6.20 hydrogen + 43.8 oxygen) submitted to dry distillation leaves about 25 per cent. of carbon, and that as much more passes off with the other elements in the products of distillation; but 6.2 per cent. of hydrogen require 37 parts of carbon to form olefiant gas; therefore more than is actually present, without taking any notice of the oxygen. Wood, therefore, is not adapted for illuminating purposes; the fats, however, are different, for example, olive oil. Nearly the whole of the 77 per cent. of carbon which this oil contains, passes over with the volatile products, when it is decomposed by heat, and this more than suffices to form oil-gas with the hydrogen which remains, namely 12 per cent., after the whole of the oxygen has taken up as much as is required to form water. Good coal contains from 80 to 85 per cent. carbon, produces, however, only from 50 to 60 per cent. of coke, and although better than wood, it is therefore inferior to oil. On the whole, the same may be said here, that was stated with reference to carbonization, viz. that the value of any material as a source of light, depends not alone upon the quantity of carbon it contains, but also upon its chemical constitution, and upon its price. Whatever material is used, two objects must always be kept in view: first, the decomposibility of the material by heat, when highly carbonized gases are evolved; and secondly, the suitable combustion of these gases for the production of light. In making use of some substances, as the fats, which cannot be carbonized, and therefore leave no residue, both objects are frequently united into one, as is the case with candles and lamps. With coal and resin, on the contrary, and all similar substances which leave carbon or foreign matter, the two processes must be separated both as regards place and time; hence *gas illumination.* The study of these processes must, from the nature of the subject, be preceded by a review of the materials most generally employed.

Of the Material for producing Light.—From amongst the great number of natural and artificial products, which are chemically qualified for the production of light, those only have, *as yet*, been selected in the arts, which, for so general and comprehensive an application, are to be had in sufficient quantity, and at a low price; these are: coal, resin, tallow (stearine, stearic acid), spermaceti, wax and the oils.

Of the Fats.—Trebly concerned in the nearest and most indispensable requisitions of domestic economy, equally important as nourishment, as material for the production of soap, and as sources of light, these products of organic life have been found as generally diffused in nature as they have been sought for. Perhaps it is reserved for chemistry, in its rapid progress, to point out a cheap mode of producing the fats, which are supplied in such enormous quantity by animals and plants, and are consumed to a still greater amount: at least, the recent discovery of Pelouze, who had succeeded in producing *butyric acid*, by subjecting *sugar* to a fermentative process by the aid of cheese, appears to have opened the way in that direction. As sources of nourishment, they must always be most valuable; those fats only which are unfit for food, can vie with each other as sources of light, or for the production of soap. For the latter purpose, the use of the fats is dependent upon other grounds; but their value as food, and as sources of light, depends upon the same properties; chiefly upon the very large amount of carbon (70—80 per cent.), as compared with that of the two other constituents, and this distinguishes this class of bodies from the greater number of compounds of organic origin. In the state in which the fats are taken from animal and vegetable bodies they are not homogeneous chemical combinations, but mixtures of such, which, taken singly, have all the properties of fats. Some of these fatty admixtures or proximate constituents are solid at common temperatures, as *stearine* (from στεαρ, tallow), others are fluid even at 32°, as *oleine* (from ἔλαιον, oleum, oil). In mutton tallow, the solid fatty ingredient has been found to differ from stearine, and on account of its mother of pearl lustre, it has been called *margarine;* sometimes, in separating a fat into its different ingredients, these three so-called primitive fats are not directly obtained, but chemical combinations of them in definite proportions; as, for instance, in olive oil. All the fats are, therefore, either direct mixtures of oleine with stearine, (or margarine,) or are combinations of these with each other. If the solid ingredient of a fat preponderates, or if the fat is itself more solid, its melting point is raised; if the fluid fat is in excess, it is lowered. The varieties of tallow belong to the first kind, the oils belong to the last; between them are the different kinds of grease having a salve-like consistence. The methods of illumination are partly calculated for solid fats (rich in stearine), partly for entirely fluid fats or oils. For the varieties of grease, the consistence of which lies between the two, Crutchett's gas apparatus has been devised. For illumination, the following varieties of oil and fat possess interest: 1, rape oil; 2, olive oil; 3, oil of madia sativa—these are of vegetable origin; and 4, wax; 5, spermaceti; 6, train oil; 7, tallow, of animal origin. The composition of the most of these in 100 parts has been ascertained as follows:

Variety of Fat.	Carbon.	Hydrogen.	Oxygen.	
Sweet oil (olive)	77.21	13.36	9.43	Gay-Lussac and Thénard.
Wax, white bees	81.80	12.67	5.54	
" Brazilian	74.11	11.77	14.12	Opperman.
" East-Indian	70.97	12.07	16 97	
Spermaceti	81.60	12.80	5.60	Chevreul.
Mutton tallow	78.10	11.70	9.30	
Colophony (rosin)	79.27	10.15	10.58	Sell and Blanchet.

The specific gravity at 59° F., of all except two, was less than that of water, and found to be:

For the oil from:

Brassica campestris	0.9136	Madia-oil	0.9170	East-Indian wax	1.0100
" napus	0.9128	Bees-wax	0.9660	Spermaceti	0.9430
Olive-oil	0.9176	Brazilian wax	1.0100	Train oil	0.9270

The temperatures at which these fats pass from the fluid to the solid state, and *vice versâ*, are very variable, and were found to be:

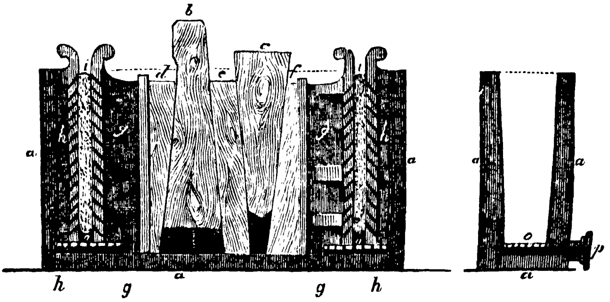
Brassica napus	—6° C.	(21° F.)	Brazilian wax	+ 97° C.	(207° F.)
" campestris	—4° "	(25° ")	East-Indian wax	+ 49° "	(121° ")
Olive-oil	+ 2.5° "	(36.5° ")	Train-oil	0° "	(32° F.) impf.
Madia-oil not even at	25° "	(77° ")	Spermaceti	44.7° "	(112° F.)
Bees-wax	+ 63° "	(145° ")	Tallow	37° to 40° "	(99°—104° F.)

The vegetable fats are most abundant in the fruit, particularly in the seed of the plant. The olive tree, only, contains oil in the fleshy integuments of the fruit; as a rare exception, it has also been found in the root. It will appear from the sequel, that the method of gathering and procuring the oil is dependent upon these facts.

Rape oil.—Several species of the genus *Brassica* belonging to the family of *Cruciferæ*, as winter rape (*B. napus*), summer rape (*B. præcox*), common wild navew (*B. campestris*), and *Brassica napo-brassica*, contain this oil in the small, round, dry seeds of their pods, together with a considerable quantity of mucus, albumen, and other substances. When the ground seeds are pressed, the whole of the fluid contents flow out, *i. e.* in addition to the oil, a considerable portion of mucus and albumen, inasmuch as these are dissolved in the natural juices of the seed; the latter are present in larger quantity in fresh seed than in such as has been kept. To avoid these admixtures, which are injurious to the oil as a source of light, only such seed is pressed as has been kept for several months (the dryest possible seed previously warmed). The albumen in the seed is thus coagulated, and can no longer be pressed out with the diminished quantity of water; the mucus is also reduced in quantity.

An upright rolling millstone (granite), like those used in fruit mills, is most appropriate for grinding the sifted seed. As the toughness and hardness of the grains are, by this means, only imperfectly overcome, or require a length of time, it is better to pass them previously through the crushing mill. Thus bruised, they are soon ground fine under the millstone. For accelerating the work, a blade revolves with the stone, for turning up the mass, and detaching that which adheres to the under stone, and returning it constantly into the track (behind it) of the roller. The fine flour of the seed is generally heated in iron pans over an open fire, although the practice is by no means judicious. The object of doing so, in addition to what has already been mentioned, is to make the oil more limpid and more easily expressed, for which, however, the heat of boiling water is sufficient. The uniform action of boilers heated by steam, prevents completely the evils arising from partial and excessive heating, which always occur at the top and bottom of the common pans. The heated flour is put into cloths (these are best made of wool, and wrapped in horse-hair cloth), in portions, and placed under the press. It is easily understood, why the oil disseminated through a large mass of seed, can, on account of its thick consistence, only be expressed by a powerful and continued pressure. Where expense is not so much an object, Bramah's press is decidedly to be preferred; in other cases, and generally, indeed, a wedge press is employed, which works as powerfully, although not with so much ease, and with much more noise. The filled cloths are laid between strong plates *h* and *g*, and placed in a square space cut in a solid block of oak wood, or as in Fig. 13 in a cast iron case *a*, and the plates are forced nearer and nearer to each other by driving in the wooden wedges which occupy the remaining space. One of these wedges *b*, serves to facilitate the disconnection of the apparatus; the strokes which drive in the wedge *c*, tending, from the reverse position of *b*, to drive it out; *f e* and *d* are intermediate pieces to prevent the wedges from coming into immediate contact. The pressing plates are each provided with 3 side ribs, the immovable ones *h h* press against the sides of the case, and the movable ones *g g* against the intermediate wedges *d f*, and they are pierced with numerous holes to allow the oil to flow out more easily. On filling the press, the wedge *b* must be suspended (by a string) at a distance *a* from the bottom, that the ap-

Fig. 13.



paratus may be easily taken to pieces. The oil trickles from the pressing plates, through the pierced horizontal plates *o o*, upon which these rest, into the pipe *p*.—Both *b* and *c* are driven by separate stampers, which are raised by a toothed wheel.

Brassica napus produces nearly 33, *B. rapa* only 16, *B. campestris* 39, *B. napo-brassica* 33, *B. præcox* 30, and *Madia sativa* as the mean quantity 32, or between 25 and 50 per cent. of oil.

Olive Oil.—The olive tree (*Olea Europæa*) belonging to the family *Jasminaceæ*, produces a kernel fruit, the fleshy, greenish brown integument of which contains an oil that exceeds all other vegetable oils in sweetness, and in the property of being saponified. The more common kinds only, which cannot be made into soap, are used for burning. Although the fruit is very juicy as compared with oil-seed, yet a certain turgidity of the tissue, and the hardness of the stone, (which is not removed, as it would involve a loss of time,) offer no inconsiderable resistance to the press. For the production of oil of the best quality, salad oil, the carefully collected crop should be put under the press as quickly as possible, yet a practice which has been handed down by tradition is found advantageous, according to which a certain amount of fermentation is allowed to proceed in the mass of heaped fruit, which decomposes the so-called water of vegetation, *i. e.* kills the olives, softens them, and causes them to part with a larger quantity of oil. This fermentation becomes perceptible by the heat that is generated; in a layer several inches in thickness, it cannot exceed 96° F. without injury to the quality of the oil. If the temperature has risen too high, and the juice flows out brown and decomposed, which is often the case, the oil is always of very inferior quality. The slightly fermented fruit is first bruised into a soft dough in fruit-mills with upright stones, collected in rush sacks, which, to the number of 18 or 20 at a time, are placed under a kind of wine press. It is necessary to tighten the press as soon as the oil has run off after each jerk, and has had time to separate from the doughy mass. The product of this first pressing is the finest oil, *virgin oil.* What remains in the cake will not flow off of itself. The press is, therefore, taken apart, the cake is broken up in the bags, and the nearly dry residue digested with hot water, and again put under the press as before; this operation is repeated two or three times. For the reception of the water containing the oil, two tanks are used, so arranged that in the one the liquids separate into two layers, whilst the other is filling. The upper layer consisting of oil is taken off with scoops, the water below, which still contains oil in suspension with mucus, is collected into a cistern for further separation, from which the water can be removed by a long syphon. The oil from a larger quantity of press-water than the cistern can properly hold, is allowed to collect in it, by drawing off the lower water which is free from oil, before the whole quantity is admitted. When a sufficient quantity of oil swims on the top, it is skimmed off as oil of second quality. The growers of oil find that the residue after the second pressure still affords so much oil of the worst quality, as to make it worth while to submit it to a third operation. The crushed cake from the press is stirred up with a large quantity of water, so as to become quite muddy. The broken stones fall to the bottom, whilst the soft kernels come to the surface, whence they are collected with hair sieves, and dried over a fire until they form a stiff paste, which is then submitted to the third pressure.

All the varieties of oil remain about 20 days in a warm place (not under 68° F.) in casks, before they are sent off, that they may have time to deposit their mucus.

Madia Oil.—The plant from which this oil is obtained, Madia sativa, belonging to the syngenesious family, originally indigenous to Chili, has lately been successfully introduced into Europe. The oil is obtained as from other dry seeds, in the manner which has been described, but it must be remarked, that sweet salad oil, for which purpose Madia oil may be used, should always be prepared in the cold. It has a golden yellow color.

Train Oil.—A great number of ships bearing all colors, set sail yearly to the Polar Seas upon the whale fishery, their object being partly the whalebone, but chiefly the blubber of the fish, which produces a fluid fat, train oil. Seals and dolphins are taken for the same purpose. The whale fishers merely cut out the blubber, pack it into casks, and carry it to the sea-ports to be melted out. The carriage gives rise to an incipient decomposition of the animal matters and of the fluids attached to the blubber, which, although it aids the melting, occasions the formation of a peculiar fat, consisting of phocenic acid and oxide of glyceryle, and is the cause of the nauseous odor which accompanies all train oil. The cellular tissue of the blubber becomes thus so disintegrated, that the oil runs off by itself, when the whole is put into casks with wire-work bottoms, such as are used in the melting houses. The train oil is heated to 212° F., that the impurities in suspension may the more easily separate, and the clear oil is drawn off from the thick portion, after having stood for some time.

Clarification of Oil.—The different fluid oils which occur in commerce, particularly rape oil, are by no means perfectly free from mucus and other matters of that kind which are expressed at the same time. These substances act in a very different manner to the oils during combustion; they do not possess the essential property of leaving no residue. It is well known, that the combustible oils do not withstand the energetic action of concentrated acids; if the action of these, however, is weakened by lessening their quantity, if only 1 to 2 per cent. of sulphuric acid is used, the acid then chiefly acts upon the foreign associated matters, and very much increases the combustibility of the oil. The acid first removes the water from the mucus, by means of which it was held in suspension in the oil, and chars the mucus itself to a black mass. The oil itself too is somewhat acted upon: it becomes green or dark brown, and after some time deposits a sediment of the same color, becoming then perfectly clear. Thénard first applied these facts to the purification of oils upon a large scale. It will be easily understood, that the action of the acid must more or less depend upon the amount of contact between the two fluids and upon the temperature. At a temperature of 140° to 158° F., the quantity of acid may be reduced to ½ per cent.

Besides the (decanting) tubs for deposition, there must be agitating tubs in a clarifying work; these should either be immovable, with a movable fan in their axis, or should themselves be movable round their axis without it. From 1 to 1½ per cent. of sulphuric acid is gradually added in a thin stream with constant agitation to the previously heated oil in these tubs. When it is borne in mind, that the same quantity of steam (at 212°) which will raise 1 part of water 108°, will raise 3.2 parts of oil to the same temperature, in consequence of their different specific heats, the advantage of steam heat will be obvious in an oil refinery. When, after continued agitation, the dark-colored oil in the tubs is evidently composed of a clear fluid with suspended flocculent matter, the action of the acid is then finished, and warm water of 140° F. (⅔ as much as of the oil) is added, keeping up the agitation, to separate as much as possible the acid, and prevent the metallic vessels from being acted upon in the subsequent employment of the oil. The water, intended to separate the acid, collects, after standing for several days, under the black flocculent matter at the bottom of the depositing tubs. The clear oil above both, however carefully it may be drawn off, must always be filtered before becoming cold, and for this purpose vats are used with conical openings in the bottom stopped with cotton plugs. Baskets lined with moss or cotton answer the same purpose. The filtration is always a difficult operation, the plugholes becoming constantly and quickly stopped. It is desirable, although seldom put in practice, to use milk of lime, and a current of steam to remove the last portions of acid. Methods of clarification, like that proposed by Watt, in which oxidizing substances are used, as chromic acid, and that of Cogen by means of a solution of potash, require further experiment to prove their advantages. On the whole, clarified oil is not much less colored than crude oil, and, according to Brandes, almond oil only, and not the combustible oils, can be decolorized by the most powerful means, as animal charcoal.

In train oil, the impurity is not mucus, but animal gelatine or glue, and besides this, volatile, fetid matters. Some use a solution of tannin for clarifying it, which forms, with the gelatine, insoluble flakes; others employ metallic salts, as blue vitriol, or sugar of lead, which act in a similar manner. The nauseous odor is best removed by bleaching powder.

Of all fluids, the oils expand the most by heat, and, indeed, to such a degree, that it becomes necessary for commercial purposes to know the extent of this expansion. For every degree of Fah. the volume of olive oil increases, according to Preisser $\frac{1}{2160}$, of rape oil $\frac{1}{2116}$, and of train oil $\frac{1}{1800}$, so that 100 measures of train oil at 32° Fah., will become in summer at 68° F. 102 measures. Another property, in which the different fluid oils vary considerably, and which has considerable influence upon their value as combustibles, is their degree of fluidity, which is estimated by the time required for a given quantity of oil to flow through a funnel of known dimensions. Schübler and Ure obtained the following results upon this point.

Fluids.	Time required to flow through a given aperture.	Fluidity. Water = 100.
Water	90 seconds.	100
Oil of Brass. campestris . . .	162 "	55.5
" " napus	159 "	56.6
" " præcox	148 "	60.8
" " napo-brass. . .	142 "	63.3
" " rapa	136 "	66.1
Olive oil	195 "	46.1
Train oil, according to Ure .	450 "	20.0

Of Tallow.—In the animal body there exists a peculiar skin-like tissue, filling up the interstices between the different organs, and surrounding them in all directions, the *cellular tissue.* In certain places in the so-called caul, for instance, the single cells formed by thin membranous walls are the chief depositories of animal fat, which, in the form of globules or small drops, swim in the animal fluid with which the cells are filled.

Melting and Purification of Tallow.—In ruminating animals the firm and (at common temperatures), solid nature of the fat is characteristic; oxen, stags, sheep, goats, all furnish tallow, although not quite of the same quality. From the scarcity of the other kinds, ox tallow is alone used as a source of light, and a small quantity of that of sheep (mutton suet). As far as their application is concerned, they are alike in properties. As a general fact, the more solid the tallow, the more valuable it is for our present purpose, and this quality of the fat has been found from experience to be greatest in animals fed upon dry ripe fodder, and least in such as are fed upon grains. Hence the tallow which comes from Russia, where the animals are fed for eight months upon dry fodder, is generally superior to that produced in Germany. The object of melting out the tallow is to unite the globules of tallow into one mass by separating them from the cells; for candles, certain parts only are used, namely those round the caul, and those in the neighborhood of the heart, of the kidneys, and of the intestines. The plan, now generally, and formerly universally, followed for purifying tallow, is by the aid of heat alone, which, however, must exceed that of boiling water if the whole quantity is to be obtained. With this view, the fat is cut up into small pieces, and melted in a boiler over an open fire. The cells are first burst by the expansion of their fluid contents; a milky liquid is formed, which becomes clear by degrees, as the water contained in the cells, or which, in some cases, is added in small quantities, evaporates. The heat is now continued and increased until the particles of skin, having lost all their water, appear hard and somewhat baked, and no longer yield any fat.

At this period the fire is so far modified as to leave the fat in a fluid state at the top; this is strained and poured out into blocks; the residue, baked a second time and pressed, furnishes a second portion of inferior quality, and generally colored. As a maximum product, which is seldom actually attained, beef suet gives 95 per cent. of tallow and 2 per cent. of refuse; mutton suet 91 per cent. and 4.5 per cent. of refuse; in the latter, there generally remains a considerable quantity of tallow, which then amounts to 8 or 10 per cent. There are several objections to this generally-adopted method; the cells are imperfectly destroyed, and become so hard that they do not readily part with the tallow under the press. It is also impossible to keep up a uniform heat throughout the melting mass; at the bottom, it is too high and injurious to the color and quality of the tallow; it there becomes softer and more fusible, and takes up copper from the sides of the vessel. Lastly, during the process of melting, the animal matters evolve inflammable (and, therefore, dangerous) gases and vapors, which carry with them such an intolerably nauseous odor that only long habit enables the workmen to bear up against them. The use of steam alone, instead of an open fire, is but a partial remedy, for the temperature is then always too low; and by conveying the steam directly into the fat, the membranous substance becomes converted into glue, which is then difficult to remove.* But the use of mechanical power, which has been applied in some places, deserves every commendation; the cells are either torn or crushed by upright millstones or in mortars, and when this is once effected, it is only necessary to obtain the requisite temperature, and the tallow separates perfectly fluid.

With the same object in view, but by chemical means, Darcet, by a method which is acknowledged to be excellent, causes weak sulphuric acid to act upon the tallow, which, destroying and breaking up the cells chemically, also combines the advantage of preventing, with careful management, the evolution of the fetid vapors, or at least of rendering them much more tolerable under ordinary circumstances. His plan is to melt the crude tallow with one-half its weight of water, which has been previously acidified with 3.3 per cent. of sulphuric acid, and to retain this at the boiling temperature until the separation of cellular and fatty matter is complete. Although the inventor proposed his plan for working with an open fire, yet the separation is so much aided by the presence of the acid, that the temperature of boiling water is sufficient to complete the process, *i. e.* steam may be used. In Taulet's apparatus, steam heat is applied from without; in Champy's, steam is admitted to the melting mass, by which means the cellular matter is made so porous as to be easily pressed, or by a second boiling, parts with the whole of its tallow. Experiments with the former apparatus produced from 2 to 4 per cent. more than were obtained with an open fire; with respect to the immediate introduction of steam, it has been found practically better

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* More or less of this is always produced.

to use less water with a greater amount of acid (about ⅛ of the weight of the tallow and 6 per cent. of acid), as the condensation of the vapor then establishes about the right proportion.

Upon the same principle as that of Darcet, a method proposed by Lefebure is founded, which recommends the finely divided tallow to be macerated three or four days in an acid bath, and then to be melted in a fresh bath.

The greater part of the tallow of commerce has been prepared with so little care, that it cannot be used by the candle makers without being remelted and purified. They call this operation *clarification*, or *rendering*, by which is to be understood a remelting with the aid of so-called means of clarification, which are nearly everywhere different, and consist of the most heterogeneous salts, as vitriol, saltpetre, sal ammoniac, common salt, alum, bitter salt, glass skimmings, and which are intended either to render insoluble, residuary portions of gelatine or glue, or to convert the water into a specifically heavier liquid, which then subsides more easily with the impurities.

Lastly, it is worthy of notice, that Darcet has proposed to carry off the fetid vapors, which cannot be entirely avoided, by a strong draught into the chimney, or to conduct them to the hearth, and thus render them innoxious to the workmen. The hood and conducting pipe, with which the boiler must then be supplied, unfortunately obstruct the process.

The use of acid not only affords a larger produce, but has another very great advantage in making the tallow harder and more sonorous.

Of Stearine.—Amongst the proximate constituents of tallow, as they have been investigated and separated by Chevreul, there are some which possess a much higher melting point than tallow, and at common temperatures are firmer, dryer, and even brittle; in other respects they are quite analogous to fat, but have ceased to feel greasy and to stain; in short, they possess those properties in the highest degree, which manufacturers have endeavored to confer upon tallow by the different modes of hardening, and which render it more similar to wax. For a long time two of these constituents under the denomination *stearine*, have been an article of manufacture, two substances which are related to each other as a salt is to an acid, therefore, chemically quite distinct. The one of these substances is called in scientific language stearine, and has already been noticed (page 103); the other is *stearic acid.* Whilst in the first instance stearine alone was the object of manufacture, this has of late years quite given place to the production of stearic acid.

Melted tallow is completely dissolved by eight times its weight of ether; on cooling the *oleine* only remains dissolved with a very little *stearine*, which almost entirely crystalizes, and can be completely purified by washing with ether. When fused, it is a solid, pulverizable substance, does not stain, and is translucent like alabaster. Its production on a large scale is not so much an absolute separation of stearine from oleine, as an augmentation of the quantity of stearine in tallow, which in its natural state contains ¾ of its weight of stearine. The method actually in use is very simple. Completely fluid and transparent melted tallow is allowed to cool as gradually as possible with constant agitation to about 100° F. At this temperature, the stearine only has become solid in the form of numerous small crystals, which, swimming in the fluid portion, thicken the whole into a whitish turbid pasty mass, this is then placed in cloths and slowly pressed, in the manner and machine about to be described when treating of stearic acid, during which operation the greater part of the oleine is imbibed by the woolen cloths. By repeating the operation, a solid cake of stearine is obtained purer and purer after each repetition, and which approaches in properties very closely to that already described.

The observations made by Liebig and Pelouze upon stearine render it highly probable that it must be considered, as is generally admitted, a salt of two bases. One of these is substituted by water, the other is the oxide of a compound radical Glyceryle = $C_6 H_{14}$, with 5 atoms of oxygen, which is contained in all fats, and is known by itself in the form of a hydrate = $C_6 H_{14}, O_5 + 3 H_2 O$. The acid of the salt has the properties of a fat, but outwardly resembles stearine: it is *stearic acid*. In a similar manner, oleine is a salt of an oily, fluid, fatty acid—of oleic acid, with the same bases; and tallow itself must, therefore, be considered chemically, as a mixture of peculiar double salts of the fatty acids* with water and the oxide of glyceryle.

The principle upon which the separation of stearic acid is founded, is the displacement of the oxide of glyceryle by a powerful mineral base, for example, lime. The resulting mixture of stearate and oleate of lime, is decomposed by the addition of sulphuric acid into sulphate of lime, and a solution of stearic in oleic acid, which by crystalization and pressure are separated from each other.

For convenience and economy, steam heat alone is employed in the manufactories of stearic acid. A steam boiler, with a safety valve, supplies steam to all parts where it is required, by means of proper pipes and stop-cocks, and first of all to the lime vessels. These are wooden troughs, lined in the interior with soldered leaden plates, (to prevent the absorption of fat, and the destructive influence of the acid,) into which, at the bottom, a branch of the steam pipe enters, furnished with a separate stop-cock, and opening in the form of a rose. When the first trough has been filled nearly to the top with water, it is charged with the tallow in fragments, and when, after opening the steam cock, the charge is melted, fresh milk of lime is added. To ensure success, rather more lime is added than would theoretically be required; if the tallow consisted only of stearic acid, 11 per cent. would be required; 14 per cent. is the quantity generally used. In a few hours the decomposition is completed, if the whole has been constantly agitated. The transparent layer of fat swimming on the surface of the water, has now become converted into a gray, crumbly mass, no longer fluid, in fact, into a lime soap, (stearate of lime mixed with oleate,) which is insoluble in water, and remains as a distinct layer on the top. On being sepa-

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* Besides oleic and stearic acids, it contains (principally in mutton suet) *margaric acid*, very similar to stearic acid, and combined in the same manner.

rated, the oxide of glyceryle takes up water to form hydrated oxide of glyceryle (commonly called glycerine); it is a syrupy, sweet fluid, amounting to about 10 per cent. of the tallow, and dissolves in the excess of water present.

In the mean time, a second trough has been got ready to receive the lime soap without the water, and into it the necessary quantity of sulphuric acid has been added. It is known by experience, that the soap contains 10 per cent. of lime, and that 17.2 parts of sulphuric acid are required to decompose it. It is therefore necessary to use at least 18.5 parts of commercial sulphuric acid of specific gravity 1.832, and these should be previously diluted with 60 to 70 times their volume of water. Aided by the heat of the steam, the decomposition of the lime soap is rapidly accomplished; *generally in about half the time that was expended in its formation. At first it softens,* then becomes more fluid and clear, whilst the water below becomes turbid from sulphate of lime, which sinks to the bottom, and at last, a clear, perfectly transparent layer of fat-like oil separates upon the surface of the water. The steam cock is now turned off, and the fluids separated; the fat is transferred to the moulds, in which it solidifies in square blocks of ½ cwt. each. These are of the same character as tallow, only yellower and discolored: they consist of a mixture of oleic and stearic acids, which have now to be separated mechanically by the press. Before they can be put under the press, it is necessary to reduce their size. For this purpose, a cutting instrument of the following construction is used: at the mouth of a wooden trough, which is open in front, and placed horizontally upon a stand, a wheel rotates with curved spokes, upon which planes or blades, all of the same kind, are fastened, and which consequently act in the manner of curved sabres. The axis of the wheel, traversing the whole length of the trough, turns behind in a plate, and is itself a screw throughout its whole length; to the female screw is attached the stay of the block of tallow. The result of this arrangement is, that the block of tallow is brought forward to the cutters (or screwed forward) just in proportion as it diminishes in length by their action. The shavings, 0.8 lines in thickness, are packed in layers of slight thickness, in cloths of strong woolen, unequally woven material, and placed between hurdles of basket-work, and sheet-iron plates, upon the slab p' of the hydraulic press Figs. 14 and 15.

The essential parts of this machine are a pump a, (forcing and sucking pump,) which is in connection with the cylinder $c\,c'$, by means of the tube t, b, u. By the workman at the lever l, water is drawn up from the reservoir b, and forced to $c\ c'$, with a power equivalent to that of the man at l, and the action of the lever together. In accordance with the law of the pressure of fluids, the pressure received by the piston s is uniformly communicated to $c\ c'$, and is there so exerted, that every portion of the surface which equals s in section, receives a pressure equivalent to that exerted by s. As this takes place in all directions, not only the sides of $c\ c'$, but also the lateral surfaces and the base of the piston p will be equally affected. The pressure on the lateral surfaces is annihilated, but not so that on the base, as the other surface is outside the cylinder, where no compensating pressure is exerted. The piston *p*, inasmuch as it is movable in its stuffing box, is therefore raised by a pressure which exceeds the power of the piston of the pump, as many times as the cross section of the latter is contained in that of the former. A portion of this force is, however, lost by the very considerable friction to be overcome. The sieve *r* is for keeping the pump clean, *g* is the safety-valve, *k* the stop-cock, by which the machine is placed out of action, and the water allowed to flow off at *v*.

Fig. 14.

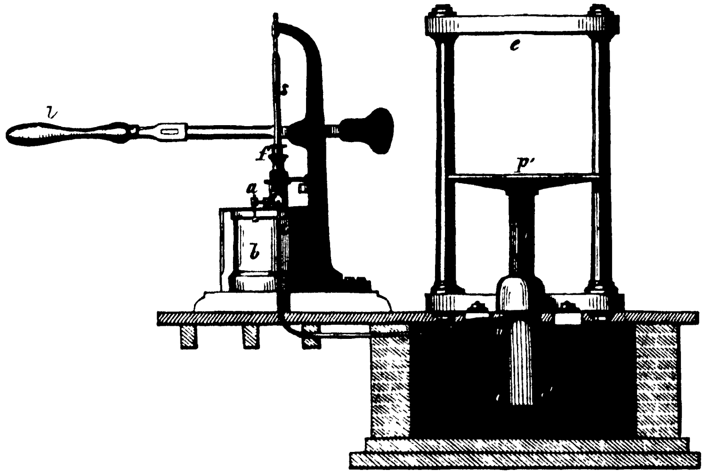
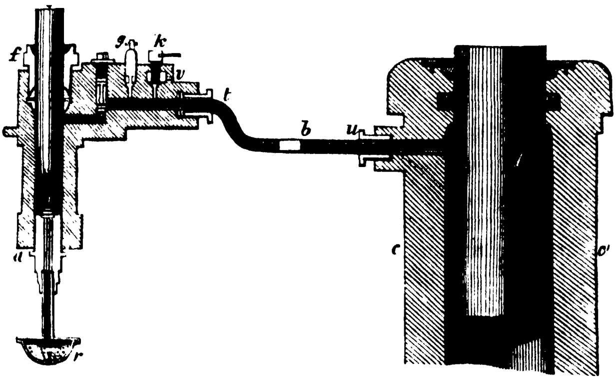
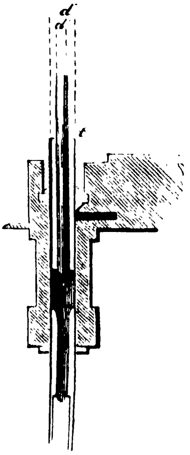


Fig. 15.



If in a press of this kind, as it is usually employed, the smaller piston is 0.5 of a square inch in section, and the larger one 113 square inches, when properly worked, a pressure of 8000 cwt. will be distributed over the surface of the pressing slab. In using the press it is absolutely necessary to proceed very slowly at first, and to close the press very gradually. By a simple contrivance, we are enabled to work at first with a lesser pressure, *i. e.* with a thicker piston to the pump, and first towards the end, with the whole force, or with the smaller piston. The sketch at Fig. 16, shows the principle of this contrivance. Between the cylinder and the piston of the hand-pump, is a hollow cylindrical piece *t*, which, by mere turning on the outside, may sometimes be firmly connected with the cylinder, at others loosened from it, and connected as firmly with the piston. During the working, therefore, the diameter of the piston may, as it were, be reduced from *d* to *d'*, and the pressure proportionally increased.

Fig. 16.



What flows from the press is oleic acid, with from 10 to 15 per cent. of stearic acid, which solidifies in the form of a brownish-yellow butter. The cake in the cloths is of a whitish-yellow color, and consists of stearic acid, some margaric acid, and about 10 per cent. of oleic acid. To complete the purification, a second similar, but horizontal press is used, called the hot-press, into which is put the cake of stearic acid, broken up and placed in fresh cloths, and in such a manner that between each two slabs of cast iron a bag, or cloth, with the cake is inserted. The slabs, up to the moment of their being used, are hung up in cases heated by steam. After rapidly inserting them, that the slabs may remain warm, the press is gradually closed, as in the first case, and the pressure kept up as long as any oleic acid drops from it. The greater part of the margaric acid separates, in consequence of its greater fusibility (it melts at 140° F., stearic acid at 158° F.). The cakes are thin, dry, and white, and consist of nearly pure stearic acid. The yellow specks, which are here and there perceptible, where the pressure has been insufficient, are carefully removed, and the remainder is melted at a low temperature; on cooling it presents a cake of a brilliant white color, with the lustre of mother-of-pearl, resembling alabaster; it has a distinctly crystaline texture, and an elegant appearance.

Concentrated sulphuric acid (indeed, any strong mineral acid), will separate the acids from the tallow, (*i. e.* from oleine and stearine.) Sulphate of oxide of glyceryle is formed, which dissolves in the watery fluid, and stearic acid rises with oleic acid to the surface, and these can then be separated by pressure. This simple process has not been adopted on a large scale, because the product cannot be obtained without much color, in consequence of the decomposition having been carried too far.

The oleic acid, mixed with a good deal of stearic and margaric acids, which is constantly obtained as a secondary product, can be immediately employed with advantage for making soap, and for greasing wool for spinning.

Spermaceti.—In some of the larger Cetacea, particularly in the white whale (*Physeter macrocephalus*) of the South Sea, there are peculiar cavities in the bones of the skull which are filled with a kind of blubber (a specifically light substance), apparently intended to shift the specific gravity of the animal further backwards towards the middle of the body, and thus to render it more capable of swimming. Immediately on leaving the skull of the slaughtered animal, this oily fluid begins to deposit small crystaline laminæ—*spermaceti*—in large quantities. By pressure, the greater part of the fluid fat, or *spermaceti oil* flows out, and by washing with moderately strong potash ley, which attacks the spermaceti with difficulty, the remainder may be removed. The residue, washed and melted into cakes over water, forms the spermaceti of commerce. It is obtained much purer when the pressed mass is fused at 212° F., and treated with a solution of potash or soda, which separates a bluish deposit that collects at the bottom. The clarified product is allowed to cool and crystalize, and the operation is then repeated a second time. Lastly, an excellent means of purification is animal charcoal, with which the pressed spermaceti is fused on a sand bath; but then very tiresome filtrations in heated vessels cannot be dispensed with. The name *spermaceti* is derived from an erroneous opinion, that this substance is the spawn of the whale tribe (*sperma ceti*). Commercial spermaceti is very white, semi-translucent, like alabaster, and much resembles stearine; it feels like soap stone, is brittle, and has a lamellar crystaline texture.—Its specific gravity is 0.943.

Commercial spermaceti is, with the exclusion of a small quantity of spermaceti oil, a peculiar fat differing chemically from the other fats; it is called *cetine*. Like tallow, it contains oleic and margaric acids, but these acids are combined in cetine with the oxide of a radical cetyle ($=C_{32}\ H_{66}$), peculiar to spermaceti, namely with oxide of cetyle ($=C_{32}\ H_{66}\ O$), and not with oxide of glyceryle. Cetine is probably a combination of two equivalents of margarate of oxide of cetyle with one equivalent of oleate of oxide of cetyle. As from tallow we obtained hydrated oxide of glyceryle, so by the decomposition of cetine we obtain hydrated oxide of cetyle. The spermaceti oil is yellow, has a weak, not exactly disagreeable smell, and is well suited for burning in lamps.

Wax.—Notwithstanding the similarity in outward appearance, and in its applications, the wax secreted by certain plants must be distinguished from another substance bearing the same name, and for which we have to thank the social activity of bees. Contrary to the general opinion, it has been proved,* that the farina collected by these insects is entirely expended in nourishment for the larvæ, but that the body of the bee is furnished with an organ, which from the nourishment peculiar to them, honey (sugar), fabricates and excretes in the form of small scales, the very wax which serves as material for the construction of the cells and store chambers for that same nutriment out of which it has been chemically formed by the vital process.

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* By the observations of Huber and Hunter.

Having got possession of the *honey-comb* by driving out the bees, the first object is to let the *virgin honey* flow out, and then to squeeze out the remainder by pressure. By simply melting in boiling water, and allowing the wax to cool slowly, the *wax discs* met with in commerce are obtained, the lower brittle layer, containing the precipitated impurities, farina, &c., having been removed. The crude or yellow wax is sometimes very pale, sometimes grayish, but generally of a very deep brownish-yellow color; it has a sharp, dry, granular and splintery fracture, is not easily kneaded, and when fresh and pure, has a very agreeable smell of honey. The high price of this article of commerce has given rise to a great deal of adulteration. The flour of peas, beans and starch, are the most common materials for this purpose; sometimes they amount to 60 per cent.; even brick dust has been used.

All these are easily detected by oil of turpentine, which leaves them undissolved; the former are converted by sulphuric acid into sugar. Resin is discovered by means of cold alcohol. The worst adulteration of all, namely, that with tallow, is also unfortunately the most difficult of detection. When the smell alone is not convincing, the formation of sebacic acid as a product of dry distillation, proves the presence of tallow.

The foreign matters derived from the farina and the honey, and which give rise to the color and to the granular fracture of the wax, should be removed under all circumstances, both for the sake of appearance and because they interfere with illumination. This is done by *bleaching*. The facility with which wax is bleached, varies with the source of the wax, and is also different at different times; it should, therefore, be first tested in small quantities taken from various parts of the whole quantity to be bleached, that it may be sorted and treated accordingly. The destruction of the foreign matters in wax is easily effected with the help of bleaching agents. If, for example, wax is melted with dilute sulphuric acid, it becomes decidedly darker, but exceedingly clear and translucent; and when it is now again melted with a dilute clear solution of bleaching powder, a slimy or soapy troubled mass is produced, thickly fluid, out of which weak hydrochloric acid separates the wax as a colorless clear layer which comes to the surface, and solidifies to a perfectly white disc. Wax so prepared, however, according to the experience of wax-chandlers, does not keep its color; its whiteness is not permanent. They, therefore, expressly refuse using it, and will only take wax bleached by the sun, in the ordinary manner.

By the common process yellow wax is melted over water in a vessel with a cock for decantation, and constantly stirred with about ¼ per cent. of tartar, which acts like a weak acid and clears the wax. After being left at rest for a few minutes, it is drawn off into a second vessel containing lukewarm water, in which it is kept at a temperature nearly approaching that at which it solidifies. In front of this vessel is a flat stone cylinder, or a kind of round grindstone, dipping half way into water. The pipe for drawing off the wax ends in a disc pierced with holes with a downward direction, and perpendicular above the stone, which turns upon its axis, and is thus kept constantly wet. As soon as the cock is turned, the wax pours out in thin streams, which, falling upon the stone, become flattened and sink into the water in the form of thin ribbons. To decolorize this *ribboned* wax, it is spread out upon linen stretched in frames, and exposed to the dew and the light of the sun, until no further alteration of color is perceptible. The ribbons are then only yellow in the middle; to bleach this part, the wax is again melted and exposed, and this operation is repeated until it is perfectly white throughout.

The observation of the wax bleachers, that in rainy weather the wax gets a grayish tinge, which cannot afterwards be removed, is as remarkable as it is difficult to explain.

Great loss of time—for it requires three or four weeks—dust, and refuse, render the process very expensive.

Bleached bees' wax is cast for commercial purposes in small discs, a few inches in diameter, and two or three lines in thickness; it has a very slight tinge of yellow, is translucent, can be kneaded, but is brittle in the cold. It is composed of two substances which can be separated by alcohol, cerine and myricine in variable proportions.

Under the name of *Japan wax*, different kinds of white wax, varying at least in fusibility, are met with in commerce at different prices, the alleged origin of these from a Japanese plant, Rhus succedania, L., belonging to the family of the Anacardineæ, still requires confirmation. It is softer and more brittle than bees' wax, bears a strong resemblance to it, but is more fatty, and like tallow to the touch, though easily kneaded; its melting point is between 104° and 108°. Containing twice as much oxygen, it is not so valuable as a source of light as bees' wax. It differs still more from bees' wax in its composition; being composed of a peculiar fatty acid, palmitic acid ($C_{32}\ H_{31}\ O_3$) with oxide of glyceryle. According to Solly, vegetable wax can be bleached easily and economically with nitric acid. With this view, sulphuric acid diluted with half its weight of water is poured into the vessel with the melted wax, and from time to time, the hot mass being constantly stirred, crystals of Chili saltpetre (nitrate of soda) are thrown in. Whilst sulphate of soda is formed, the nitric acid, evolved in considerable quantity and at all parts, penetrates the layer of wax, and destroys the foreign coloring matters by oxidation.

Resin.—The sap of the whole genus Pinus, belonging to the family of the *Coniferæ*, in the fresh state sometimes perfectly clear, at others only partially so, colorless or yellow, thickly fluid, and having an aromatic odor, belongs to the class of resinous vegetable substances called *balsams;* and is known by the name of *turpentine*. It is the solution of a resin in oil of turpentine, both of which substances stand chemically in such close relationship to one another, that the former is produced from the latter by the action of atmospheric oxygen. If oil of turpentine = ($C_{20}\ H_{16}$) is a hydrogen compound of a like nature to the hydrogen acids, *i. e.*, a combination of a carbo-hydrogen with hydrogen ($C_{20}\ H_{15} + H$), and judging from experiment it cannot well be otherwise, then the formation of the resin is nothing more than an abstraction of the hydrogen (H) by oxygen, for the production of water, and a substitution of another equal quantity of oxygen in its place. The resin of turpentine is therefore a mixture of two substances of this kind, which are allied to the acids, and have a like composition; they are sylvic acid ($C_{20} H_{15} O_2$), and pinic acid ($C_{20} H_{15} O_2$). Different proportions of oil and resin, and certain outward indications, serve to distinguish the varieties of turpentine in commerce. *Common turpentine*, from *Pinus sylvestris* and *abies* (also called fat turpentine to distinguish it from oil of turpentine, which in the arts is called simply turpentine), contains from 5 to 25 per cent. of oil; it is less clear, and whitish-yellow, soon becoming hard. *Venice turpentine*, from *Pinus larix*, is beautifully clear and colorless, containing 18 to 25 per cent. of oil; the thinner Strasburg turpentine, derived from *Pinus picea*, contains 33 per cent. of oil. The Carpathian and Hungarian varieties are obtained from *Pinus cembra* and *mugo*, the American (Canadian) from *Pinus canadensis* and *balsamea*.

When common turpentine dries up, or hardens into resin upon the trees, it is called *pine resin*, or white resin. Internally it is soft, but harder on the outside; it can be kneaded, and contains 10 per cent. of oil of turpentine. When it is completely melted and drained from the particles of wood, the only residue is (Burgundy) *pitch*, or *cobbler's-wax*.

To obtain the oil of turpentine, which is much more valuable than the resin, the turpentine is distilled in a copper retort, with about ¼ part of water. When no more oil and water passes over, the melted resin is drawn off and strained. On cooling, it forms a brown, transparent brittle mass, more or less dark in color according to the extent to which distillation has been carried, and is then called "*rosin*" or *colophony*. At a temperature of 156° F., it becomes soft, and can be kneaded, at 275° F. it is completely fluid. Heated without access of air, it evolves gas, combustible oil, and an acid water, leaving about 0.75 per cent. of carbon as residue. Its specific gravity is 1.07 to 1.08. Colophony consists essentially of pinic acid, mixed with a little sylvic acid; its dark color is attributable to the easily decomposed pinic acid, which has been partially converted into another resinous acid, colophonic acid. By fusing together 3 parts of colophony, and 1 part of white resin, another resin is produced, which is also sold as cobbler's-wax. For the same purposes as those for which pine resin is used, besides the resinous and tarry products of the dry distillation of wood, certain fossil substances of a similar kind are employed; these are partly fluid, partly solid, and impregnate the sand, clay, and limestone deposits of the secondary formation. In Genoa it is reported, that the naphtha of a neighboring spring (Amiano) is used for lighting the streets; on a larger scale in France, the bituminous shale of Autun (Dep. de Saône et Loire) is employed for gas illumination, and is distilled for this purpose with aqueous vapor. The shale produces from 10 to 25, sometimes as much as 50 per cent. of mineral tar, from which gas is prepared.

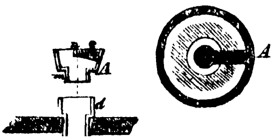
Of Coal.—All that is requisite for our present purpose, concerning the properties of this substance has already been stated at pages 25 and 54. Those kinds of coal are best fitted for illumination, which produce, when distilled, the most luminous and the largest quantity of gas; in general, these are such as cake, and leave little, or else very porous, coke, properties which depend not so much upon an excess of hydrogen as upon the general constitution of the coal. In England, the best gas for illumination is almost entirely got from cannel coal.

Of Illumination, and of the Methods of effecting it.—As has already been pointed out, the methods and arrangements for obtaining artificial light, vary with the nature and properties of the material, although on the whole the same principles are observed throughout. All the substances producing light, which leave charcoal or other residue after decomposition, can only be used for gas illumination; the others, which leave no residue, or mere traces of charcoal, are burnt in *lamps*, when they are fluid at common temperatures (oils), or as *candles*, when they are solid (tallow, wax, &c.).

Of Candles, and the Mode of preparing them.—Candles are cylindrical or slightly conical rods, formed of solid fat, in the axis of which a bundle of parallel or woven fibres of cotton is enclosed.

Tallow Candles.—When tallow candles are made by repeatedly dipping the wick into the melted fat, they are called *dips*, to distinguish them from *moulds*. For moulding, besides the common metal moulds (a mixture of tin and lead), moulds of glass are used. The former are very slightly tapering tubes, polished inside, Fig. 17, *a*, the lower end of which terminates in an open point *b*. In the stool or candle frame many of these moulds are arranged in holes made for that purpose, and rest in these upon shoulders somewhat below the upper orifice, in such a position that the point of the future candle shall have a downward direction. The wick passes somewhat prominently through the aperture *b*, where it serves as a stopper, and is fastened at the top of the vessel *A* which forms a part of the mould, and consists of a movable top, fitting exactly into the tube with its narrower part *m*. From a point in the margin *c*, a piece *e* is soldered in the direction of the radius with a round opening or eye *n*, so that the two orifices for the wick *n* and *b* are exactly opposite to each other, and the wick itself is thus brought exactly into the axis of the mould. The upper end of the wick (or the lower in the candle) is previously saturated with tallow to give it more consistence. Otherwise, when the little vessel *A* is not used, as with the glass moulds, a peg is put through the end of the wick formed into a loop, and rested upon the end of the mould, whilst the wick is pulled tight from below. Candles are also made in which there is no visible wick at the base, but which have the appearance

Fig. 17.



of being quite massive. In making these, a wick is chosen somewhat shorter than the mould, and is kept tight in the first instance by a looped thread, which is afterwards drawn out.

Whatever arrangement may be adopted with the moulds, it is always absolutely necessary that a certain quantity of tallow should be melted and cast in an *upright* position. It is essential in moulding that the tallow should completely fill the mould, that it should remain entire on cooling, without cracks, and should be easily removed from the mould. These requisitions can, however, only be attained when the fatty particles at the sides cool more quickly than those in the interior, and when the whole candle is rapidly cooled, *i. e.*, when it contracts but little. For this reason, a cool season of the year is preferable; but a certain condition of the tallow, namely, that which it possesses at a temperature very near its melting-point, is absolutely necessary. The candle-makers recognize the proper consistence of the tallow for moulding by the appearance of a scum upon the surface, which forms in hot weather between 111° and 119° F., in mild weather at 108°, and in cold at about 104°. The tallow is usually melted by itself, sometimes, however, over a solution of alum. The filling is generally done with a small can, but much better with a tinned iron syphon. The candles are most easily removed from the mould the day after casting, to be cut and trimmed at the base; when the little capsules are used, the whole portion with which they are filled is removed.

In the process of *dipping*, two vessels are used, one for melting a supply, the other containing tallow in the proper condition for dipping. The wicks, according as 6 or 8 candles are to go to the pound, are hung side by side on a wooden rod, *broach*, 16 or 18 together. That the broaches may be set aside conveniently and without interruption during the operation, in the same order in which they have been dipped, a frame of laths (*the port*) is placed over a flat tray to collect the droppings. The first thing in the operation is to saturate the wicks with hot tallow; cold tallow would not penetrate sufficiently into the fibres of the wick, and would become solid long before the next operation, the *dipping*. The saturated wicks are rounded and smoothed, either in the palm of the hand or upon a flat board, and taken lastly from the port in the same order in which they were saturated and dipped a broach at a time. The dipping is done by a quick, steady motion of the hand, only to be acquired by practice; having been once dipped in the upright vessel with cooled tallow, the dips are placed again upon the port, and the operation is repeated again and again in the same order until the candle has acquired the proper thickness. By a more or less deep immersion in the tallow, and particularly at last, when the candles are left so long immersed that the lower part may be melted off, the natural tendency of the tallow to collect in too thick a layer below is obviated, and the candles assume a cylindrical form. In some places the wicks are attached to the edge of small discs, which again are arranged on the periphery of a wheel movable upon a perpendicular axis, so that, as the wheel is turned, the discs are successively brought above the melted tallow, and can be detached for immersion. A warm piece of iron with a round hole to suit the size of the candles, aids in giving them their regular form.

Although the process of dipping is much more laborious and troublesome than moulding, yet it admits of inferior kinds of tallow being employed for the inner parts, whilst the best is used for the outer. It must be further remarked, that stored candles are very much better and harder than those freshly prepared, and that these latter often turn out yellow, but can always be bleached by exposure to the air.

Wax Candles.—Wax is not adapted for moulding, in consequence of the contraction which it undergoes in cooling, and the tenacity with which it adheres to the sides of the vessels. The method adopted in preparing wax candles is, therefore, more analogous to the process of dipping, only that the wicks, instead of being dipped into the wax, are basted with it.

The wicks, previously warmed in a stove, are attached to a ring of wood or metal, suspended over the melting vessel, in the same position which they eventually retain in the candle. Whilst the wick is kept constantly turned round its axis by the fingers, hot melted wax is poured slowly over it from a ladle, beginning about 1½ inches below the loop; by turning the ring, the next wick is put through the same operation, and so on. Before more wax is poured over the wicks, their position on the ring is reversed, and that no wax may attach itself to the free portion of the wick, that part is covered with a cap or tube of tin. Wax is now again poured upon the wicks one after the other, keeping them constantly turned round as before. When the candle has attained a proper thickness at the bottom, the basting ceases, that the shape, the bottom being always thinner, may be made uniform. This is done by rolling them upon a wet table with a rolling board whilst they are still warm; and to keep them warm after taking them off the ring, they are laid between hot flannel. The candles are then hung up again in their first position, the cap or tube having been removed from the prominent part of the wick, and they are basted a third time, the eye of the workman being the only guide to determine the proper amount. When the candles have attained the proper size, they are again rolled and cut to a certain length. When a wax candle is broken, the annular layers, like the yearly rings in wood, can easily be counted, and their number indicates the number of times the candle has had wax poured over it. By dexterous management and much practice, time may be spared, and the wicks, hanging in the first position, may be covered at once with the proper quantity of wax.

The large church candles are not moulded, but are made by placing a wick upon a slab of wax, bending this together and then rolling it.

The long thin, coiled wax tapers are made in a peculiar manner. The wick, which must be very uniform, and wound round a drum, passes from the latter into the wax pan, at the bottom of which a guiding roller is fixed, and from thence through a drawing-plate to a second drum. The drawing-plate is quite similar to that used in wire-drawing; it is a metallic plate, with holes corresponding in size to the diameter of the taper; these are, therefore, round when the taper is to be cylindrical; and in the shape of a star, when the taper is to be grooved. The wick passes through smaller and smaller holes successively, until it has attained the required thickness.

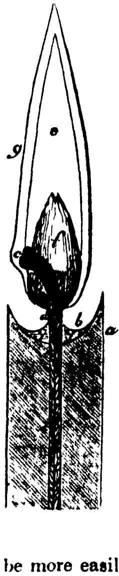
Stearine and Spermaceti Candles.—Stearine candles are always cast in moulds, although the tendency to crystalize in this substance, is an obstacle difficult to be overcome. Pure stearine, cooled under ordinary circumstances, does not attach itself to the sides of the mould, but is uneven on the surface, as a result of crystalization; it is, consequently, never employed alone, but with the addition of 1¼ to 2 per cent. of wax. The mixture, melted in pans by steam heat, must be allowed to cool, with constant agitation, until it has a milky appearance, and is still fluid. In this state, a portion is already solid, in the form of small crystaline needles, which remain suspended in the fluid, and give it a milky and thick appearance; cast in this state, stearine produces smooth and well-formed candles, but without the agreeable translucency of pure stearine. By wiping the candles with a rag steeped in alcohol, they regain the requisite lustre.*

Candles are moulded precisely in the same manner from spermaceti.

Both wax and stearine candles should be exposed at the same time to sun-light and dew, which together gradually bleach them.

On the Evolution of Light by Candles.—The candle may be considered as a real microcosm of illumination, in which all the individual functions regulate each other. The curious manner in which the separate functions mingle in a candle, and pass one into the other, in carrying out the main object, as well as the force of long habit, render the very same apparatus, (as far as the principle is concerned,) performing the same operations, less remarkable to the casual observer than gas illumination, which, being carried out on so extensive a scale, and at a vast expense, excites more general astonishment.

Fig. 18.



In a candle in full flame, Fig. 18, *a*, the fat below the flame is melted into the form of a hollow cup by the heat radiating in all directions. A reservoir is thus formed, in which that which is melted by the heat collects, and from whence, at the same time, it is supplied to the flame. The quantity melted exceeds, under nearly all circumstances, the quantity consumed, and there is consequently always a store of melted fat *b*, which is constantly being renewed. It is easy to conceive that it would be no impossibility to ignite a stick of tallow or wax by itself (without wick); but with what difficulty! A mass of fat of the thickness of a candle

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* The use of white arsenic to cause the wicks of stearine candles to be more easily reduced to ash, must never be permitted, as it is most injurious to health.

can only be set on fire by a corresponding amount of heat, to produce which, a common match is quite insufficient. On the other hand, if it were exposed to a sufficiently hot flame, it would be melted away long before it could take fire. Supposing, nevertheless, that it could be ignited, then the whole section of fat would naturally be on fire at once, a much greater quantity therefore than would correspond with the simultaneous supply of air, and the first requisite for the production of a clear flame would thus be wanting; a large, thick, smoky flame would result, the excessive heat of which would probably melt down the remaining fat before it had time to take fire. It would be superfluous to examine further, why a candle cannot be ignited from below. Hence, therefore, arises the absolute necessity of *supplying the flame*, every moment during the combustion, *with as much melted fat from the mass as can be consumed by it without smoke*, with a given amount of air supplied to the flame. The whole function of the *wick* has been herein expressed, but it must not be forgotten, that it is necessary to *raise* the insulated portion of fat to the flame which is above it. The power employed for raising the fluid, is *capillary attraction*, inasmuch as the interstices between the fibres of the wick form a number of capillary cylindrical spaces, whose action, however, depends upon the property of moistening the fibres which the fluid to be raised must possess, and which fortunately is the case with the fats to a considerable extent. Quicksilver, for instance, instead of being raised, would be depressed in these minute channels. Besides capillarity, the wick must possess another property quite as essential, and which is easily measured. The flame is always produced at that part of the free wick which is in the middle between its point of most active capillary action, and the point where the flow of melted fat is excessive, therefore, always at the same distance from the bottom of the cup *a*. In proportion as the candle diminishes, the flame is lowered and leaves the wick behind it; so that, at last, the wick extends the whole length of the flame or beyond it, and thus prevents the evolution of a great part of the light. The wicks, therefore, if the candle is to regulate itself, must shorten as the candle diminishes, *i. e.* they must be prepared from a substance which is combustible in the heat of the flame. The wick-cotton met with in the shops, is the soft, smooth spun cotton of the first spinning process. A skein with half as many fibres as the future wick is to possess, is doubled, (so that the loop which is always at one end of a new candle may be formed,) and so rolled with the hand, that the single fibres acquire a spiral twist which keeps them together, and prevents them from spreading out in the flame like a sheaf. An unavoidable circumstance, however, always opposes the natural regular consumption of the wick. From the position of the wick in the axis of the flame, the requisite quantity of air, being used up by the flame itself, does not reach the wick and completely consume it. The fibres of cotton are therefore charred; and they remain so until some part projects beyond the flame, and coming into contact with the air is consumed. If this happens as it generally does, too late, then soot collects in consequence of the interruption of the flame, as a spongy snuff at the top darkens the flame, and falls eventually into the cup *a*, where it causes further interruption to the process. In wax, stearine, and sperm candles, this evil has been ingeniously avoided by platting the wick like a cue, or by twisting it very much. The tension thus caused to exist amongst the fibres, obliges the free part of the wick to bend considerably, which brings the end *c* sufficiently soon out of the flame to be constantly reduced to ash.* The symmetry of the flame is partially destroyed by this arrangement; it follows the inclination of the wick, and consequently melts too much fat on the one side, which soon gutters over the melted edge of the cup. With the above substances, this guttering is less perceptible; but with tallow, which melts at from 68° to 86° F., it occurs to such an extent as to preclude altogether the use of platted wicks, and the charred ends must therefore constantly be removed with the snuffers.

Wax, stearine and spermaceti, besides possessing the unessential properties of producing no fatty stains, of being dry and not greasy to the touch, and of presenting an agreeable appearance to the eye, all fuse at a higher temperature than tallow, a property which is essential to the establishment of proper equilibrium between the quantity of fat melted by the flame and the quantity simultaneously consumed. The former quantity is generally in excess; the reservoir *b* becomes over full, breaks through the side of *a*, flows down and solidifies as a ridge on the side of the candle, which thus becomes thickened *on one side.*

Generally speaking, *no* candle actually exhibits this equilibrium, whatever may be the material of which it is composed; tallow candles, generally, much less than the others. For, independent of the fusibility of the material, it is influenced by the relation which the mass of fat, *i. e.*, the thickness of the candle, bears to the size of the wick, a relation which has been established approximately by long experience. The usual dimensions of a candle are, therefore, not fixed arbitrarily or by chance, but are absolutely necessary to a well-regulated process of combustion. If the wick is too large in proportion to the surrounding mass of fat, as is the case in tapers, no reservoir is then formed, and all the advantages attending it are lost. In the opposite case, which applies to all common candles, the wick which is rather too small produces a flame, whilst the outermost layer of fat is beyond the sphere in which fusion is going on. A thin ring-

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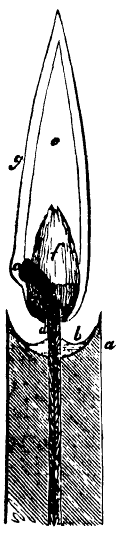
* Palmer's tallow candles, the invention of an Englishman, are made upon this principle. Partly by a particular twist in both wick halves, partly by winding a thin wire round these halves separately, they are made to separate like a fork, when both ends passing out of the flame are constantly consumed; the facility with which tallow becomes fluid, causes it to run down so rapidly by this extension of the flame, that this becomes a great objection to Palmer's invention. (This is completely obviated by using Palmer's candle lamps, in which the candle is enclosed in a hollow metallic tube forming the stem of the lamp, and is kept down by a nozzle, through which the wick projects; a spring at the bottom of the tube forces the candle up to the nozzle in proportion as it is consumed and thus maintains the flame always at the same height.)

shaped wall, as is easily observed in the less fusible stearine candles, remains erect up to a certain height, and is very objectionable from the shadow which it throws, but more so from its being gradually undermined, and falling into the reservoir which it overfills, and causes the candle to gutter. When it has once overflowed, the evil is doubled, for all the fat which, by overflowing, has formed ridges, is still further removed from the region of the flame. In night lights, made of stearine or wax, where intensity of light is a secondary consideration, this circumstance has been turned to account. These are made with a common sized wick, but a disproportionate thickness of fat, so that a very deep and full reservoir is formed, an excess, therefore, of melted fat, which, as too much of the free part of the wick remains immersed, causes them to give a very small quantity of light. For the sake of safety, they are made so short, that they will swim upright upon a basin of water. Several periods must be distinguished in the whole course of the process which is going on in a lighted candle. The heat generated by the flame, and for the greater part carried upwards by the current of air, acts, however, by radiation to such a degree downwards, that sufficient, or rather too much, fat is melted, for supplying food to the flame. The fat is supplied directly by the wick, the capillarity of which is constantly at work, sucking up the fluid matter, and carrying it to the sphere of combustion. The lower uncharred portion of the wick (up to *d*) acts the part of a sucking pump ; the decomposition takes place in the entire upper black portion. The fat which arrives there, is immediately exposed to a high temperature, without being able to come into direct contact with the air; it is in the same position as if it were enclosed in an iron retort between red hot coals, and it suffers consequently dry distillation. The gaseous and vaporous combustible products form the dark nucleus *f* of the flame,* between which and the surrounding air, the sphere of successive combustion is situated. The air streaming from below upwards, to the gases in *f*, consumes in the first instance the hydrogen, and separates the carbon as incandescent soot; this occurs in the luminous part of the flame *e*. Lastly, on the outside, in the hardly perceptible bluish halo *g*, the carbon is consumed; this occurs chiefly at the base, which does not appear luminous, in consequence of the air exerting its full influence at that part.

Fig. 18 *b*.



Every portion of tallow, which burns and gives out light, prepares the following portion for undergoing the same process. The different states of the flame may be partially made visible by an interesting

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* Imagine a thin circular section of these gases insulated in the flame; this will rise, and during its ascent, by reason of the constant combustion, will diminish in diameter until it entirely disappears. The velocity of this diminution, together with the velocity of the ascent (of the current of air), gives rise to the conical shape of the flame.

experiment that is easy of execution. If a bottle is filled with water, and supplied through the cork with a syphon in a downward direction, and a tube drawn out to a point in an upward direction, and this point be brought into the interior of the flame whilst the water is allowed to run slowly from the syphon, the bottle becomes filled with the combustible vapors in the form of a gray smoke. The vapors obtained from a stearine candle condense for the most part, to a dry, solid, fatty acid; not so those from oil or tallow. On blowing with the mouth, these vapors may be expelled from the bottle, and they burn, when ignited, with a distinct flame, which is but slightly luminous, in consequence of the admixture of air. The experiment may be made without danger with a common pipe, and by suction with the mouth. The importance of using hard solid tallow, to prevent guttering, is obvious, and all the materials should likewise be as pure as possible; for whatever is not decomposed in the same manner as tallow or wax, will obstruct the capillary tubes of the wick.

Of Lamps. Night Lamp without Wick.—The upper part of a candle, the hollow with the exposed portion of the wick, which we have called the reservoir, and in which the fluid (melted) fat is burned, is not different in principle from ordinary lamps, for these are only arrangements for burning materials (fat) which are fluid at common temperatures, as the oils. The first object is to isolate as much of the oil as is required for the production of a flame. The simplest manner in which this can be effected is that practised in the night lights shown in Fig. 19. On a layer of oil (*A*) covering the surface of the water (*B*) swims a brass cup *c c*, at the bottom of which is a small piece of glass tube fitted tight by a cork. Although, before ignition, the oil rises in the interior of the tube above the level on the outside, yet (as an addition to what has already been stated concerning the wick), the capillarity of the tube is annihilated by the heat, and the fluid is actually depressed. To obviate this, the tube must be fixed so far below the surface of the oil, that the greater pressure of the oil without shall overcome the depression within. In this manner, the insulated oil in the upper part of *a* may be ignited, and continue to burn by itself. The conditions under which the oil is consumed, so far as the production of light is concerned, are the most unfavorable, although the purpose of a night-lamp is fully answered: the flame, in the first place, is much too small to produce sufficient light for common purposes; and if the size of the tube is increased, the oil will no longer burn. The flame is, moreover, so deep down, that only the ceiling of the room is illuminated, and not the surrounding part. Both these evils, and particularly the latter, are avoided by the use of wicks; but others of quite as grave a nature are substituted in their stead. The oldest

Fig. 19.

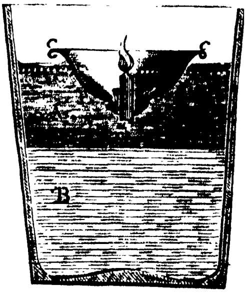


Fig. 20.

arrangement of this kind, the antique lamp Fig. 20, with all its artistic perfection of form, which so often excites the wonder of connoisseurs, is nevertheless, technically considered, the most imperfect of all. In an extended, open, or closed oil vessel, is placed an unspun round wick, which is held by a nozzle at the beak; the wick here, therefore, as in lamps generally, serves to regulate the supply of lighting material, besides having other important functions. It admits of giving more scope to the flame, and also by reason of its capillary action, of raising the flame above the surface of the oil in the vessel; but this is attended with fresh disadvantages. In the first place, it is obvious that the surface of the oil must sink with the consumption, and the wick is thus expected to raise the oil to a height that exceeds its power: the flame gradually grows dimmer, and is at last extinguished. Further, the thickness of the wick requisite to produce sufficient flame, involves a disproportion between the supply of oil which ascends for consumption, and the amount of air from without. As this is supplied from the outside, there must be a nucleus *a*, in the section of the wick, Fig. 21, which is deprived of all air by the surrounding part *b*, so that unburnt particles and soot in particular must escape, and cause the flame to smoke. The shadow of the oil vessel is, lastly, very considerable, although in a downward and backward direction. It is obvious, that this shadow will be lessened, by bringing the flame forward away from the vessel. The common kitchen lamp, shown in Figs. 22 and 23, has this single advantage over the antique lamp,

Fig. 21.

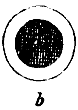


Fig. 22.

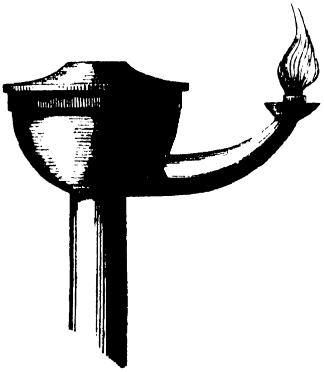
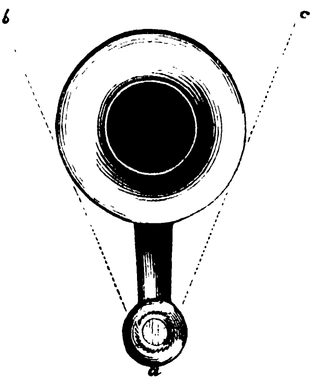


Fig. 23.



the beak being removed from the vessel, the distance between the vessel and the flame is increased, or the angle *b a c* is made more acute. The whole series of improvements made in lamps up to the present time, must be considered as the reward of no inconsiderable expenditure of ingenuity in the inventors themselves, and of a clear perception of the working of physical laws, enabling them not only to overcome the difficulties of the subject itself, but also to adapt the new contrivances to general use, and to the management of the unskilled. A general view of this interesting subject, will place clearly before us the essential points, which it has been the object of the inventors to attain, sometimes singly, sometimes several at once. They are these:

a) To select such a form (section) of wick that the quantity of decomposed oil, and the simultaneous supply of air, may stand in such relation to each other, that the hydrogen and carbon may be consecutively consumed, and consequently no *smoke* produced.

b) To make the distance between the burning part of the wick and the surface of the oil as unchangeable as possible, in order that as much oil may be drawn up at last as at first.

c) To place the reservoir of oil in such a position, that the shadow shall occasion little or no inconvenience. The use made of the lamp must, of course, here regulate its form; it is not, however, always a fault when these do not exactly correspond. Thus the shadow thrown by wall lamps is unimportant, as the lamp itself covers the shadow: in like manner, the shadow of a common study lamp cannot be considered as a fault, being used only by one person, although its prevention is always an improvement.

d) To throw the light, radiating from the flame, by means of collectors and reflectors, from those parts where it is of little service, in the direction where it is most required.

The requisitions stated under *a*), have been complied with in two ways: on the one hand, by controlling the access of air (the quantity of air); on the other, by regulating the supply of oil, and often by both at the same time. They have reference to that part of the lamp called the burner.

The scrupulous enumeration of the manifold modifications, and for the greater part, unimportant improvements in lamps, which have been presented to the public during the last twenty or thirty years, would be but a tedious labor; and in the following observations, we shall only lay before the attentive observer those inventions which appear to indicate important progress, or form epochs in the history of this subject. When particular parts only are concerned, these are treated of separately; when the improvements are more general, and include several parts, they are described in connection with the whole lamp, that a clear insight into their functions may be obtained.

Worms'-Lamp.—In the countries bordering on the Rhine, the Worms'-lamp, shown at Figs. 24 and 25, is well known, and characterized by the shape of the wick *t*. The fibres of the wick, instead of being collected into a round bundle, are placed in small bundles side by side, forming together a flat ribbon. The effect of this is obvious. The edges of the flame are at no point so distant, that a nucleus can form in the centre, which from want of air will burn incompletely, and smoke. The flat socket *c*, serves to hold the wick; it is soldered in the diameter of the wide ring *d*, which, with its recurved edge, rests upon that of the glass globe *a a*. An important addition to its flat form, is its *movability*, and this is common to all the following kinds of lamps. The teeth of a wheel *e* and *e′*, more distinctly seen in Fig. 25, are somewhat advanced into the space occupied by the wick, a cut being made in the socket, so that they press the wick in some measure against the back side. According as the screws are turned, the wick is either raised or lowered, and a larger or smaller portion of it is engaged in the combustion. When the wick is high, a large quantity of oil is decomposed; and when low, a small quantity in the same space of time; the supply of oil is, therefore, easily regulated.

Fig. 24.

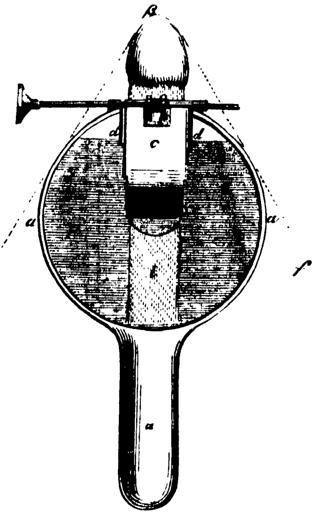


Fig. 25.

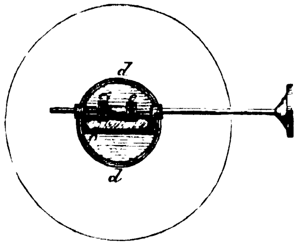
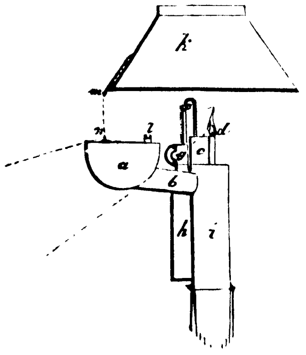


Fig. 26.



By means of the stem *a*, the oil vessel can be placed upon any kind of foot. Besides the very unequal, constantly decreasing height of the surface of the oil, another objection may be raised to this arrangement, on account of the size and disadvantageous direction of the shadow, the conical space between *β f*, and *β g*, receiving no direct light.

Study-Lamp.—In the common study-lamp, Fig. 26, the oil vessel *a* is more flat, and instead of being situated below, is behind, and at the side of the flame, so that its shadow falls much beyond the immediate vicinity of the flame, and in no way interferes with the person in front of the lamp. The greater part of the light passing upwards, is collected by the shade *k*, and from every point of its inner surface is reflected downwards towards the opposite side. The inclination of the sides of the conical shade is, therefore, not unimportant, and should be at an angle of about 60°. The shade can be turned on the support *m n*. The motion communicated to the wick *d* is not from above, as in Figs. 24 and 25, in which arrangement the pressure interferes too much with the supply of oil, and the flame is too much cooled by the proximity of the wheels, but it is from below. The clamp *u*, Fig. 27, which sustains the wick, is firmly connected with the toothed rod *e*. By turning the wheel *o*, this and the wick are raised up or down; the wheel works in the separate compartment *g*, as does the toothed rod in descending into *h*, whilst the clamp, the rod of wire, and the wick, by means of a rectangular appendage *c*, Fig. 28, are all enclosed in the space allotted to the burner. This communicates with the oil vessel through the tube *b*; *i* is the enclosure round the burner. The motion of the wick, by means of a toothed rod and wheel is, under various modifications, common to most lamps. The stopper *l*, at the aperture for filling the oil vessel, must be pierced, that the air without may not depress the oil in the burner.

Fig. 27.

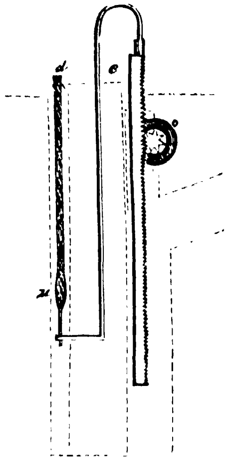
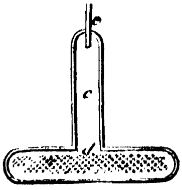
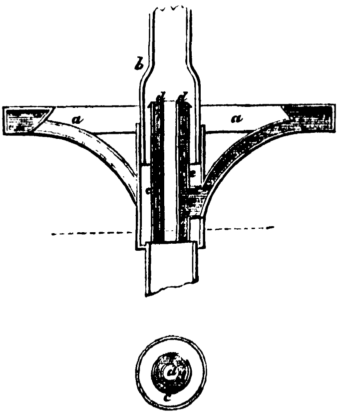


Fig. 28.



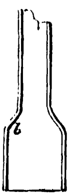
The Astral-lamp.—The astral-lamp, of which a sketch is given in Fig. 29, was constructed by Bordier Marcet, with the idea of making as imperceptible as possible the sinking of the level of the oil, and at the same time the diminution of the flame by means of a very flat oil vessel, in which, therefore, a larger quantity of oil only occupies a very insignificant height. It is clear, that the annular flat oil vessel will produce only a small unimportant shadow, although this will necessarily be thrown on all sides. At the same time, the side nearest the flame *a a* is so inclined, that it acts like a shade. The burner is not peculiar to the astral lamp, but is the well-known invention of Ami Argand, in 1789, and named after him; it is by far the most important kind of burner employed for illuminating purposes. The Argand burner, with double draught, consists of two metallic cylinders, one within the other, *c* and *d*: in the ring-shaped space between

Fig. 29.



them, which is closed at bottom, contains the oil and the cylindrically woven wick; the latter is clamped between two rings, which are connected with the screw. The inner cylinder is open at top and bottom. The extraordinary advantages of this arrangement are easily understood. It has been already shown, that with entire (massive) wicks, a nucleus is formed in the middle of the candle, which illumines but little, and smokes from want of air; with the hollow wick, a current of air is directed exactly to that spot, so that the flame is surrounded by two concentric currents of the same kind. The current produced in the air by a freely burning hollow-wick flame, or the natural supply of air, is by no means sufficient to produce the requisite amount of light. As soon as by raising the wick, the size of the flame is increased, a thick smoke is the result; and when the wick is so regulated as to produce no smoke, then the flame is weak and deficient. But Argand understood how to give a real practical use to his invention, by applying the happy idea of an artificial draught. The principle is the same as that of chimneys: a rest on the outside of the burner supports a straight glass cylinder,* which, including the inner and outer draught of air, exerts a powerful influence upon the velocity of both, in proportion to its height With this arrangement, the point at which smoke begins to be evolved, corresponds with a much higher intensity of flame. Another advantage, not at first anticipated, is the great steadiness caused by the chimney. When a draught of air comes in contact with an unprotected flame, its force and cooling influence produce diminished combustion, and at the same time flickering and smoke; in Argand's burner, on the contrary, the supply of air to the flame is become self-dependent, whilst the heat itself is made the motive power. The cylinder protects it from any direct interruption, and that arising from the draught apertures, is hardly felt at all in the interior. It must not be left unnoticed that the straight Argand cylinders, whilst assisting the draught, fall into an opposite extreme, and supply too large and injurious an amount of air. This was remedied, soon after the original invention, by Lange, and forms an important improvement; in consists in contracting the diameter of the glass chimney at a certain height above the burner at *b*, thus forming a shoulder of a few lines in width, as in Fig. 29 and 29*a*. The draught, moving in the simple cylinder, in a parallel direction to the axis of the cylinder, is thus broken at the shoulder, and thrown into the flame at a certain angle. The supply of air is, therefore, lessened, but the direction given to it is preferable; and that part of the current, which, without taking part in the combustion, cooled the flame in a useless manner, and passed along the inner surface of the cylinder, is almost entirely removed. The glass chimneys are, however, applicable to all burners with flat, round, or semi-circular wicks.

Fig. 29 *a.*



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* The original chimneys used by Argand were made of sheet iron, and arranged above the flame.

Fig. 30.

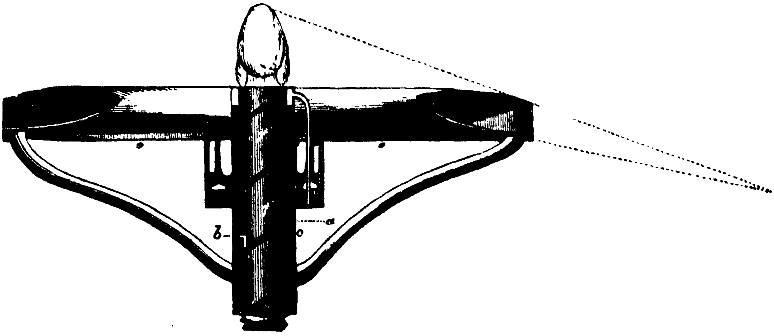
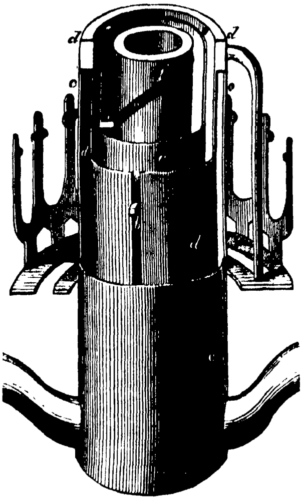


Fig. 31.

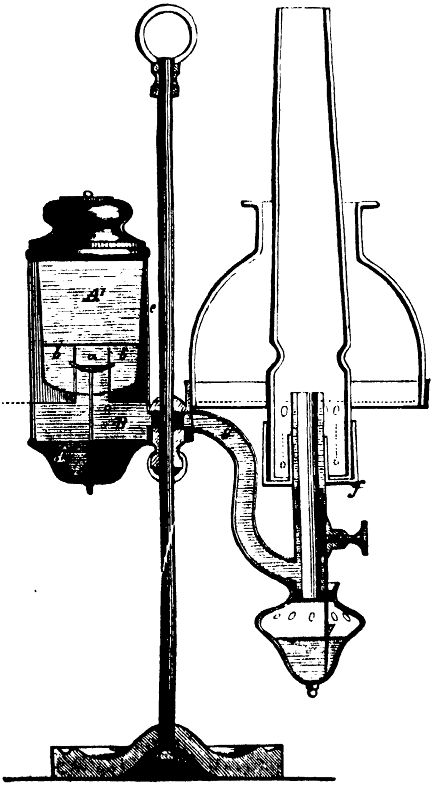
Fig. 32.



Sinumbra Lamp.—When the astral lamp is used as a hanging lamp, the shadow of the circular oil vessel is thrown more towards the ceiling; this is not the case when it stands in an upright position. By an ingenious modification, Phillips has succeeded in his Sinumbra lamp, Figs. 31 and 32, (*sine umbra*), in rendering the shadow imperceptible even in the latter kind, and this is done by the peculiar shape (section) of the circular vessel *o*. Its three surfaces meet in the form of a flat wedge, the sharp edge of which is directed towards the flame. The position of the flame, in relation to the oil vessel is such, that two tangents drawn from the apex and base of the flame to the latter, meet a few inches behind it in *x*. Beyond this, the vessel can cast no shadow; but even in this small space it is almost entirely destroyed by a vase-shaped ground-glass shade, which, resting upon the oil vessel, surrounds the chimney, and scatters the light in all directions around. The manner in which the wick is moved in the sinumbra burner is original, and deserves notice; there is neither screw nor toothed rod employed. The inner cylinder *f*, is furnished on its outer surface with a deep, much inclined spiral groove, into which the short peg, or appendage *a* of the wick-holder *e* fits. If, therefore, the latter is turned on its axis, the peg moves along the groove, and forces *e* up or down. From its position in the burner, however, *e* cannot be approached by the fingers, and directly turned; this is effected by the cylinder *d*, which throughout its whole length—that of the burner—has a slit, into which a second peg *b*, on the outer side of *e*, fits. By this arrangement *d* can at any time be freely moved up or down, but cannot be turned without taking with it the wick-holder, causing this either to be raised or depressed. In order that *d* may be moved easily, and without danger from the flame, it is firmly connected with the support for the chimney, terminating above in a thick ring, 2 or 3 lines wide, which rests upon the edge of the cylinder *c*, this being purposely made lower, and the whole is thus brought up to the full height of the burner. In this ring, the supports for the chimney are fixed. If these are turned with the hand, *d* is turned at the same time, and with it the wick-holder, which is thus moved up and down. Great mobility characterizes this arrangement, and no forcing or compression of the ring holding the wick can occur.

All the lamps as yet described are subject to one common evil, that of having the oil vessel, at all events within a few lines of the level of the burner, in a position, therefore, which throws the most objectionable shadow. A whole series of contrivances have consequently resulted from the efforts of inventors to transpose this cistern either to a considerable distance above the flame—when its shadow would fall upon the ceiling of the room—or to a position much below the flame, when it would fall at the foot of the lamp. Both resources, however, when applied, give rise to new and critical difficulties; the former requires that the supply of oil which flows *downwards* to the burner, should be accurately regulated. The most common and general application of this method, is that adopted in the standing lamp, Fig. 33. The oil cistern *A* is a movable metallic vessel, capable of being closed at the bottom by a valve *a*, which moves between the regulating rods *b b*. In the upright position, the valve falls back, and leaves the aperture open for filling

Fig. 33.



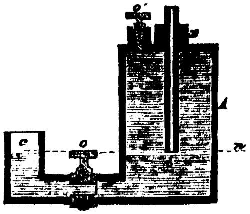
the vessel; if the valve is then pulled up by its rod, the aperture is closed, and the bottle can be inverted, and put in its place in the case *B* (as in the figure). It is no sooner there, than an alteration occurs. The rod attached to the valve is so long that the valve is raised as soon as it touches the bottom of the case *d*. The oil, therefore, flows out for a few seconds, until it has risen so high in the case as to stop the aperture of the bottle *A*. From this instant, equilibrium is established, and as the mouth of *A* is on a level with the height of the burner, this becomes filled at the same moment, connection having been made by means of the tube *g*. The lamp has really two oil cisterns, an under one, which directly feeds the burner, and an upper one, the inverted bottle, for the supply of the lower as the oil is gradually consumed. As long as the level of the oil in *B* remains unchanged, and the mouth of *A* consequently closed, no air can enter *A*, and the whole stock of oil is kept up by the pressure of the atmosphere. When the lamp has been lighted some time, and the oil sinks below the mouth of the bottle, a few air bubbles enter, and take the place of an equal bulk of oil, which flowing out raises the level in *B* until the mouth is again closed. The same operation is repeated, as long as oil is present in *A*.

The other parts of the lamp are easily understood: *f* is the support for the cylinder (the peculiar form of which will be explained below), *q* is the vessel for the toothed rod, and *e* is an aperture in the case, for the easy admission of air into the interior.

On reflection it will be immediately perceived, that in all similar lamps, from the peculiar arrangement of the oil cistern, the height of the oil in the burner will not be always quite constant, but will alternately sink and immediately rise again to its former height, whilst in the lamps previously described, the suction of the wick is rendered more and more difficult by the constant sinking of the level of the oil.

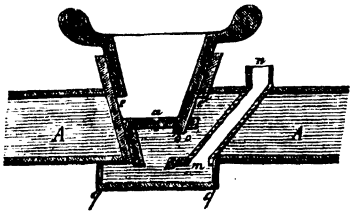
The principle in question has been put into practice with better success by means of a simple vessel without case, as for instance, that represented in Fig. 34. The mouth of the movable oil bottle corresponds here with the lower opening *b* of the tube *a b*, which, passing through the air-tight collar *x*, is movable in the lid of *A*. The oil consumed in the burner *e* is replaced from the stock contained (above the level *n n*) in *A*, the place of which is then occupied by air, which enters at *b*. As soon as the consumption of oil in *e b* ceases, no more air bubbles enter, and vice versa. As the level of the oil in the burner is dependent upon the position of the mouth *b*, this can be most accurately adapted to circumstances, *a b* being movable. The cocks *o* and *o′* are only used in filling the vessel.

Fig. 34.



This principle can be applied in the same manner, or in a much more compact form to lamps with circular oil vessels, by means of Caron's stop-cock, Fig. 35. The conical plug of the cock is completely hollow, and at a certain distance from the middle, it is supplied with a cross bottom *a*, dividing the space into two unequal parts. In the upper part, the round lateral aperture *e* is made opposite to *o* in the lower part; *e'* and *o'* are the corresponding apertures in the case. In the position represented in the drawing, *e* is closed, whilst *o* is in free communication with the stock of oil in the circular vessel *A A*. This stock comprises the whole quantity, situated above the mouth *m* of the tube *m n*, corresponding with the tube *a b* of Fig. 34. The side tube communicating with the burner also opens into *q q*. In the opposite position of the cock, (by closing *o*,) the space *A*, and, in the first instance, *q q* is shut off from communicating with the burner, whilst the same space *A* can then be filled, *e* being open.

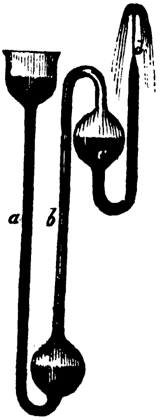
Fig. 35.



By transposing the oil cistern to the foot of the lamp, by which means all shadow is avoided, we forego the important advantage which the free flow (fall) of oil occasions, and by means of which it can easily be conducted to the burner; and, as consumption goes on, the oil must then be *raised.* The lamps made upon this principle are interesting on account of the ingenious, but at the same time very complicated elevating apparatus, which partly depends upon hydrodynamic, partly upon hydrostatic laws, and is partly also a mere mechanical arrangement.

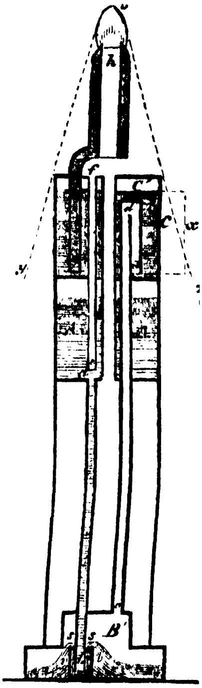
Girard's Lamp.—Girard's (hydrostatic) lamp is constructed upon precisely the same principles as the air-chamber of a fire-engine, or resembles rather Hero's fountain, Fig. 36. In these arrangements it is well known that the pressure exerted in a vessel is transferred to any other distant cistern by means of compressed air, and is the means of forcing a liquid from its previous position, for example, in an upward direction. In Hero's fountain, the primary pressure is produced by the column of water *a* fed from the vessel above it; the air enclosed between *c* and the lower bulb is thus compressed, acts upon the surface of the fluid in *c*, and forces it to a corresponding height in *d*. All these compartments are also present in Girard's lamp, but are closely packed together for the sake of saving space, as is seen by the sketch Fig. 37, where the unimportant parts are left out. *A* is the reservoir for the forcing column of oil in the tube *a b*, *B* the lower vessel with the enclosed air (*B'*), which conveys the pressure received from *a b* through

Fig. 36.



c d' d to the vessel *C*, and in the first instance to the air *C'* contained in it. As long, therefore, as there is pressure from *a b*, the air *C'* will cause the oil in *C* to rise in the tube *g h* to a corresponding height (to the burner). This height, therefore, depends upon the uniformity of pressure in general, and ultimately upon the constant uniformity of height in the column of oil *a b*, which has a tendency every moment to shorten the play of the whole, both from above and below; from above, by the sinking of the oil in *A*, from below, by its rise in *B*. To avoid the former, at least for the duration of an evening's consumption, the vessel *A* is furnished with a tube *e f*, upon the same principle as that described in the oil cistern at Fig. 34, so that the height of the column of oil exerting pressure coincides with the aperture *e*, and all the oil above that must be considered as a store for the supply of that column. The latter is obviated by the narrow vessel *v* which surrounds the aperture *b*, and is filled up to *s s* in a few moments by the oil flowing from *A*, thus constituting a basis of uniform height for the column. Both contrivances are effective until the oil in *A* sinks below *e*, and has risen on the outside of *v* above the level *s s* in *B*. With the requisite height of the lamps, the pressure of the column would raise the oil to a greater height than is desirable. To avoid an excessive length of burner, the tube *c d' d* may be curved like a syphon, as indeed was done by Girard, by which means the oil in *e f* is caused to rise as much less, as *d* is below the fluid level in *C*, therefore *x* less. The pressure is first exerted to overcome the column of oil *x*, and it is only the excess that exerts an upward influence in *g h*; the result is, therefore, the same as if the elevation in *g h* was effected not from the level of the oil at *C*, but at *g*, for $gh = e\ s\ s$.

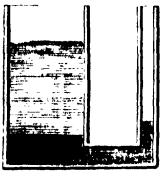
Fig. 37.



Future endeavors to bring the principle of Girard's lamp into a form more suited to daily use will, perhaps, be successful; for the limited application which has been made of it must be ascribed to its inconvenient shape. The following points deserve particular notice; first, as is obvious enough, the working of the lamp is not independent of the changes of temperature and pressure in the atmosphere. Increasing pressure (rise of the barometer) and a lower temperature will diminish the bulk of the air enclosed in *B* and *C*, and cause an augmented flow of oil from *A* towards *B*. A fall in the barometer, and a higher temperature will produce an opposite effect, and cause the oil to flow from the burner. The effect of temperature is the stronger of the two; but both by proper means can be rendered imperceptible, at least for the duration of an evening. Another and a greater objection arises from the position and the shape of the vessel *C*, upon which, as may be seen by the sketch, the supply of the burner is solely dependent, whilst the oil of *A* and *B* is only employed as a fluid pressure. *C* cannot well be made deeper without increasing immoderately the height of the lamp; there is, therefore, no other means of affording space for the requisite quantity of oil for an evening's consumption, than by adding to the breadth of this vessel. When this is done, and from its being placed immediately under the burner, the shadow falling between *o y* and *o z* will very much exceed the space occupied by the foot of the lamp. Lastly, the necessary additions and apparatus for filling the lamp deprive it of that ease and simplicity in the management which daily use justly demands.

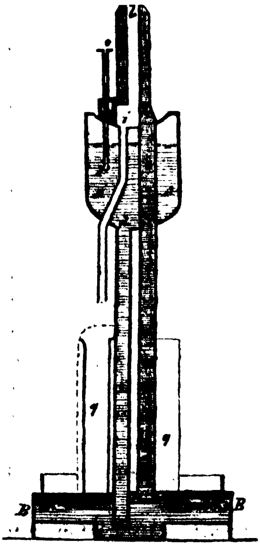
The Hydrostatic Lamp.—The doctrine of the equilibrium of fluid pressure has found an application in the hydrostatic lamps, which Fig. 38 will illustrate. Two different fluids, brought into tubes which are connected at the bottom, will balance each other at different heights above *g h*, according to their respective densities. The fluid above *h* will form a column as many times lower as its density exceeds that of the other fluid. A column of mercury requires to be only 1 inch in height to balance a column of sulphuric ether of 19 inches, or a column of oil of 14 inches.

Fig. 38.



After salt and water, syrup, honey, mercury, had all been tried as heavy liquids, Thilorier succeeded in 1825, at Paris, in giving a decided pre-eminence to his lamp, by the use of a solution of white vitriol (sulphate of zinc) and by a suitable apparatus. When we consider, that the fluid producing the pressure must not affect the oil or the sides of the vessel (tinned iron), that it must not become solid (crystalize) at a temperature several degrees below the freezing point of water, that it must be cheap, and have the proper density, we shall then understand how to appreciate the discrimination which led Thilorier to employ a solution of equal parts, white vitriol and water. Such a solution is 1.57 times denser than oil, so that a solution of zinc 10 inches high can support a column of oil 15.7 inches in height.

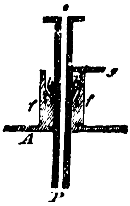
Fig. 39.



It is obvious that, with the diminution of the column of oil (the consumption of oil in the burner) the solution of zinc will sink to a corresponding level, and will only be enabled to force the oil to the original height, when it itself is fed by a reservoir of zinc solution. The cistern *A* in the section of the lamp, Fig. 39, is solely for this purpose.

In a chamber *B*, in the foot of the lamp, both the equally poised columns terminate, namely, the column of oil in the tube *a b*, which terminates above in the burner, and the column of zinc solution in *e d*, above which the cistern *A* is situated containing the zinc solution. The flow is effected in the manner described in Fig. 34, by means of the tube *o P*, through which the external air enters bubble by bubble, as the solution in *e d* threatens to sink. The height of the column must, therefore, be reckoned from *P*; *B* is completely filled, and by both fluids at the same time, so that no air remains in it. Into the lower solution of zinc (extending to *n n* in the Fig.) the tube *e d* is plunged; into the oil above, on the contrary, the tube *a b* does not enter beyond the top layer of the fluid in *B*. From the time of lighting and during the combustion, the level *n n* naturally becomes higher and higher. At length *B* becomes quite filled with solution of zinc, and oil must be supplied. This is done by a separate funnel through the burner, which obliges the solution of zinc to return to its former position, an outlet being afforded for the air in *A*. The tube *o P*, Fig. 40, (twice its proper size,) is intended for this purpose, having a conical appendage *h*, accurately ground to fit into *f f*, and luted into the lid of *A*. The position represented is that for filling, and this is effected by the peg *g*, which is fixed to *o P*, and only rests on the edge of *f f*; when *h* is to be closed, the tube is turned until *g* falls into a perpendicular cavity. The oil which overflows the burner in filling, and at other times collects in the concave lid of *A*, and passes off by *i i*, to a ring-shaped movable vessel *q*. This vessel is open, and ring-shaped to admit of the passage of *a b* and *e d* through the middle of it.

Fig. 40.



It must not be supposed, even when everything goes on regularly, and the supply in *A* is not exhausted, that the level of the oil in the burner always remains the same, for the column *n a b* is constantly shortened by the rise in *n n*, and more rapidly than is the case with the zinc column *n P* during the same time. The inventor has succeeded in rendering this imperceptible for a duration of six hours, by making the diameter of *B* very large in proportion to that of *a b*. The difference of level does not actually exceed 2 to 3 lines, whilst the oil in the burners of astral and sinumbra lamps frequently falls 1 inch.

Thus far Thilorier's lamp would combine a great number of advantages, if these were not accompanied by one very critical circumstance; it cannot be carried, nor indeed moved, without the danger of being extinguished, for the slightest inclination, as in the barometer, produces considerable fluctuations in the respective levels of the two fluids, and these fluctuations are always 1.57 times greater in the column of oil than in that of the zinc solution. For this reason, the lamp has not been so generally introduced as its other very great advantages would warrant.

Pump Lamps.—The general conclusion may be inferred from what has been said, that the different static lamps either do not attain the important advantages which their construction was intended to confer, or are accompanied with corresponding disadvantages. In contradistinction to these we have the lamps with a mechanical arrangement for raising the oil; and as a pump is generally employed for that purpose, they are called *pump lamps.*

The simplest example of these is the pump lamp with a flat wick, very much used in the south of France. The motion of the pump is produced by the hand, but in a very imperfect manner. The piston of the pump is kept constantly raised by the tension of a spiral spring. As soon as the piston rod, which is also the ascending tube, and in firm connection with the burner, is forced down, by overcoming the power of the spring, the descending piston forces the oil in the cylinder to rise through the tube to the burner. When the stroke is ended, the elasticity of the spring brings the piston to its former position, and the cylinder becomes again filled. As candles require snuffing from time to time, so here, the pump must be used at short intervals. In lamps of this kind, with double draught, the burner is fixed, but then there is a piston rod with a handle at the side of the ascending tube. The uniform working of such a lamp depends, therefore, upon the care which is taken to supply the oil that is consumed by repeated use of the pump. If this is only done at long intervals, the flame will vary from its utmost intensity to a very dingy light.

The numerous improvements which have here been noticed, with reference to the most successful and interesting inventions, must be considered as important advances; but they have nevertheless left one point out of view, upon which the most indispensable conditions for combining a perfect, and at all times, uniform evolution of light, depend; a point which is indisputably the most difficult of all to accomplish. It has already been mentioned (p. 134), when speaking of the general principles of lamp and candle illumination, how the lowering of the oil level obstructs more and more the functions of the wick, and consequently diminishes in an equal degree the brilliancy of the flame. The lamps with a supply, upon the principle of connected tubes, are subject to this evil in its entire extent; those with an inverted bottle or similar arrangement are also influenced by it within certain limits. In the former, the brilliancy rapidly diminishes; in the latter it becomes lessened, and returns to its original state at regular intervals.

Carcel's Clock-work or Mechanical Lamp.—Carcel, in the year 1800, was the first to carry out the idea of pumping up the oil from the foot of the lamp to the wick, by simple machinery like that of clocks, and, moreover, in such quantity as to exceed the quantity consumed during the whole period of burning. The invention of his clock-lamp is without precedent, with reference to the uninterrupted and perfect supply of oil to the wick. Whilst in the other lamps, the burner contains a stationary column of oil, which either constantly decreases from above, or is reinstated from time to time, the oil in

Carcel's burner forms a constant ascending current, which always supplies the wick with as much as it can possibly require; and lastly, the unconsumed portion flows back to the foot over the outside of the burner.

Carcel's invention left only unimportant points connected with the works and the pump to his successors, to which the skill of Gagneau, Nicod, Careau, and others have been applied. The Figs. 41 to 43 present a section of Carcel's lamp, and its various parts with Penot's improvements. The chief parts of the lamp are arranged as follows. The case for the works *B* and the space *A* for the stock of oil, form the foot of the lamp. The stem of the column contains only the ascending tube *b*, which separates above (over the capital) into a forked appendage (crutch), upon which rests the burner with its two concentric tubes *e e*. The burner and the ascending tube form, therefore, a space which is connected with *A* by means of the pump. This latter is a so called *priest-pump*, and is more simply represented in Fig. 44. The space *x* is closed at the top by a piece of elastic cloth or leather, in the middle of which, when it is considered as a piston, the piston rod is fixed. By its upward and downward motion, an alternate expansion and contraction of *x* are effected. In the first case, the valve *s* opens, and oil enters *x* from *r r*; in the

Fig. 41.

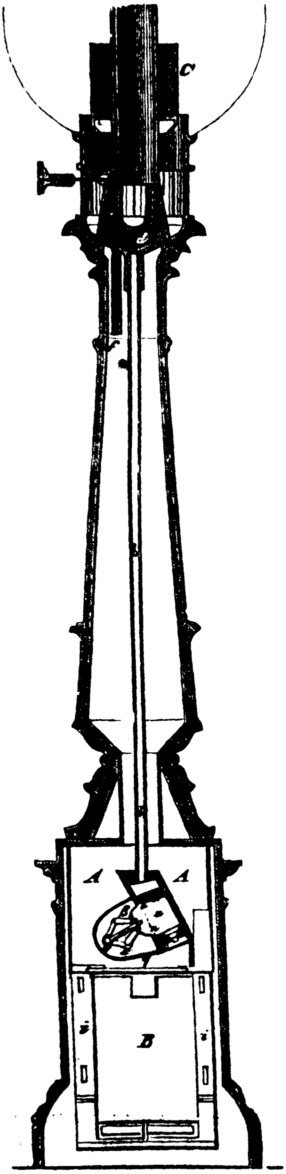


Fig. 42.

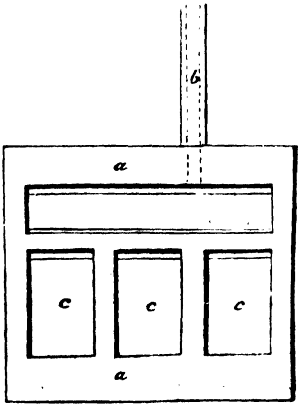
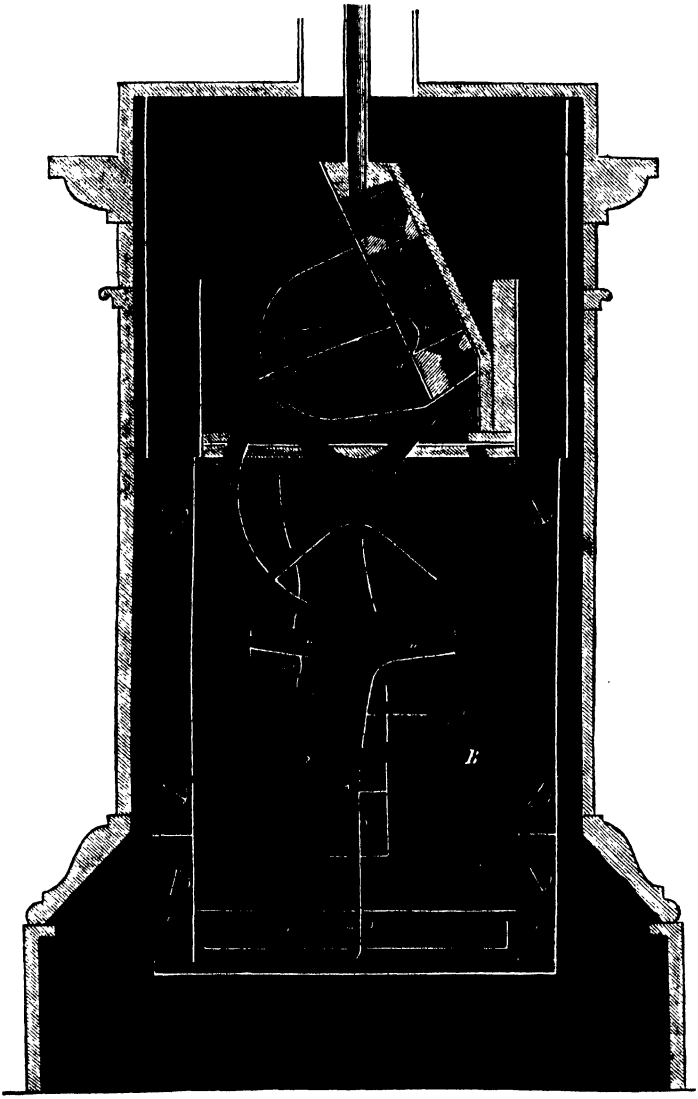
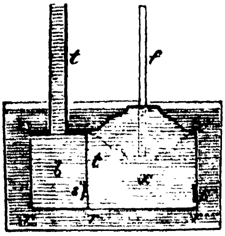


Fig. 43.



other case, through the valve *s′*, oil passes from *x*, and is raised in the tube *t*. The motion of the cloth or leather acts in short in the manner of the cheeks and muscles in drinking and blowing. To meet the unavoidable obstructions which would result from the presence of impurities in the oil, it is all made to pass, whilst still in *A* and before entering the pumps, through a metallic sieve with fine holes *q*, which surrounds the whole of the front part, including the entrances to the valves below.

Fig. 44.



The quadrangular box of the pump contains, for preserving uniformity of action, three simple priest-pumps *c c c*, made of gold-beater's skin, which, during every moment they are in action, alter their positions relative to each other. This necessary circumstance is self-evident from the whole arrangement of the pump. Each single pump has two valves, an entrance valve (the under one in the figure) and an exit valve (the upper). *a* is a separate chamber for each, the space for receiving the oil above the exit valve, on the contrary, is common to all. The three short piston rods, if they may be so called, work upon three crooked arms *B y x* on the same axis, but in different directions. One pump must, therefore, always be forcing, whilst the second is sucking, and the other midway between the two. Below, or in the direction of *B*, the chamber *A* is completely closed, with the exception of a stuffing box, through which the crooked pin of the axle is moved. The wheel *t* passes under a box placed at the side, in which this stuffing box is situated. The iron frame *i i* serves to give steadiness to the works in *B*; the most important parts of the arrangement may be seen in Fig. 43. Motion is obtained by the spring wound up in the case *o*, *o*, *o*, which is furnished with cogs. The cogs of *o*, *o*, *o*, first move the toothed wheel *t* upon the same axis by means of *x*. The wheel *t* catches the second cog *y* above, which has the same axis as the piston rods, and thus the pumps are set in motion. Below, however, *t* moves the endless screw on the axis of which is the fly wheel *d* for regulating the works, by means of *z*, and the toothed wheel *u* and *v*. At the very bottom, on one side of the foot of the lamp, is a small bolt, which, when pushed forward, catches the fly wheel, and either stops the works, when in motion, or sets them going when it is pulled back, and the whole has been wound up.

The stopping wheel *W*, is used for winding up the machine with a key.

The toothed rod *g*, with the wick-holder, works below the crutch of the ascending tube, in the case *f*.

Experience has shown that the whole arrangement of the works is not so tender and brittle as might, at first sight, have been supposed.

The overflow of oil from the burner makes it necessary to screw the wick up somewhat higher than in common lamps; and this brings with it the great advantage of the flame being more raised above the edge of the burner, where less heat is conducted from it, and it burns more perfectly, producing no carbonaceous matter on the wick and about the edge of the burner, which, in general, so materially interferes with the regular flow of oil.

Carcel's lamp would, without exaggeration, have been prized as much as Argand's had been sixteen years previously, if a less expensive and more suitable form for general use could have been given to it.

At an earlier period, and again, more recently, (Joanne, Franchot, and Houghton,) the idea has occurred to those versed in these matters, to replace the complicated clock-work, either by the force of a falling body, (for instance, a piston in a cylinder,) or, at least, to cause the tense spring to act upon a larger piston of that kind. In both cases the oil is contained in a lamp-like vessel, resembling the cylinder of a pump, from whence it is slowly forced upwards by the piston (moved either by gravity or a spring), to the burner.

So far, all is simple and easy; but the practical use of the lamps has always foundered on the difficulty of regulating the *acceleration* of the fall, or the *diminution of the force of the spring*, to the uniform demand of the burner. The arrangements of this kind are all wanting in simplicity, or they effect their purpose but imperfectly. Generally, the ascending tube is contracted conically at a certain spot, into which a conical plug fits. The spring in rising enlarges the aperture at the contracted spot, whilst the sinking piston lessens it by forcing the plug either backwards or forwards, in proportion as their motion is irregular.*

The application of a natural agency for raising the oil in lamps, first proposed by Celarier, is worthy of notice, from its novelty and simplicity, and because it may possibly be productive of something else, not from the use actually made of it at present, which is by no means established. It is of very common occurrence, and may easily be observed. Celarier's lamp consists principally of two vessels, fixed one above the other, which are separated from each other by a partition; the upper contains oil, the lower air. In the partition, a narrow tube is placed, which opens into the air chamber below by a valve, and somewhat higher in the oil vessel, with a simple aperture. On filling the lamp, the oil in this tube rises to the same height as in the vessel; but as soon as the valve is opened, the air begins to escape by the same tube as that through which the oil is passing, in endeavoring to fill the lower vessel. The result is, with such a narrow tube, that with the bubbles of air, drops of oil, or rather little columns of oil, are carried up much above the level of the oil. Another plan, applied by Samuel Parker and Mallet, in which the oil is warmed in a ring-shaped vessel above the flame, before reaching the burner, promises theoretically to be of value, but requires to be subjected to further proof.†

Vapor Lamps.—At the commencement of this section it was stated, that volatile oils, inasmuch as they deposit carbon instantaneously, and are yet completely consumed, are applicable as illuminating materials, as far as their high price will permit; it must, however, be observed, that these oils, on account of the large quantity of carbon

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* A pressure lamp, patented some years ago, and now manufactured to a considerable extent, in which the flow of oil is regulated by a silver tube of very narrow bore, will be noticed in the Appendix.

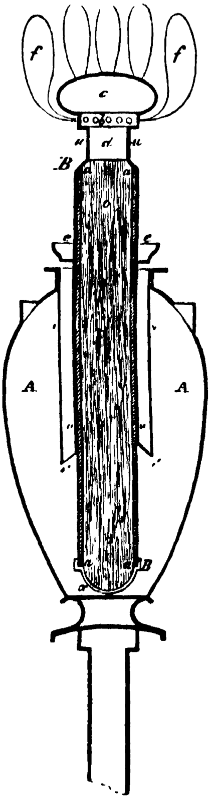
† Parker's hot oil-lamp will be described in the Appendix.

which they contain, will deposit soot under the same circumstances in which a common candle will not do so. There are two ways of preventing this, either by increasing very much the draught of air, or as Lüdersdorff has done in the lamp bearing his name, by mixing substances with the oil, which reduce its per centage of carbon.

Lüdersdorff's Lamp.—In some places, as at Berlin, for instance, prices admit of using, instead of pure oil of turpentine (for that is the lighting material of Lüdersdorff), a mixture of this spirit with 4 parts of strong alcohol of at least 90 per cent. This strength is necessary; for with a greater amount of water, the flame would be too much cooled, the oil of turpentine be imperfectly held in solution. The carbon, and originally amounting to 88 per cent., or 8 times the quantity of hydrogen, is diminished by this mixture (illuminating spirit) to 63 per cent., or 3 times the hydrogen, which is much less than is contained in oil or tallow. The less evolution of light, from the same weight of spirit, is, however, actually compensated, although at some cost, by the greater rapidity with which the light is evolved from the same quantity. Lüdersdorff's lamp, Fig. 45, is well adapted to show the different mode adopted in burning the volatile oils, from that employed with the fats.

A is the vase for the illuminating spirit, into which the burner *B* descends from above almost to the bottom. It consists first of a straight, pretty wide, metal tube *a a*, fitting tightly into the real burner tube *u u*, which surrounds a loose cotton wick *o o*, and fastens it by the semicircular piece *x*. Above *A*, at a distance of about 2 inches, (the wick extending thus far,) the tube becomes narrower, and ends at *d*, in the knob *c*, which is the real burner; at the base of *b*, from ten to twelve holes, ¼ line in bore, are made in a circle at equal distances from each other. When the lamp is to be used, common spirits of wine is ignited in the cup *e e*, to vaporize the illuminating spirit in the upper part of the wick. As soon as the vapor issues from the apertures *b*, it is ignited, and forms the flames *f*, which surround the knob *c*. The metallic mass is then sufficient, on account of its high temperature, to keep up vaporization with ease (even at the distance of *c* from the wick), and the lamp continues to burn by itself. To protect *A* from the action of the burner, which gradually becomes heated, the latter is surrounded, to the depth of three inches, with a wide case *i i*, which is attached to it below (at *i i*), so that a space filled with air surrounds it thus far. Lamps of this

Fig. 45.



kind give a costly but brilliant light, free from all the inconveniences of common wicks.*

Beale and d'Hanens' Lamps.—For the coal districts, England and Belgium, where abundance of coal naphtha, or oil of coal tar, is obtained from tar, Beale and d'Hanens have contrived lamps without wicks, for obtaining light from that substance. Both lamps are fed by means of bellows, by a current of air, therefore, of considerable velocity. In Beale's "steam and vapor lamp," but not in d'Hanens', this current traverses the oil, and becomes saturated with it. The former produces a flame from 6 to 7 inches high, when supported by a double current of air, whilst that of d'Hanens', from a knob surrounded by ten holes, in the manner of Lüdersdorff's lamp, throws out a crown, consisting of as many single flames. Both lamps produce dazzling white flames, which, in themselves, are without smell, and only disseminate the penetrating odor of tar oil for a few moments after they have been extinguished. They are, therefore, adapted for lighting streets and workshops, but not for rooms.

Reflectors, Shades, &c.—The production of light from oil in the greatest possible quantity, is by no means the only object of illumination generally, or of that by means of lamps in particular: the proper dissemination of the light with judicious regard to the nature of the eye, is a second, and not less important object. All light that is more intense than that of the illuminated objects (the room, for instance), weakens the impression made by them upon the eye, and makes them appear darker and less distinct. The eye is thus said to be dazzled by the light itself, it can no longer distinguish distinctly the objects in the immediate neighborhood of the flame, whilst the more distant ones, or those which are less illumined, it perceives with perfect clearness, because the impression obtained in this case is not weakened by the simultaneous and more powerful action of the flame.

Ground-glass, or translucent glass, (milk-glass), in the form of hollow globes, half-globes, bell-shaped, or vase-shaped, vessels, are the common means of deadening the dazzling effect of the flame. Mention has already been made of this, in speaking of the Sinumbra-lamp, in which the dull bell-glass is an essential part. The action of these is generally surprising; the outline of the flame itself vanishes from the eye, whilst all the rays of light proceed from the surface of the globe or bell, which thus has the appearance of being self-luminous, and as the rays sent from it cross each other in all directions, the objects in the neighborhood can only throw short, indistinct shadows. Colored glasses are but little used, probably from their imparting an unnatural color to all surrounding objects.

As light naturally spreads from any flame or source uniformly in all directions, contrivances are necessary to collect the portions which

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* For an account of the methods recently introduced for burning camphine (oil of turpentine) in lamps, *see* Appendix. [A great number of lamps for burning lard have been patented in the United States, some notice of which will be given in a subsequent part of the work.]—AM. ED.

would be wasted, and direct them to the parts where they are required. The intensity of the light, from the ordinary (divergent) rays, diminishes rapidly, in the ratio of the square, with the distance from its source. When, therefore, the *shades* and *ground-glasses*—these being the ordinary means of diverting the rays—not only throw back the rays, but also give them a parallel direction, their use becomes of a double kind, and the diminution of their intensity no longer occurs. The parallelism of the rays can only be produced with mathematical precision in two ways: either when the flame is in the focus of a glass lens—by refraction of the permeating light—or when it is in the focus of a parabolic mirror, by reflection. A semi-circular can replace a parabolic mirror in its action, although only approximatively, when the flame is placed at the distance of ½ the radius from its centre. For the common lighting of rooms, very expensive lenses and reflectors are never used, but frequently simple tinned screens, the inner surface of which is polished or whitened, to prevent the absorption of light; for lighting the streets, on the contrary, parabolic metallic mirrors are used.

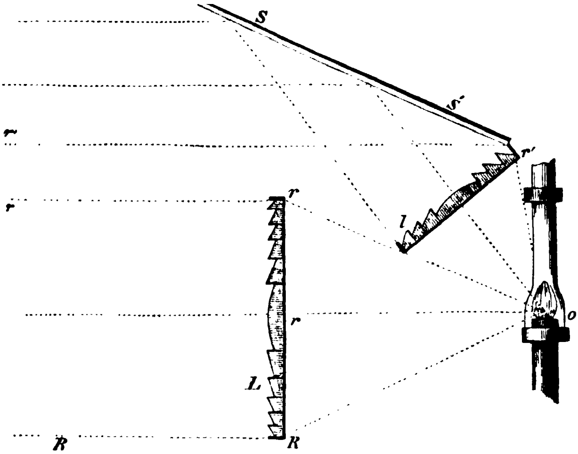
To direct the light downwards, which would otherwise escape above—the most common case—conical shades are generally used, like that in Fig. 26. This light is reflected from the straight sides of the cone, as from a number of flat surfaces. The diffusion of the rays, in consequence of the slight height of the lamp, is here of little consequence. This is not the case with wall lamps, where the whole of the rays of light should be reflected and carried forward in a horizontal direction. Tinned screens, somewhat parabolic, are then used, or screens made of small pieces of glass mirrors, which together, as a whole, approach the form of the parabola.

Although, for common purposes, it would be superfluous to devote much attention to the means of refracting and reflecting the illuminating rays, yet for the more important and grander objects of illumination, all the knowledge of the learned, and the ingenuity of the artist, must be called into play. An individual case, where these are required, will be better suited to give a clear view of the arrangement and adaptation, than a long description of the matter in its whole extent. The description of the French light-house lamp, and of a similar one for illuminating theatres, as regards their most important parts, will prove particularly instructive.

The construction of the modern French light-houses resulted from the united efforts of Arago and Fresnel, in the year 1822. The burner of the lamp—as much light as possible being required in a small space—consists (according to the rank of the light-house) of two, three, or four, Argand burners, placed one within the other, each having a double draught of air, and which together are supplied with a constant flow of oil, upon Carcel's principle. The wick-holder is separate in each, but the glass chimney, lengthened by a tinned tube beyond the box, is common to all. Thus constituted, the compound burner forms the centre of the case (of the lamp), which is nearly as tall as a man, and is composed of optical mirrors and lenses, in metallic frames.

It is well known, that the fabrication of glass lenses several feet in diameter, is practically impossible. These, therefore, are made up, at Fresnel's suggestion, of single polished lens-rings, surrounded by a frame, which together assume the surface of a perfect lens, and produce the same effect. The position of these lenses, and of the reflectors in relation to the burner, will be evident from Fig. 46.

Fig. 46.



Two rows, consisting of eight lenses each, surround the burner in a ring, the larger ones *L*, and the smaller inclined ones *l*; above both are placed the reflectors *S*. The rays between *R* and *r* are collected by the lens *L*; and, as the flame is in the focus *O* of all the lenses *L* and *l*, the rays are refracted, and proceed in the form of a bundle of parallel rays. Those which have an upward direction between *r* and *r'*, suffer the same refraction by means of the lens *l*. Thus far, the whole light would be emitted in the form of two cylindrical rays,—in reality, slightly conical—from the imperfection in the lenses, of which one only would proceed horizontally in the direction of the ships, the other would be uselessly directed towards the sky. This is obviated by every lens *l* being associated with a flat mirror *S*, the inclination of which corresponds with half the angle of inclination of the bundle of rays directed upwards, so that this is reflected in a horizontal direction. The effect of parabolic reflectors, instead of the lenses, is too partial, as it is impossible to adapt many to one burner; the ships, in every direction, would consequently not profit by the light. These lanterns revolve upon their axis, by which means, at each revolution, light and darkness are caused to succeed each other eight times alternately; the eight double bundles of rays being separated from each other. Thus the crew are enabled to distinguish the light-house from all other lights upon the coast.

Peclet, in his celebrated work upon illumination, mentions that these, or similar methods of illumination might be used with advantage in theatres, which are often very inadequately lighted. The position of the chandelier at the height of the upper boxes, dazzles those occupying that position to such a degree, that the middle of the stage is to them quite darkened. Locatelli succeeded in obviating this evil, by an experiment made in the year 1825, in the Theatre Fenice, at Venice, which appears to be as ingenious as it is worthy of imitation. The chandelier is there placed in a round opening in the ceiling, therefore quite without the theatre, and in such a position that the burner can be directly seen from no point. An apparatus of parabolic mirrors throws the light as a cylindrical bundle downwards into this opening, where a second arrangement of dispersing lenses spreads it in all directions over the space below.

It is self-evident, that all arrangements for reflecting or deadening the light, must themselves entirely absorb a portion of it.

Of Gas Illumination. Historical.—The observation was made in the year 1664 by Dr. Clayton, that combustible, illuminating gas was produced during the decomposition of coal by heat, and that this could be collected; one hundred years afterwards application was made of the fact. Lord Dundonald built some coke furnaces in 1786, and amused himself by collecting the evolved gases in tubes and burning them, but without any definite object. Since the year 1792, another Englishman, of the name of Murdoch, to whom we are indebted for the invention of the useful application of gas, occupied himself incessantly with experiments up to the year 1796, which were crowned, in 1798, by the erection of the gas-work for illuminating the manufactory of Boulton and Watt. Independently, and about the same time, Le Bon, a Frenchman, succeeded in illuminating his house, which was warmed by the same means—thermo-lamp—by an apparatus in which he evolved bad gas from wood. Gas was employed by Winsor for street illumination in the year 1812 in London, and 1815 in Paris. Oil gas was first prepared on a large scale by Taylor in 1815.

Illuminating gas occurs in nature, and not very rarely, but it is not of such good quality as that artificially produced. It has always been observed where matter of organic origin, contained in rocks, is undergoing gradual decomposition, (p. 31.) The celebrated holy fires at Baku (Prov. Schirvan) on the Caspian Sea, are due to the ignition of a gas which issues from the earth, and which Hesz has shown to be light carburetted hydrogen with some naphtha vapor. It contained 77.5 carbon to 22.5 hydrogen. In New York they have gone still further; the practical tact of the Americans has already made use for industrial purposes of similar sources of gas at Fredonia on Lake Erie. The gas is there collected in gasometers and used for illumination.* The

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* It appears from a paper of Mr. Richard Cowling Taylor, published in the Philosophical Magazine, for March 1846, that the Chinese, although perhaps not gas manufacturers, have been nevertheless acquainted with the use of coal gas both for illuminating and heating purposes, long before the knowledge of its application was acquired by Europeans. Beds of coal are frequently pierced in China by the borers for salt water, and the inflammable gas is conveyed in pipes to the salt works, where it is used for boiling and evaporating the

burning fountain of Dauphiné is of like origin; but the soil of Italy, particularly in the neighborhood of the Apennines, is remarkably rich in such phenomena; Pietra Mala, Barigazzo, Bologna, Parma, are the chief localities of this kind. Phenomena of a similar nature occur in the Cordilleras, in Hungary, Greece, England, and other countries.

Nature of Illuminating Gas.—The general principles of illumination (p. 112) show that the lighting properties of a gas or mixture of gases, must depend upon the relation which the carbon in it bears to the hydrogen, and that it can only be turned to a useful purpose when there is more of the former of the two elements present than in fire-damp, and when the proportion of both approaches that of olefiant gas. Light carburetted hydrogen ($C\ H_2$) contains 75.4 carbon to 24.6 hydrogen; olefiant gas ($C_2 H_2$) 86 carbon to 12 hydrogen. The latter would have a decided preference above all, if it could be procured sufficiently cheap. This, however, is not the case, and we are obliged to be content, from motives of economy, with a mixture of gases, which is produced by the decomposition of certain substances of organic origin, and which contains so much olefiant gas that it far exceeds light carburetted hydrogen in illuminating power. When these organic substances are exposed to a certain temperature in closed vessels, the following process results. A coaly residue (coke) remains, and certain volatile products escape, which partly condense on cooling into tar, and an aqueous fluid, while the rest is a mixture of gases, but contains, also, no inconsiderable portion of the volatile vapors of different compounds which remain dissolved in the cooled gases, without being condensed to liquids. The researches of Sell, Blanchet, Runge, Kidd and others upon coal tar, have led to the knowledge of a number of oily, volatile products, of very different chemical character, and which are mostly carbo-hydrogens with a very large proportion of carbon. To these belong kyanole, leucole, pyrrole, rosolic and carbolic acids, and naphthaline. Most of these contain 90 per cent. of carbon, naphthaline as much as 94 per cent., and in burning they deposit it in still greater quantity than olefiant gas. It is, therefore, easily conceived why the vapors of these substances remaining with the gas, so very much enhance its value. Such mixtures of gas and vapor are called illuminating gas, without reference to the separation of noxious and useless impurities before it is used. We have, therefore, to consider illuminating gas, not as a definite compound, not as light carburetted hydrogen or olefiant gas, but rather as a mechanical mixture of very various bodies, some of which are slightly or not luminous; whilst others are exceedingly luminous, as olefiant gas and the carbo-hydrogens which possess similar properties, and to which the mixture is indebted for its illuminating power. It is a remarkable chemical peculiarity, that carbon and hydrogen are capable of uniting in the same proportions by weight to

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salt; other tubes convey the gas intended for lighting the streets and the larger apartments and kitchens. When there is still more gas than is required, the excess is conducted beyond the limits of the salt-works, and there forms separate chimneys or columns of flame.

form a series of gases and liquids, which are only different on account of the different amount of contraction of volume which their elements undergo in the moment of combination, and this alone can explain the great multiplicity of solid, liquid and gaseous hydro-carbons which are known to exist. It has already been stated how differently certain substances, as wood, fat and coal are suited for the production of light gas. Coal, fats or oils, resin and tar, asphaltum, soap-water and the refuse of animal bodies, are all practically employed (some experimentally) according to the locality, in the production of gas. The different nature of these bodies requires that different modes of preparing the gas from them should be adopted; and these must be considered separately.

Coal Gas.—Experience has proved that cannel coal is far superior to all other kinds, both as regards the quantity and quality of the gas, which it yields. Scotch Parrot coal is the next best kind. Even the Berlin gas works use cannel coal from England. In countries where this is not to be met with, as in France, highly caking coal, of a similar character, is chosen for this purpose, and on the east coast of England caking coal is generally employed for gas making.

The amount of gas obtained from a given quantity of coal depends very much upon the quality of the coal, and upon the manner in which the distillation is conducted; it is, therefore, very variable, as will be seen by the table below.

	Locality of the Coal.	1 lb. hess. gives C. F. hess.	Duration of the distillation hours.	Works at which the observations were made.
Observations upon a large scale by Hedley.	Dean coal, from Cumberland . . .	8.66	6	Alliance Company in Dublin.
	Carlisle coal (Blenkinsopp) . . .	9.92	6	
	Equal parts Cannel and Cardiff coal	8.2	4	
Results obtained by the common process.	Lump coal, from West Bromwich .	5.7	—	Birmingham Company.
	Wigan Cannel and Oldham Watergate coal, mixed } . . .	8.44	—	Manchester.
	Wigan coal, small	7.3	—	Liverpool old Company
	Wigan Cannel coal	8.4	—	" new "
	Derbyshire coal	6.67	—	Leicester.
	Newcastle coal	7.56	—	London.

According to Accum, 100 cubic feet of coal give from 18,700 to 9200 cubic feet of gas, according as the best kinds of Scotch or Lancashire coal are used, or the worst kinds of Staffordshire coal. At the hospital St. Louis, at Paris, the yearly average from as much coal was 12,300 cubic feet of gas; which is equivalent to 493 cubic feet of gas to the cwt. of coal; Prechtl estimates the produce at 700 cubic feet; so that the statements as regards the weight of the gas, vary from 12 to 17 per cent. The decomposition of the coal begins with the incipient red heat of the enclosing vessels and lasts, when large quantities are employed, several hours, the quantity of gas gradually diminishing towards the end. According to Peckston, in an eight hours' distillation, the relative quantities of gas given off are, in the first hour 20, in the second 15, in the third 14, in the fourth nearly 13, in the fifth 12, in the sixth 10, in the seventh 9, and in the eighth about 8 per cent. of the whole quantity, when the fire is uniform and the vessels are constantly at a red heat. The cubic foot at the end, therefore, costs 2½ times as much as at the beginning. The quality of the gas, at the different periods of the distillation, however, must also be taken into consideration.

For this purpose it will be proper to cast a glance at the ingredients of the gaseous mixture in general; this consists, after the separation of the tar and the aqueous liquid, of: *olefiant gas, light carburetted hydrogen, carbonic oxide, hydrogen, vapors of the volatile oils of tar, sulphuret of carbon, ammonia, sulphuretted hydrogen, carbonic acid, cyanogen, sulpho-cyanogen, sulphurous acid, hydrochloric acid, aqueous vapor, and nitrogen.* The carbonic oxide and a part of the free hydrogen have doubtless the same origin, being formed from the moisture in the coal, or from the first portions of aqueous vapor that are generated, which passing over the red hot coke are converted into those two gases. The nitrogen of the coal is obtained entirely as cyanogen and ammonia, partly in combination, and the latter is also found combined with sulpho-cyanogen and the other acids forming volatile salts; the *free* nitrogen, on the contrary, is the residue of atmospheric air contained in the retort. Sulphuretted hydrogen and sulphurous acid are due to the sulphur (as iron pyrites) in the coal. The first four of the ingredients named, with the illuminating vapors of tar oil, form the proper bulk of the gas; the others are small quantities of impurities which should have been separated with the tar. It has been found by experience, that the relative proportions of these four ingredients vary with the duration of the distillation and not in favor of the illuminating portion of the gas. When chlorine is added to light gas, it forms with the olefiant gas and the vapors of tar oil—with those constituents, therefore, upon which the illuminating power depends—a fluid compound, which separates, and the original volume is consequently diminished. The diminution which the volume of the gas suffers when mixed with chlorine is, therefore, in direct proportion to its illuminating power, and to the value of the gas, to the amount of olefiant gas (and tar oil vapors) which it contains. This explains the following statements, which contain the experiments of Henry, and are, so far, a correct representation of the process and trustworthy, inasmuch, as that observer followed analytically, step by step, the whole course of the evolution of gas. Henry found, that below a cherry red heat, almost nothing but hydrogen, atmospheric air, and some tar passed off with hardly any illuminating gas, but that, at that temperature, illuminating gas alone appeared, and this was composed of a mixture of gases in the following relative proportions:

Time of collection.	Specific gravity.	Absorbed by chlorine.	Carburetted hydrogen.	Carbonic oxide.	Hydrogen.	Nitrogen.
		out of 100 parts of gas from Wigan Cannel coal.				
In the first hour	0.650	13	82.5	3.2	0	1.3
	0.620	12	72	1.9	8.8	5.3
	0.630	12	58	12.3	16	1.7
5 hours after the	0.500	7	56	11	21.3	4.7
10 commencement.	0.345	0	20	10	60	10

As a general result, therefore, carburetted hydrogen is formed in decided excess, and the most luminous portion of this, which is condensible by chlorine, comprises only about $\frac{1}{5}$ of the whole. These numbers also prove distinctly, that, after about the fifth hour the quantity only increases, but the quality does not improve, indeed this deteriorates so rapidly, that at the expiration of ten hours, the gas which passes over is hardly luminous when ignited, but burns with a very faint blue flame.* The immense increase of hydrogen, which at this last period amounts to 60 per cent., is remarkable and very important to the manufacturer, an increase, which is no longer due to the decomposition of aqueous vapors, but to that of the carbo-hydrogens themselves. In accordance with an old observation, these are decomposed at a high red heat and deposit a portion of their carbon on the sides of the vessel. More recent experiments of Marchand show the progress of this decomposition very clearly. When olefiant gas was conducted through a red hot tube and the heat constantly augmented, the gas passing off, collected in successive portions, contained the following quantities of carbon to 100 of hydrogen.

Hydrogen : Carbon	Nature and temperature of the gas.	Hydrogen : Carbon	Nature and temperature of the gas.
100 : 614	Olefiant gas.	100 : 367	
100 : 580	Red heat.	100 : 325	Intense white heat.
100 : 533		100 : 307	Light carburetted hydrogen.
100 : 472			
		100 : 7	Continued white heat (nearly pure hydrogen.)

It is evident that this decarbonization is at last complete, and that it is very unfavorable to the illuminating power of the gas; it increases with the degree of heat, with the extension of the red hot

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* The specific gravity, as will be seen, keeps pace with the quality of the gas, and can thus far be taken as a test of its value. As pure olefiant gas has about the specific gravity of the air (0.98), the density of an illuminating gas must increase with the quantity of olefiant gas contained in it; yet an extraordinary amount of carbonic oxide (sp. gr. = 0.97), or of carbonic acid (sp. gr. = 1.52) may give rise to errors of some magnitude.

sides of the retort, and with the time that the gas is in contact with them. On a large scale, when the whole charge becomes at last converted into red hot coke, this noxious influence can never be entirely avoided, but with proper precautions it can be kept within certain limits. Whatever precautions may be taken, the carbo-hydrogens must always pass over red hot surfaces before they can reach the conducting tube, and hence, although only for a short time, they find the opportunity of depositing carbon, which is constantly produced in greater quantity than is desirable.

The practical man will find no further difficulty in adapting apparatus to suit the conditions prescribed. The best product will be obtained, when none but dry coal is used, and when this is directly brought into the retorts at a cherry red heat, a uniform temperature being kept up throughout the process, which should be immediately stopped after the expiration of five or more hours, when the illuminating power of the gas begins to diminish. It must not be supposed, however, that the gas is directly produced from the coal, for the observations lead to the conclusion, that tar is the first product, and that, by the further decomposition of it, the gas is generated. Hence a certain temperature (below a red heat) gives rise to tar only.

The individual parts of the gas works depend upon the general principles which have here been explained.

The Retorts.—The vessels used for decomposition are called retorts, and were originally cast iron tubes of about one inch in thickness, about 7 feet long, and 1 foot wide; they are closed at the back and furnished with a short thick peg cast in the direction of their axis.

The flaws which often occur in cast iron, arising from particles of clay, air bubbles, &c., make it necessary that each should be tested, before being used, with reference to its impermeability to gas. This is also requisite with the conducting tubes (see below), and is done by forcing water into them under a pressure of 1½ to 2 atmospheres, or even better, by means of air at the same pressure, the tubes being then placed in water, the escape of the air, if such should occur, can be observed. The retorts are not cast in one piece, for the hinder part which is exposed to the fire becomes from time to time useless, and must be changed, whilst the neck or mouth-piece remains quite unacted upon. The neck and body of the retort are connected by flanges and screws. The neck is open in front for the convenience of charging and discharging, and furnished with an easily fitted lid *d*, Fig. 47, which is fixed by means of the screw *w* and the hold-fast *v*. The latter, by means of a hinge at one end, and a peg at the

Fig. 47.

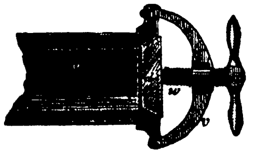
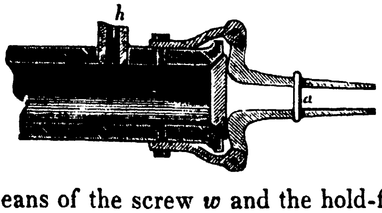


Fig. 48.



other, can be turned back, or firmly pressed against the mouth of the retort *a a*. The mouth of the retort and the lid are ground conically like a valve; if clay is applied between the two inclined surfaces, and the hold-fast screwed up, in a few moments an air-tight joint can be made. Instead of this, two bent levers, Fig. 48, may be used, which when the ring *a* is forced up, press with their shoulders against the lid. In all cases, the mouth-piece is furnished with a wide tube *h* (Fig. 48) cast on to it.

That form of retort would be the best which would bring the whole charge into connection with the red hot sides. Hence, at the instigation of Prechtl, the original circular form of retort (Fig. 49) was soon superseded by the elliptical form (Fig. 50), and this has been improved by bending in the lower surface (Fig. 51). With the same length of 6.5 feet, (exposed to the fire), 150 lbs. of coal, when they only half fill the retort, will cover, in the round retort, a red hot surface of 10 inches in width, in the oval one a surface of nearly 12 inches. The layer of coal in the latter retort is 4 inches thick, and about one-third nearer to the top of the retort than in the circular form. These advantages, which are self-evident, are strikingly shown in practice, the requisite time for heating being reduced nearly one-half.

Fig. 49.

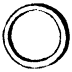


Fig. 50.

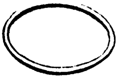
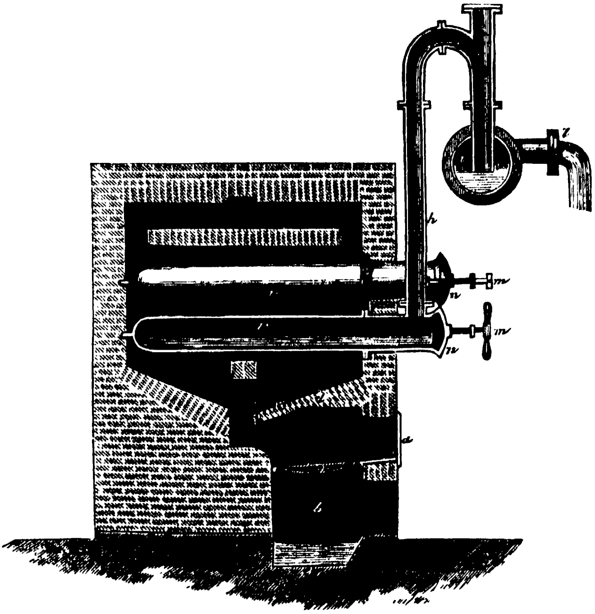


Fig. 51.

The Furnace.—Fig. 52 shows the arrangement and position of the retorts, of which there are generally five pyramidally placed in one

Fig. 52.



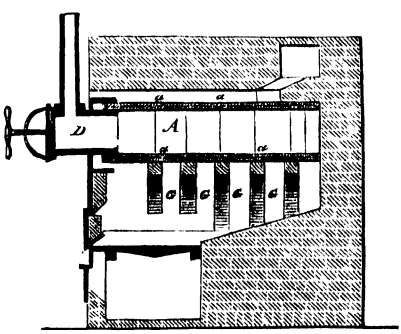
furnace: Fig. 53 is a front view of the same. To the three fires of the furnace, *a* is the door, *c* the grate, and *b* the ash pit, with a well *e* for occasionally drying lime-mud (see below); *d* are three arches which pass transversely over each fire and divide the flame, *c c* is a large arch overspreading the retorts *r r*, against which the flame breaks and escapes at the side. The conducting tubes rise side by side above the furnace, passing behind a large horizontal tube *i*, called the hydraulic main, and lastly turn over above it, and enter it, dipping down nearly to the bottom. As this main *i* is filled with tar, the mouths of the tubes *h h* are closed, and there is no connection established between the separate retorts. One may therefore be opened and charged, without in the least interfering with the process going on in the other. The greatest portion of the tar separates from the gas in *i*, which latter passes off through *l*, whilst the former is carried away by the tube *m*, (curved for the purpose of keeping *i* half full,) through *n* to a tar cistern sunk in the ground; *i* can be completely emptied by means of *k*. A very hot flame, mixed with an excess of unconsumed air (oxydizing flame), is unnecessary and deleterious, both for the evolution of gas, and on account of the rapid destruction of the retorts which it occasions; everything, therefore, depends upon a uniform, steady fire. The destruction of the retorts is incredibly rapid, and dependent upon several circumstances; besides the combustion caused by the hot air of the fire, the sulphur in the coal converts the surface into sulphuret of iron, which melts off, and lastly, the deposit of carbon in the interior is of no slight importance. This carbon is partly in the form of a hair-like deposit, partly stalactitic, from the droppings of tar, but generally occurs as a coating, 1 or 2 inches thick, in concentric layers, and combined with iron to form graphite. The specific gravity of these layers increases rapidly from the innermost layer to those on the outside, from 1.7 to 2.3. The outermost contain 1.72 per cent. of iron, the inner layers less; sometimes they are so hard, that they will strike fire with steel, and can be polished like glass. Carbon, sulphur, and the oxygen of the air, are, therefore, conjointly the enemies of the sides of the retort.

Fig. 53.

The retorts suffer most from the air which enters at the door when the fire is poked, and attacks them whilst red-hot. To protect them from this, the stoking hole is sometimes situated at the back of the furnace, in a continuation of the chimney, when the noxious draught passes up the chimney without attacking the retorts.

Clay Retorts.—As a remedy for this great evil, Grafton at length succeeded in introducing *clay* retorts, which are now very generally used in England. Large sized retorts, in the shape of a ⌓, with the bottom somewhat bent in, are preferred; three of these are placed in one furnace, but each has a separate fire. Their shape and position in the furnace, will be evident from Figs. 54 and 55, and it will be perceived that the furnace does not differ materially from the ordinary gas furnace; *A* is the retort, 7 feet long, 4 to 5 feet wide, and 1 foot high, supported by the pillars *G G*; it is connected with a cast-iron mouth-piece *D*, and is composed of clay partially mixed with sand, and pounded clay-ware; the single pieces are connected at their joints *a a a* with the same clay. The loss caused by the escape of gas through the pores of the clay, is certainly less than that occasioned by the destruction of the iron retorts.

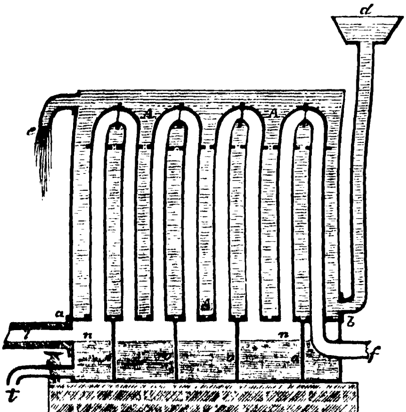
Fig. 54.



Distillation.—The process of distillation hardly requires further notice; it is begun by shoveling the coal into the glowing retorts (27° Wdg.), and spreading it about, when the lid is immediately screwed on. The process requires 5, 6, or 8 hours, according to the nature of the coal, and the shape of the retort; the lid is then quickly unscrewed, for the removal of the glowing coke in iron barrows, and the retort is re-charged as quickly as possible. Inasmuch as the coke is taken from the furnace red-hot, the heat required to raise it to that temperature is lost. To remedy this, Croll introduced the practice of burning the coke as fuel, immediately after its removal, and this plan is said to cause a saving of 10 per cent. In the large ⌓-shaped retorts, which are said to last twelve years, 1 cwt. of coal can be distilled in the hour, for which operation (as the average of many months) 22 to 23 lbs. of coke are requisite. With the old retorts, half as much coal as the quantity distilled, was allowed for heating. In the hospital at Paris, mentioned before, $\frac{1}{2}\frac{4}{5}$ of the coal distilled, appears to be the general average quantity required for heating. In general, the ordinary arrangement of the retorts, and the process of distillation carried on in them, has one evil, viz. that the favorable circumstances under which the gas is evolved at first, are constantly changing, and very much to the detriment of the last portion of gas; as it at present exists, the arrangement renders it impossible to check this evil. For this reason, an idea of Heginbotham is worthy of notice, which is, that the retorts should be furnished with a movable screw throughout their whole length, the worm of which works against the inner side of the retort. The whole thus assumes the appearance of an Archimedian screw; the internal space, therefore, instead of being cylindrical, forms a spiral channel. From the one end, the small coal is constantly taken up into this channel, and slowly propelled by the screw through the red-hot body of the retort, to be expelled at the opposite end, where it falls, as coke, through a funnel into a closed water chamber. In this arrangement, without reference to other difficulties which have not yet been obviated, the excessive evolution of hydrogen towards the end of the operation, does not occur. The contents of the retort are placed during the whole process in the same favorable circumstances as they were at the commencement.*

The Condenser.—The warm gas which issues from *l*, Fig. 53, laden with an excess of the vapor, which, if allowed to condense in distant parts of the apparatus, might stop up the tubes, is conducted from thence to the *coolers*, or *condensers*, all of which are intended to cool the gas, but are very variously constructed.—The ordinary condenser, Fig. 56, consists of a large iron chest, with a false bottom *a b*; the upper part *A*, which is filled with water, contains also a series of tubes, connected together by saddle-joints, each single one of which is mounted air and water-tight, upon *a b*. The lower part is intersected by four plates *o o o o*, forming as many distinct cells, in which the fluids collect until they attain the level *n n*, when they flow out by the tube *l*. Cold water flows into the apparatus through *d*, and the warm water runs out at *e*; the gas itself pursues its course through *f*; *t* is used for drawing off the tar. Other condensers consist of a very high perpendicular tank, with a system of gas tubes in zigzag, over which an uninterrupted shower of water rains from above.

Fig. 56.



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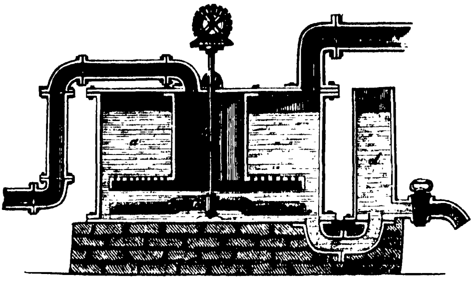
* A new mode of arranging clay and iron retorts in one furnace with a great saving of fuel, and much less detriment to the retorts, will be described in the Appendix.

On leaving the condenser, the gas still contains all the ingredients mentioned; amongst these, several are useless, namely, carbonic oxide, and free hydrogen, which burn with a very slight evolution of light, and only tend to dilute the gas; others, on the contrary, are detrimental when burnt, as ammonia, combined with carbonic, muriatic, sulphuric, and sulphurous acids, and sulphuretted hydrogen.* The purification of the gas has reference only to the latter class of impurities, and not to the former, however much it may be to the interest of the consumer and the producer to remove them all. The chemical nature of carbonic oxide and hydrogen does not admit of their being removed in so convenient a manner as the salts of ammonia, for which latter purpose slaked-lime is employed.

The Lime Purifier.—In the first instance, lime was employed (as milk of lime stirred up with water) in the apparatus shown in Fig. 57. To the lid of the outer vessel, a funnel-shaped appendage, expanding below, is fixed, dipping to a considerable depth into the milk of lime *a*. The gas entering through this, forces the milk of lime down to the extended part, and escapes through the sieve-like apertures into the lime in small bubbles. The space traversed by a bubble passing directly upwards, is much too short to effect the complete purification of the gas; its course is therefore lengthened by agitating the lime with the rouser, or agitator *b*. The axis of this is turned by wheel and pinion work on a point below, and passes through a stuffing box above; above the bottom of the vessel a framework *c* is fixed to it, which keeps the lime in a constant rotary motion. Thus the lime is kept constantly in suspension, and the gas bubbles are forced to assume a long, spiral course. The additional tube *d*, enables the workman to empty the vessel without taking it to pieces.

Fig. 57.



The action of lime applied in this manner is unsatisfactory; first, because the acids must be separated from the ammonia, before they can unite with the lime, and time is not allowed for effecting this; secondly, because all the ammonia is allowed to pass off with the gas;† and lastly, because the gas bubbles—quite contrary to the

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* Sulphuretted hydrogen blackens metals and oil colors when it is evolved with the gas and not ignited; when burnt, it forms sulphurous acid and water; ammonia burns to nitric acid and water; sulphuret of carbon, and sulphocyanogen, when burnt, also form sulphurous acid; but cyanogen naturally causes the formation of carbonic acid and nitrogen.

† According to Mallet, coal affords $\frac{1}{5000}$ of its weight of ammonia; and the gas, before entering the purifier, contains $\frac{1}{300}$ of its volume.

principle of the purification—must pass through the apparatus, under a pressure of about 28 inches (water), and consequently with a diminution of their volume, and the pressure, reacting upon the retorts, forces the gas to escape with great velocity, even from the minutest aperture. Darcet, therefore, proposed, instead of forcing the gas through the milk of lime by its own pressure, to use an Archimedean water screw, which must then be made to turn in an opposite direction. As the simplest and most effective plan, without any pressure whatever, the method introduced by Bérard has been generally adopted; no milk of lime is used, but moss which has been previously well mixed up with moist lime. Trellis work or sieves covered with the moss are placed, 3 or 4 one above the other, in vessels with two divisions under one cover, and these are made air-tight by a water valve. There are generally 4 of these purifiers; the 4th is kept in readiness whilst 3 are in action, so that the gas enters the one containing the most impure lime, and leaves by the 3d containing the freshest. As soon as the gas begins to blacken lead paper (showing the presence of sulphuretted hydrogen), the first purifier is removed, and the gas is passed into the second and out of the 4th, whilst the lime in the first is renewed. The refuse lime cannot be immediately thrown away without causing annoyance, on account of its noxious smell (sulphuretted hydrogen); it is, therefore, thrown under the ash pit *e*, Fig. 52, where the fire destroys the injurious vapors, and the residue is used as cement for the retorts. Graham found that the action of the lime could be very much increased by the addition of an equivalent of 4½ parts of Glauber's salt (sulphate of soda), for sulphate of soda exposed to the action of the gas is decomposed into hydrate of soda (caustic soda), with a simultaneous formation of gypsum. All the sulphuretted hydrogen is thus speedily taken from the ammonia to form the hydro-sulphuret of sulphuret of sodium. All the defects are thus removed, with the exception of the chemical insufficiency of the purifying material (the lime). The safest plan would evidently be to bind the volatile ammoniacal salts by double decomposition with an earthy or metallic salt, so that non-volatile salts should be produced. This, in fact, is the idea upon which the most recent improvements are based. Pénot was the first to employ, with perfect success, the sulphate of lead waste from the cotton print works, which he suspended in water in the manner of milk of lime. Sulphate of ammonia is produced on the one hand, and sulphuret of lead on the other; the abstraction of the sulphuretted hydrogen is thus complete, but a lime purifier is still required on account of the carbonic acid, and the sulphate of lead cannot be obtained in sufficient quantity, nor is it sufficiently cheap for use in the gas works. Hence, it appears, that the more recent method of purification proposed by Mallet, deserves the preference, inasmuch as a nearly valueless salt, proto-sulphate of manganese, which is produced in abundance in the bleaching powder works, is employed. Instead of this salt, green vitriol (sulphate of iron) may also be used. In every case, however, as well for the preservation of the vessels as for obtaining the proper action, it is necessary to neutralize the excess of acid contained in it, by the ammoniacal water of the tar cistern. In the washing vessels, 3 or 4 of which are sufficient, the gas comes in contact with the neutral manganese, or iron solution in the form of a kind of waterfall, the total pressure not exceeding 4 to 6 inches. Sulphate and muriate of ammonia, which dissolve, and carbonate of manganese, with sulphurets and cyanides of the metals, are the compounds which result: the lime is, therefore, quite superfluous; but sulphuretted hydrogen, if in combination, for instance, as a higher sulphuret of ammonium, will nevertheless escape, and hence a lime purifier beyond Mallet's apparatus, may be of service. The interesting observation has lastly been made with reference to naphthaline, (a peculiar volatile product of the decomposition of coal,) that the presence of its vapor in illuminating gas is due to the ammonia; it is at least separated in large quantity, with other similar substances above the solution of manganese. Notwithstanding the increase of illuminating power which the vapor of naphthaline communicates to the gas (49 carbon to 6 hydrogen), yet its separation is desirable, as it occasionally deposits in a crystaline form in the tubes. The salts of ammonia are valuable as secondary products of the gas works; it is, therefore, advisable to wash the gas with pure water before it enters the manganese purifier; the water becomes gradually pretty well saturated with ammonia, and at the same time a great saving is effected in the quantity of manganese.*

Oil Gas.—It appears, at first sight, both inexpedient and superfluous to distil oil for the production of gas, when we consider that oil can be burnt in lamps without any further preparation, whilst it loses carbon by deposition in the retorts. Purified lamp-oil is consequently never used; but gas can be prepared from impure oils, train-oil, or refuse fat, with as much ease as from the purer kinds. The manufacture of gas is, therefore, under certain circumstances, an admirable means of using up such materials for the production of light, as could not otherwise be employed, or only applied to the lowest uses. The experiments of Henry, which extend also to this part of the subject, show at once the plan that must be adopted upon a large scale. His results were as follows:

Substances distilled.	Temperature of the Distillation.	Specific gravity of the gas.	In 100 parts of illuminating gas were				
			Absorbed by chlorine	Light carburetted hydrogen	Carbonic oxide	Hydrogen	Nitrogen
Oil . .	Bright red heat	0.464	6	28.2	14 1	45.1	6.6
	Ditto	0.590	19	32.4	12.2	32.4	4
	Lowest possible temperature	0.758	22.5	50.3	15.5	7.7	4
Train-oil	Low red heat	0.906	38	46.5	9.5	3	3

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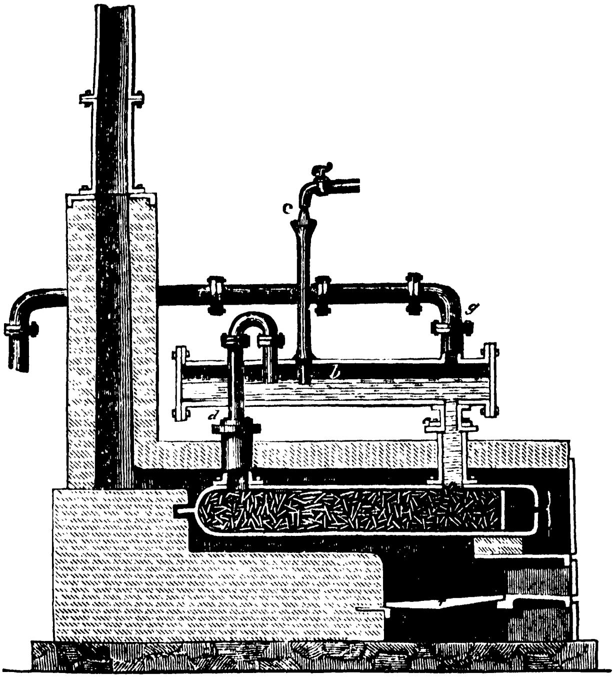
* An improved method of purification will be described in the Appendix.

It appears, then, that oil gas is superior to that obtained from coal, as is also shown by its density, and that the produce, dependent chiefly upon the temperature, is of the best quality when obtained at a low red heat. This temperature suffices to convert the oil into gas, but is not sufficiently high to decarbonize the gas to any great extent. The apparatus for obtaining gas by the distillation of oil is represented in the drawing below, Fig. 58. To accelerate the evolution of gas, and shorten the time which the gas already produced has to remain in the red-hot vessel, the retort *a* is filled with bricks, or lumps of coke, which extend the red-hot surface very materially. The second cylinder *b*, serves both as reservoir and hydraulic main at the same time, and with this object in view *a* and *b* are connected in two places *d* and *e*. Oil flows from a large cistern above the apparatus in a constant stream through the tube *c* to *b*, which (*b*) is thus kept filled up to a certain level. From *b* the oil descends through *e* to *a*, is converted into gas and tar, returning through *d* to *b*. The tube *d* makes a short bend, and just enters below the fluid level in *b*, so that the vapors of the decomposed oil must constantly pass through the reservoir of oil, and deposit their tar. The retort *a* is, therefore, constantly supplied, not only with oil, but with a mixture of oil and tar, in such a manner, that all the condensed products return to the retort together with a fresh quantity of oil, until they are completely converted into gas. If the experiment is made in a long tube, inclined

Fig. 58.



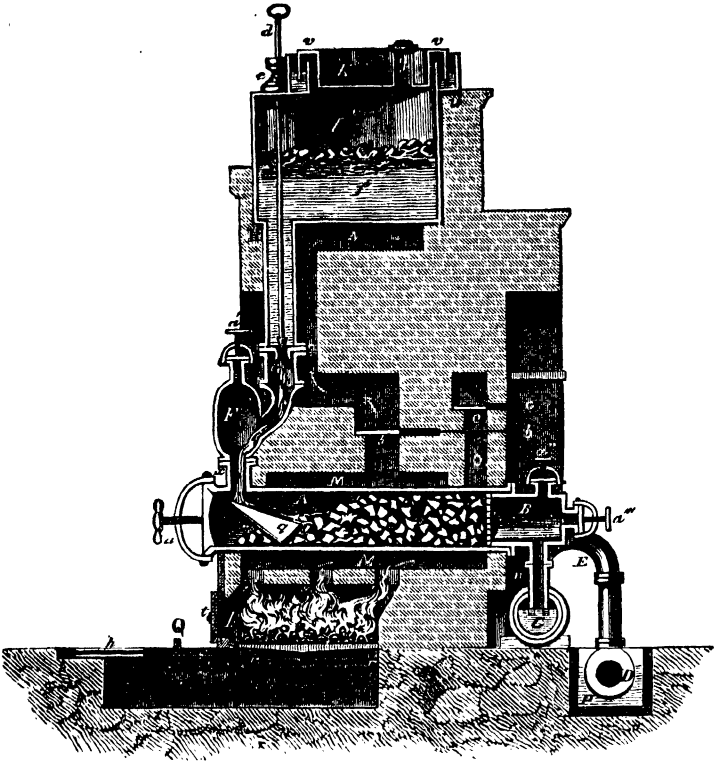
at the hinder part, whilst the front is kept cool, hardly any tar will be produced. The gas which collects above the oil in *b*, passes on through the tube *g*. As the objections raised in the case of coal-gas do not here occur, cast iron retorts are solely used in oil-gas works, with the same firing in other respects, *r* being the grate. According to trustworthy statements, 1 cubic foot (= about 4 gallons) of oil produce from 600 to 700 cubic feet of gas, which is equivalent to from 90 to 96 per cent. by weight; the remainder is carbon, which is deposited between the coke or bricks, and some unavoidable loss. The production of oil-gas is a continuous process, and thus differs from the distillation of coal. The retorts only require opening now and then, for the removal of the deposit of graphite. Vapors of the same composition and properties are found in oil-gas, as in coal-gas. Thus, according to Hesz, all the volatile empyreumatic oils, which occur mixed with each other in tar from oil, have the same composition per cent. as olefiant gas. Faraday had previously observed in England, where oil-gas was compressed for technical purposes with a pressure of 30 atmospheres, that these vapors were condensed to a fluid, of which 1 part occupied the space of 7500 parts of gas. Amongst the other oily bodies present which contain from 80 to 90 per cent. of carbon, he was enabled to study some in an isolated state, as triyle ($C_3 H_3$), dytriyle ($C_2 H_4$), and a third hydro-carbon ($C_2 H_3$).

Rosin Gas.—If rosin (colophony) were usually fluid, instead of being solid, there would be no difference in the mode of obtaining gas from it to that practised in the oil-gas manufacture; as this, however, is not the case, it becomes necessary to render the rosin fluid by some suitable means, that it may be easily supplied to the retort. The volatile oil from tar is frequently used for this purpose.

The flame from the retort fire, before escaping by the chimney, is caused to heat up a vessel containing rosin. As this melts, it trickles through a sieve, into the second division of the vessel, leaving the impurities and the solid portion behind, where it is mixed with an equal part of the oil of rosin (tar). Thus a solution which will no longer solidify is obtained, and with it the retort is supplied, as with oil, in the former case. When the gas has parted with its condensible vapors in the coolers, it is in a fit state for consumption, no further purification being required, as is likewise the case with oil-gas.

One of the best arrangements for rosin-gas, and which has stood the test of practice, is that which has been extensively carried out by Chaussenot, and is shown in Fig. 59; the rosin is here melted by itself, and the oil of tar collected and disposed of as a secondary product. The draught to the fire-place *P* is regulated through the ash-pit by means of the plate *Q*, which can be moved horizontally backwards and forwards in the groove *h*. The air passing from below through the grate *r r*, and the fuel, creates a powerful flame, which passing, in the first instance, through the apertures *g g g* in the roof, plays round the retort *A*, in the space *M*, and then, before reaching the chimney, heats the vessel *I* containing the rosin, by means of the flue *N N*. If this vessel requires filling, the fire is shut off from *N*,

Fig. 59.*



by the damper *b*, and is allowed free egress at the aperture *O*, by drawing back the damper *c*. Both the dampers are worked by iron rings and rods from without. In Chaussenot's apparatus, it is not necessary to dissolve the rosin in tar-oil, because the vessel *I*, in which the rosin is melted, and the conducting tube *H*, being constantly surrounded with hot air, no solidification of the melting rosin at the bottom *f*, need be apprehended. Combustible gases are generated by merely melting the rosin, which may possibly endanger the whole apparatus. To avoid such contingencies, the edge of *I* is furnished with a groove, filled with water *u u*, into which the lid *K* dips at *v v*, and is consequently secured by a water-valve. By means of the appendage *y*, the vapors can be conducted into the chimney, or under the grate. The melted rosin flows consecutively through *H*, *G*, and *x*, into the retort *A*. Between *G* and *H* is a plate *o*, with a funnel-shaped aperture in the middle, in which the conical end of the rod *d* is movable. If this is raised through the stuffing-box *e*, the retort *A* receives a larger flow of melted rosin; if it is pushed down, the stream diminishes, or the flow ceases entirely. The rosin flowing

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[*] In the above apparatus the melted rosin, tar, &c., are seen to enter the retort through a channel near the front part of the retort. Some rosin-gas apparatuses constructed in this country, Coston's for example, have furnished the liquid an entrance through a tube running into the retort directly through the hot air-chamber as at *A*.—Am. Ed.

from *x*, is carried to that part of the retort containing the coke, by means of the inclined plate *g*. The coke is prevented falling into the neck of the retort by the grating *l*; here, too, the gas escapes through a tube downwards to the tar cistern *C*, and from thence through *E* to the cooling-pipe *D*, which is immersed in water in a long trough *P*. *C* is constantly nearly filled with tar, that the mouth of *w* may always remain immersed; this, therefore, dips into *C*, whilst the gas-pipe *E*, behind the sectional level in the drawing, only just passes through the material of the main *C*. The neck *F*, situated above *x*, has a small appendage a'; this, as well as a'', and a''', is constantly immersed, and all three are used only for introducing iron rods in cleansing the approaches to the retort; *a* is a similarly constructed appendage for screwing up the lid of the retort; *a*, a', a'', and a''', are all furnished with iron semi-circles and screws, for forcing iron plates flat against the apertures. In such a furnace, therefore, distillation goes on continuously, until the deposition of carbon renders a renewal of the coke necessary. Rosin-gas is not so highly illuminating as oil-gas, and is of about the same quality as coal-gas;* it is used in many towns, as in Frankfort-on-the-Maine, Antwerp, &c. 14 to 23 cubic feet of gas are obtained from 1 lb. of rosin.

Gas from Soap-water.—Few cases are adapted to give so favorable an idea of the practical value of gas illumination, as the process carried out at the works of Houseau Muiron, at Rheims, where very good gas is obtained from refuse which previously cost something to throw away, and which now is a source of profit to the manufacturer. This refuse is the soap-water, in which woollen stuffs have been freed from fat. Besides the unchanged fat, with which those goods are charged as they come from the loom, the soap-water contains a solution of oleate and stearate of soda, and compounds of the same acids with lime in suspended flakes, and lastly, animal matters extracted from the wool. From all parts of the town the soap-water is collected, and brought to the reservoirs of the works, where 300 cwts. at a time are treated with 2 per cent. of sulphuric acid, (or twice as much hydrochloric,) mixed with equal parts of water. After the lapse of 12 to 18 hours, complete coagulation is effected. The water contains Glauber's salt (sulphate of soda) in solution; a little gypsum is formed at the same time, and an impure gray, fatty matter rises to the surface. This consists of the fatty acids, oil, and animal matter with much water; the greater part of the latter has already been mechanically separated, and the remainder is removed by melting in copper vessels, the contents are then drawn off into a second boiler containing some sulphuric acid to effect a clarification. The filtration which follows affords a clear oil, and this gives with crude soda (containing sulphuret of sodium), a very tolerable soap, whilst sulphuret of iron separates, together with a black solid residue, containing much fat

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* Rosin gas is generally much heavier and more highly illuminating than *ordinary* coal gas, and for this reason a certain quantity of rosin is sometimes used with the coal, especially at the Philadelphia gas works. It is not conveyed to the retorts in a melted state, but thrown in solid, along with the coal.—Am. Ed.

for distillation in the gas retorts. The process of distillation is like that practised with rosin: the tar produced the first day, is used on the morrow to dissolve and render fluid the solid residue, and so on.

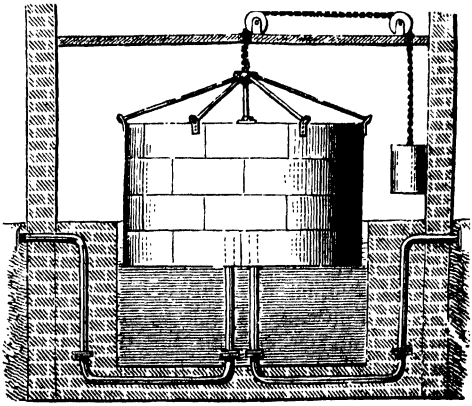
Gas from Animal Matter.—In the distillation of animal matters, bones, flesh, &c., as it has long been practised for the production of bone-charcoal and bone-black, tar (fetid oil, Dippel's animal oil) and gases are generated. The illuminating power of the latter has latterly attracted the attention of manufacturers. Seguin, in particular, has carried on the process on a large scale, making use of the gases. The material, for instance, the flesh of dead animals, contains 60 per cent. of water, which must be removed by drying, before being placed in the retorts, and the latter should be kept at a cherry red heat. The sulphur (a constituent of albumen, fibrine, &c.) is chiefly found in the gas as sulphuret of carbon, the nitrogen of the flesh, as carbonate of ammonia. After being properly cooled, the gas is first passed through a solution of chloride of calcium, where carbonate of lime and sal-ammoniac are formed, and from thence through tubes containing lumps of sulphur, which condense the sulphuret of carbon to the fluid state, and dissolve in it. The latter would be converted in the flame into sulphurous acid and carbonic oxide.

Illuminating Gas of Selligue.—After remaining stationary for a long time, some new improvements have latterly been introduced in the manufacture of gas, which, instead of applying the destructive process to a single material, regulate the decomposition of several substances in such a manner, that the elements of illuminating gas are obtained from as many different sources. The most important of these, is the process discovered by Selligue, in Paris, by which resinous matters are decomposed in the presence of carbonic oxide, and free hydrogen. It is difficult to specify what kind of chemical process may have furnished the leading idea for this invention; but whatever that may have been, according to the statements made to the Academy by Thénard, Darcet, Dumas, and by Payen in another place, as well as from the experience gained at the Royal Printworks, the invention must be of interest as a step in advance.

The bituminous slate-marl of Autun, as it is used by Selligue, affords, when distilled, about 10 to 20 per cent. of oily products, $\frac{2}{3}$ of which consist of a light oil, of specific gravity 0.766 to 0.810, for the production of gas. Three red-hot cylinders are used in the process, which are walled in an upright position in a furnace. The first two are filled with wood charcoal, which is replaced from time to time as it is consumed; the last is filled with chain and pieces of iron. A thin stream of water flows into the first cylinder, and is converted there, in contact with the red-hot coals, into carbonic oxide and hydrogen, a process which is completed in the second retort, from whence both gases enter the third retort, in which a stream of the slate-oil is being decomposed by the red-hot iron. The decomposed vapors of the water (carbonic oxide and hydrogen) form here, with the vapors of the slate-oil, the new illuminating gas. By the simultaneous decomposition of 157 lbs. of oil, and 160 lbs. of water in this manner, 13,461 cubic feet of gas (of 0.65 specific gravity) are said to have been obtained; and, moreover, of such a quality that its illuminating power was twice as great as that of ordinary gas: 86 cubic feet of this better kind of gas are, therefore, obtained from 1 lb. of oil, whilst the same quantity of slate-oil, treated in the usual manner, would only produce from 15 to 28 cubic feet. The existing statements are quite inadequate to explain the contradiction between the evidence of the authorities, above quoted, and the apparent improbability of such an extraordinary result. Those statements mention the remarkable fact, that in the third retort there is no deposition of carbon whatever upon the iron chain, and that, consequently, the gas prepared by Selligue's method, must contain all the carbon that is deposited as graphite in the retorts by the ordinary process; they remark further, that Selligue's gas deposits no condensible vapors at—25° C. (—77° F.,) nor is it deteriorated in quality by that temperature, whence it appears that the value of the gas depends upon its chemical, and not upon its physical, constitution; but they give no facts which are calculated to explain the chemical process concerned in its production.

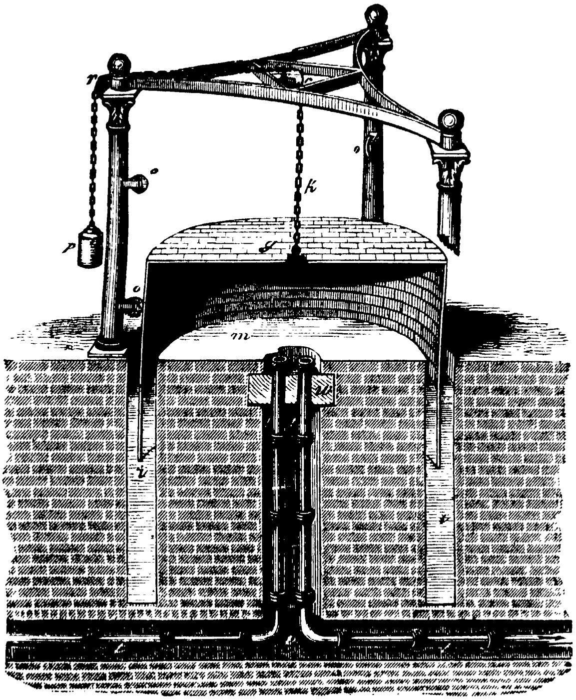
Collection and Distribution of the Gas.—The production of gas, and its consumption, do not go hand-in-hand, for the gas is not consumed at the same time, nor in the same quantity, as it is evolved from the retorts; the primary pressure in the latter would also be too strong and too variable for the production of steamy gas flames. To avoid these evils, and yet fulfil all the requisitions, large cylindrical inverted vessels are employed, open at bottom, and dipping into water; they are repositories for the gas, and are also intended at the same time—and this is of great importance—to force the gas onward with just the requisite amount of pressure for burning properly at its destination. These repositories are very improperly called *gasometers*. In Fig. 60, the different parts are easily distinguished. The flat cylindrical vessel hangs, by means of a chain from its top, which passes over two pulleys on the beam above, and at the other end is attached to a counterpoise. The lower open end dips into a reservoir of water, into which also the pipes open for the entrance and egress of the gas. With large gasometers, there are practical difficulties attending this mode of suspension, inasmuch as the longer beam cannot sustain the weight without bending; the large quantity of water also, which is frequently as much as 2,419,519 gall.,

Fig. 60.



is a source of much inconvenience, particularly in cold weather, when steam must often be conveyed into it to prevent its freezing. In this case the arrangement shown in Fig. 61 is preferable. The gasometer *g* is a large drum of sheet-iron riveted together in the manner of a steam-boiler. Several coatings of tar, put on hot on both sides, is sufficient, notwithstanding the number of rivets, to make it quite gas-tight. Instead of being sunk in an entire basin, the gasometer *g* works in a ring-shaped space *i i*, surrounded by brickwork; in the round pillar *m*, there is a channel for the pipes

Fig. 61.



t and *t′*, which can be made to enter through *i*, but not so conveniently. This channel *v* must of course be closed somewhere—at *w* in the drawing—to prevent the escape of the gas. The sides of *i* are covered with cement, which renders them quite water-tight. The drum is suspended from its centre by the chain *K*, the rollers *r r* being fixed upon the triangular (cast-iron) frame, *p* is the counterpoise. To prevent all lateral motion, the iron drum *g* is moved up and down against the guiding rollers *o o o*. A layer of tar is poured upon the surface of the water in *i*, that it may not require frequent renewal, which would otherwise be the case, on account of the constant evaporation which takes place into each new volume of gas. It is frequently cheaper, although much less commodious, and more space is required, to construct the water cistern of cast-iron plates, instead of brickwork, the whole then stands above the ground. The ease with which this arrangement can be repaired, and the lasting value of the materials, are advantages which counterbalance its less durable character. Very large gasometers are best suspended in the following manner, in which no framework is required, and the counterpoise, instead of being on the outside, is brought into the middle of the apparatus. In the centre of the drum a wide tube, open at both ends, is attached to the top, so that the whole forms a kind of (very thick) ring; a second, somewhat smaller tube, passes up from the bottom of the water cistern, and with it three strong iron rods with pulleys. This last fixed tube, with the three rods, remains stationary in the tube attached to the drum, whilst the gasometer moves up and down. The three chains pass over the pulleys, and support the counterpoise, which moves in the interior of both tubes. In large gas-works a number of middle-sized gasometers are preferred to one very large one, although they are more expensive. Tait's proposition is intended to meet this difficulty; in one and the same water cistern, 3, 4, or more cylinders are placed one within the other, like the separate limbs of a telescope, the outermost of which only is closed at the top. The upper edge of each limb is broad and flanged on the outside; each lower edge has likewise a flange, but turned inwards. When the gas enters, the outer drum first rises, and having arrived at its greatest height, raises the second, by means of its flange catching the flange of the second, whilst both are immersed in water, the flange itself thus becomes filled with water, which prevents the escape of the gas. In every case, the management of this apparatus is attended with difficulty.

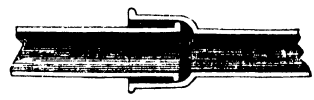
With reference to the shape of the gasometers, those deserve the preference which hold the most gas with the least expenditure of material (sheet iron). A cylinder, the radius and height of which are equal, is, therefore, best suited to this purpose, (other shapes are not applicable;) a foot, however, is added to the height, that the margin may always be under water. The capacity, and consequently the diameter, or the height of the gasometer, must depend upon the demand for gas; if the cylinder, at its extreme height, is to contain q cubic feet of gas, then it follows from $3.14\ r^2\ h = q$ first $3.14\ r^3 = q$, (because $r = h$,) and hence $r = \sqrt[3]{\frac{q}{3.14}}$.—The operation of the whole machine is easily understood. On filling the gasometer, the tube t is closed, and the gas flowing from t' soon begins to raise it, its weight being borne by p. Besides, the weight of the cylinder, and that of the gas together, are much less than the weight of an equal volume of water. A gasometer 40 feet in diameter, (and consequently 21 feet high,) when at its greatest height weighs, gas and iron together, about 123 cwt., whilst an equal volume of water would weigh 7,800 cwt. As soon as the drum is filled up to the height of its radius, t' is closed, and the connection between the gasometer and the furnace is thus cut off. The next object is to cause the cylinder to sink in such a manner that the gas shall flow out with that degree of force which experience has shown to be desirable, and which corresponds with the pressure of a column of water from 1 to 2 inches high; the water on the outside must, therefore, stand from 1 to 2 inches higher than on the inside. This state of things is brought about by connecting a bent tube containing water (a manometer), with the exit pipe, and by altering the counterpoise until the water in the manometer has risen from 1 to 2 inches. From obvious reasons, however, this pressure would not long remain the same. For by dipping lower into the water of the cistern, the drum loses more and more of its weight, and, moreover, just as much, as the weight of the water displaced by the edge; the same, therefore, happens as would result from a gradual increase in the weight of the counterpoise; the pressure is diminished. With a drum of the above dimensions, the cubic space occupied by 10 feet of the margin would be nearly 30 cubic feet, which, therefore, displace 30 cubic feet = 927 lbs. of water, and the pressure is diminished ⅙th inch. This dimunition may be counteracted by the chain, if it has been constructed of the proper weight. In every position of the chain, one portion on the side of the counterpoise will balance another portion on the other side of the pulleys. The lower the drum sinks, the more of the chain passes to its side of the pulley; each link, however, is a weight, taken from the counterpoise and added to that of the cylinder, so that this is increased in weight by twice the weight of chain which has passed the pulley. The weight of the chain must, therefore, be such, that the portion passing the pulley weighs just half as much as the water which is displaced at the same time. In addition to this, it is obvious that the specific gravity of the gas must have an effect upon the working of the gasometer. Oil gas has nearly the same density as the air, and the weight of the enclosed gas is, therefore, not sensibly different from that of an equal volume of air; it will, consequently, be in equilibrium with the external air. This is not the case with coal and rosin-gas, which is 1⅔ times lighter. The portion already above the water will stand in the same relation to the surrounding air, as the portion still immersed stands to the surrounding water; it will endeavor to rise, although with less force. In other words, the part above the water is in the condition of an air balloon, the enclosed gas being lighter than the same number of cubic feet of air which it displaces. If this difference in the gravities were greater than the weight of the iron composing the vessel, then the gasometer would rise; under existing circumstances, its tendency to rise merely diminishes its weight. A cylinder 40 feet in diameter, and 20 feet at its highest stand, contains 25,231 cubic feet of coal gas; the same number of cubic feet of air will weigh 1911 lbs., whilst the gas will only weigh 1242 lbs.; in this position, therefore, the external pressure of the air will diminish the weight of the gasometer 669 lbs., and this must be taken into calculation in regulating the chain. The tendency to rise in the gasometer, increases as it fills, or rises, but at the same time its loss of weight by submersion in water diminishes. Farther, the tendency of the cylinder to rise increases with its capacity and dimensions, the loss of weight on the contrary with its amount of surface, therefore, in diminished proportion, so that, with a certain diameter, these two compensate each other, or the pressure may even diminish as the cylinder sinks.

Gas-Pipes.—The distribution of the gas from the gasometer is effected, as far as the principal mains are concerned, by means of cast iron pipes, which have already been spoken of above; the smaller mains for the supply of houses are composed of drawn leaden tubes. Experience has shown copper tubes to be dangerous, on account of the production of a peculiar pulverulent deposit, formed from the metal and the ingredients of the gas, which takes fire spontaneously in the air.

The gas passing through the tubes is subjected to friction against their sides, which increases rapidly as their diameter diminishes. As it is very inconvenient to overcome by a greater pressure in the gasometer, the diminution of velocity in the current of gas caused by this friction, it becomes necessary to widen the pipes to such an extent, that the velocity of flow in the gas at different distances from the gasometer may not vary too much, and it is, consequently, of importance to be able to calculate the effects of friction. Assuming a constant pressure to exist in the gasometer, the resistance caused by friction will stand in some relation to the root of the length of the pipe (l). The quantity of gas q, which flows out depends, therefore, first upon that relation (upon $\sqrt{l}$), and also upon the width, *i. e.*, upon the square of the diameter (d^2), increasing with the latter, and diminishing with the former. We, therefore, have $q = \frac{d^2}{\sqrt{l}}$. A tube 316 feet in length, allows 400 cubic feet of gas to pass in an hour, when its diameter is one inch (= 0.1 feet). We obtain, therefore, $q : \frac{d^2}{\sqrt{l}} = 400 : \frac{0.1^2}{\sqrt{316}}$, whence $d = \sqrt{\frac{q\sqrt{l}}{711000}}$ (Prechtl).* From that point where the first portion of gas passes into the side main, d may be diminished in proportion.

The iron pipes are about 9 or 10 feet long, and are cast with a turned up margin or shoulder at the one end, and a mouth-piece at the other. Fig. 62 shows the manner in which the shoulder of the one pipe is placed into the mouth-piece of the other when they are laid down. The space between the two is filled up with greased tow, and then leaded all round, which renders it perfectly air-tight. It is still more easy to form a tight joint with the smaller pipes, the leaden tube being flexible and easily soldered. The proper distribution, as well as the management of the gasometer, render it necessary

Fig. 62.



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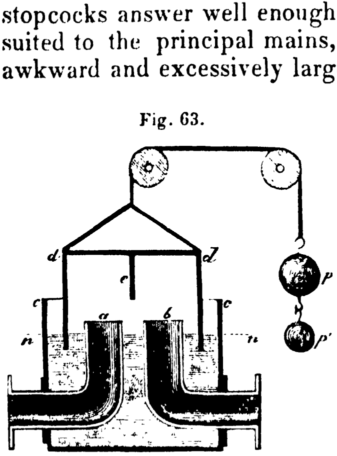
* See for a complete investigation of this subject, Weisbach's Mechanics of Engineering, Am. edition, p. 428 to 438 inclusive.—AM. ED.

that there should be stops in different parts of the conducting pipes; stopcocks answer well enough for the smaller tubes, but they are not suited to the principal mains, where they would necessarily be very awkward and excessively large. The more convenient water-valve, Fig. 63, has been used instead of them, and by its means a perfect stoppage is effected without any turning. The two separate pipe-ends *a* and *b* enter the vessel *c c*, which is filled with water, above which a tin drum *d d* is suspended, dipping below the level of the water *n*, and attached to a counterpoise *p*. In the position shown in the drawing, the tubes are in connection; this, however, can immediately be stopped by means of the partition *e*, when the drum *d* is so far lowered by the removal of the weight *p'*, that *e* comes into contact with the water. Leakage in the pipes, which often occurs at bends and corners, is attended not only with loss but with danger, for illuminating gas explodes when mixed with air in certain proportions. The fact, that such explosions are uncommon, and have never occurred in rooms, is singular, but easy of explanation. For the gas, on entering a room becomes mixed with much more air than that proportion with which alone it is explosive, and danger is consequently avoided; in crevices in the walls and ceilings, however, where such cases alone have occurred, the probability of the explosive mixture being generated is much greater.

Fig. 63.



Gas-Meter.—As a check upon the gas-works themselves, and as a means of calculating between the works and the larger consumers, when the gas cannot be paid for by the number of burners or hours of consumption, a safe and easy method of ascertaining the quantity of gas consumed becomes necessary; this is effected by the *gas-clock* or *gas-meter.* Fig. 64 is a simple section of this instrument, and Fig. 65 a section in perspective at right angles; Fig. 66 is a similar section parallel to the axis in the direction of the line α β in Fig. 64. The principle is the following. When a number of vessels of a certain capacity, for example, 1 cubic foot, are so arranged, that (without loss of gas in the interval) one after the other shall be filled by the gas in passing, and for this purpose are inverted in water into which the gas enters, just as was the case on a large scale with the gasometer, it follows, that just as many cubic feet of gas will have passed, as there are vessels that have been filled. If all these vessels, (for instance, 4,) are attached to a common axis, upon which they revolve as they fill and rise, every revolution of the axis will corresponds with 4 cubic feet of gas that have passed through. In the gas-meter itself, instead of separate vessels each containing 1 cubic foot, compartments of a drum of equal and known capacities are employed. In a case *b b*, more than half filled with water, this drum *d d* revolves,

Fig. 64.

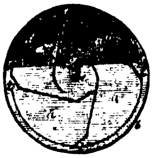
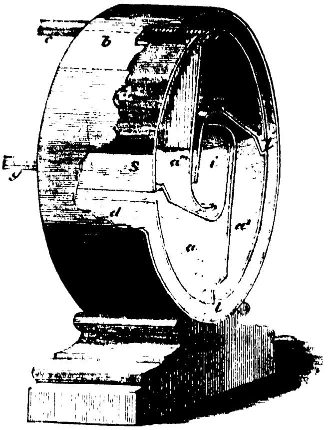
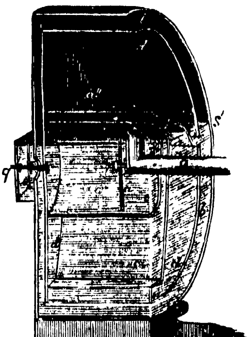


Fig. 65.



and is divided by 4 crooked partitions into as many chambers a, a', a'', and a'''. The contents of each chamber are enclosed at the front and back by the straight sides of the drum d, above by the crooked partition, and below by the water s s. Towards the middle, the partitions are bent round to form the space i, and slits are thus left for the passage of the gas from one chamber to the next, similar slits t t are made at the periphery of the drum for the exit of the gas. The tube g for the admission of the gas passes through the back of b, enters d by an aperture (under water), and extends a few inches into i, it is there turned upwards, with its mouth above the level of the water, (into the chamber directly over it, in this case a'). At the bend in g, one of the pivots r of the drum d is fixed, which works in the rod u. The latter u, is fixed in two points at i, (therefore on d itself.) The peg q on the back side of d, is the other pivot; it passes through an aperture in b, and sustains the toothed wheel o. The chamber a, or a', &c., in being filled with the gas, becomes lighter and rises, causing d to revolve, until it rises above the level of the water s s, it then parts with its contents through the slit t, to the space between b and d, from whence the gas is carried forward through the tube c. It is obvious, that at the same moment (in which the gas is evolved) the next chamber becomes closed above g to receive the next portion of gas, and so on. The toothed wheel o turns a hand, by means of works, upon a clock-plate in the front of d, so that each division indicated on the plate, represents either 1, 10, or 100 revolutions, and thus the quantity of gas which has passed is ascertained in cubic feet. In determining the amount

Fig. 66.

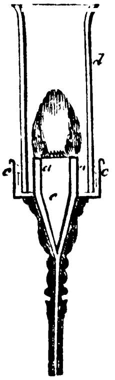


of gas by means of the meter, the temperature ought to be taken into consideration, for 1000 cubic feet at 0° C. (32° F.), will become 1075 cubic feet at 20° (68° F.)*

The Burners.—From the leaden pipes—in the circuit of which the meter is placed, if used at all—the gas enters brass tubes which project from the wall, and passes to the *burners*, each of which must be furnished with a separate brass stop-cock. Good, tight stop-cocks are much more difficult to make for so light a gas, than for liquids. Instead of fixing the carefully ground conical plug into its place by a screw, which occasions either too much friction, or an imperfect joint, it is better to use a watch-spring, which in spite of the wear, keeps the plug always tight. Gas-burners are very similar to lamp-burners; by the former we are to understand the different mouthpieces attached to the ends of the tubes for burning gas. As neither the wick, nor the level of the oil, has here to be considered, the management of these burners is comparatively simple; but as the amount of fat in candles and lamps required regulation, so here the amount of gas consumed in a given time, must bear a proper relation to the current of air from without, *i. e.*, the flame must neither smoke, nor must it be too short and blue. Such regulation is partly effected by the cock attached to the burner, and all excess of gas is avoided from the beginning, by allowing the gas to issue only from very small apertures. In passing through such apertures, the original velocity of the current of gas is much increased, and the flame thus acquires the proper size and height. The same quantity of gas issuing from a wide opening, would produce a wide, short, and dull flame, because the surface in contact with the air would thus be increased. A gas flame issuing from such wide openings, is essentially faulty, for the same reasons as the flame produced by thick massive lamp-wicks.

When the brass burner has a single aperture of the diameter of a bristle, ($\frac{1}{28}$ of an inch is the width calculated for coal gas, $\frac{1}{15}$ of an inch for oil-gas), a *simple jet* is produced in the form of a long, thin, conical flame. The *bat's-wing*, or flattened flame, which the gas forms when it issues from a narrow slit, instead of a round aperture, is much more appropriate, and combines all the advantages of the flat wicks before mentioned. A similar and equally good flame is produced by a burner with two apertures close to each other, the channels of which are inclined inwards, so that both the currents of gas cross each other at their base. They then form a flat flame, spreading out in the form of an inverted triangle, the *fish-tail burner.*

Fig. 67.



Simple flames of this kind are generally burnt without any appendages. When a greater quantity of light is required, and more particularly when great intensity of flame is desirable, the Argand burner is generally chosen, Fig. 67. The gas from the pipe enters the annular space

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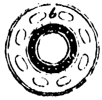
* The most recent improvements in the construction of gas-meters, particularly of dry gas-meters, will be noticed in the Appendix.

a a, which is closed above by the flat plate *b*, Fig. 68. In this plate are a number of fine apertures, arranged in a circle, and so near to each other, that the separate flames unite to form one hollow cone. The appendage *c* supports the chimney *d*; to produce an internal current of air, *e* is open at the sides. Experience has shown, that the best results are obtained from such burners when the apertures are $\frac{1}{32}$ of an inch wide for coal-gas, and $\frac{1}{60}$ of an inch for oil-gas; for the former they should be $\frac{1}{8}$ of an inch, for the latter $\frac{1}{6}$ of an inch apart. These dimensions are, therefore, larger for coal-gas than for oil-gas, the latter possessing double the illuminating power of the former. The holes should be uniformly bored, and as accurately as possible; if this is not done, there will be parts of the flame which will smoke. Sometimes the heat of the flame is applied to warm the current of gas before it issues from the burner, by which means the flame is less cooled, and whiter light is produced. For this purpose the gas-pipe is formed into several revolutions at a certain height above the flame.

Fig. 68.



An important improvement upon Argand's burner for illuminating public places, bridges, &c., where one large lamp and a very intense light is preferred to a number of smaller ones, is the *bude burner*, proposed by Gurney, upon the principle of Fresnel's lamp. Two, three, or more hollow ring tubes, each furnished at the top with a circle of holes, form the principal part of the burner, and are connected at bottom with parts of the gas pipe bent horizontally, from which they receive the gas. Each inner ring is placed somewhat higher than the one before it, so that a number of concentric flames are produced, the light of which is thrown by reflectors in the proper direction. The bude burner must not be confounded with the *bude light* of the same inventor, which is produced by conveying oxygen into the inner space of an Argand oil lamp. A similar effect to that of the bude burner is produced by a number of single flat flames arranged in a ring. The Victoria Bridge, at Manchester, for instance, is lighted by such a burner, consisting of two concentric rings, each containing 12, therefore, altogether 24 flat flames; the inner ring, 4 inches in diameter, stands 1 inch higher than the outer, which is 6½ inches in diameter, the whole thus being rounded off in the shape of a rose.*

Regulators.—Whoever has had occasion to use gaslight, knows from experience, that the size and brilliancy of the flame, after having been once brought to the right pitch, do not remain the same, but require from time to time, to be brought back to the normal state by altering the cock; this is chiefly the case in the late hours of the evening. The changes in the flame are true indications of an alteration in the pressure, which is exerted as far back as the gasometer; yet the latter cannot be the cause of these irregularities, as we are enabled to compensate all the irregularities in its working. On the

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* Whinfield's improved patent gas burner will be described in the Appendix.

contrary, the chief cause, independent of some secondary causes, is due to the different times at which the burners in connection with the same pipe are closed. Suppose a pipe to supply 1000 burners of equal size, and one of these to have been regulated in the beginning to its highest pitch—without smoking; then, at 10 o'clock in the evening, when two hundred householders have put out their gas, ¼ more gas will issue from the burner in the same time, and the cock will have to be closed in proportion. Inventions for preventing this irregularity, so called *regulators*, have been recently proposed in great number, although not one of them has been generally adopted. To render the action of the burner perfectly independent of any alteration in the pressure, it has been the endeavor to make these changes of pressure themselves work a mechanical arrangement, enlarging or lessening the aperture of supply in such a manner, that an equal quantity of gas shall always pass out.

Portable Gas.—The distribution of gas by pipes is exceedingly expensive, both as regards laying them down and the cost of repairs, and is also attended with the inconvenience that the light cannot, as with candles and lamps, be carried to any particular spot. Even the joints in the arms of the burners, as they are sometimes used, only admit of a short circular motion, and no real change of place. These deficiencies have given rise to two inventions which must not be overlooked.

Compressed Gas.—The first, and older of the two, is the use of compressed gas; the plan was to force the gas into small vessels, contained in the foot of lamp-like burners, which should contain sufficient gas for several hours' consumption. Oil-gas, on account of its greater illuminating power, is decidedly preferable for this purpose, for ½ a volume will produce as much light as 1 volume of coal-gas. It has been ascertained, that a common burner consumes 1 cubic foot of oil-gas in the hour; for an evening of six hours, therefore, to be on the safe side, we should require 8 cubic feet, which must be compressed into the space of ¼ cubic foot—the largest space that can be allowed for the foot of a lamp—and for this we should require the enormous pressure of 32 atmospheres, a pressure which would be very much increased by slight warming. The vessels of these gas lamps must, therefore, be constructed to resist, at least, double this pressure. The diminution of illuminating power by the condensation of the carbo-hydrogens, (page 162,) as well as the danger of explosion, has prevented the adoption of this method at present. There is also great difficulty in obtaining a uniform flow of gas, as the pressure in the vessel diminishes with the consumption.

Portable uncompressed Gas.—Another method, which, however, does not answer the same purpose as the foregoing, was introduced by Houzeau-Muiron, at Rheims, and speedily adopted at Amiens, Rouen, Paris, &c. The distribution of the gas within the houses remaining the same; the burners and the flame, therefore, being immovable, Muiron has endeavored to avoid the grand expense of conducting mains. He employs very large vans, or rather very large cases of light sheet metal upon wheels, in which are placed wide bags of gas-tight varnished material. Two valves opening in opposite directions serve for the entrance and egress of the gas. The bag is first pressed together, to force out the air, and the filling-tube is screwed into the mouth of the proper valve. This tube goes into the gasometer of the works, which has only to be lowered to fill the bag with gas, which then of itself keeps the valve closed by which it had entered. The van is then driven to the house of the consumer, in whose cellar there must be a small gasometer constructed of sheet zinc inverted in a wooden cistern, and supplied with a filling tube, which is now connected with the exit valve of the bag. The two flat wooden ends of the cylindrical bag are then drawn together by means of strings; the bag is thus emptied and the gas forced through the tube into the gas-holder, from whence by leaden pipes it may be carried forward in all directions. The small gasometers are so simple that they do not cost more than about 30 to 35 florins (about $15). The bags contain from 200 to 1000 cubic feet of gas. The first time that they are filled, the bags may possibly retain a little air in the folds, which is afterwards expelled by the gas.

We add, in conclusion, a few statistical data with reference to the illumination of London with gas in 1840, that some idea may be formed of the extent of the works in large towns. In London there are twelve companies concerned in the working of eighteen gas-works, which together represent a capital of about 3 millions sterling, 15 millions of dollars, which returns about £500,000 ($2,500,000) per annum. From 362,880 cwt. of coal, 2646 millions cubic feet of gas (about 132 millions of lbs.) are annually obtained. In the longest night, 13 millions cubic feet are used, for the production of which 17,942 cwt. of coals are required. The 176 gasometers of the eighteen works will hold 10 millions cubic feet of gas. There are 2500 persons employed upon the works, and 380 more are employed as lamp-lighters. Since 1822, the consumption of gas was doubled in five years; in fifteen years it has been quadrupled.*

Effects of different Illuminating Materials and Methods of Illumination, and their Relative Values.—The accurate determination of the value of the different means of illumination is not only interesting in itself, but is of great importance as a matter of daily traffic, light being essentially necessary to all classes of the population, even to the most needy. Every simplification, even the smallest abatement in price, which progressive industry is enabled to make in this department, is a donation of thousands divided amongst the poor; every augmentation of the brilliancy and whiteness of the light is a welcome addition to the comforts of the domestic homes of the rich; every improvement, in short, in the modes of obtaining light, particularly in those adapted for public purposes, is a service done to the public at large. Without entering more minutely into the subject, it is evident

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* Additional matter upon gas illumination will be found in the Appendix.

that the value of any means of illumination must depend upon two things, namely: upon the *quantity of light* evolved, and upon the *consumption of lighting material* which accompanies it.* A candle, or a lamp, &c., will be the more valuable the more light it gives from as little tallow or oil as possible. The consumption of illuminating material, together with its market price, show the cost of the light, to which the outlay caused by the method of illumination must in many cases be added. The determination of the quantity of illuminating material consumed, as well as the calculation of what it will cost, is a simple matter within everybody's comprehension; the determination of the quantity of light, on the contrary, requires more explanation. Light cannot be measured with reference to its quantity any more than heat; it cannot be estimated how much light a flame emits, but it can be scientifically ascertained, how much more or less light it evolves, than another flame.

All determinations of this nature, are, therefore, comparative. The most casual observation of two flames, for example, that of a candle and of gas, shows the one, although both are of equal size, to be infinitely brighter than the other. The eye receives, therefore, at the same moment, much more light from the one than from the other. This emission of unequal quantities of light in the same time (or in the unity of time) is called the *intensity*, or *illuminating power* of the flame, or of other sources. It is thus obvious that the knowledge of the relation of intensity of two sources of light must necessarily lead to that of the quantities of light when the time is taken into consideration, or that it exactly expresses the relation of quantity, when the time in both cases is the same.

The dissemination of light is entirely effected by radiation; the intensity may, therefore, be said to express the sum of the rays, which are emitted to a certain surface, for example, to a square foot. It is evident, that the sum must be diminished by the distance from the source, as the rays separate more and more from each other. According to the laws of optics, the intensity (or sum of impinging rays) is in relation to the square of the distance; when, therefore, a surface is illumined to the same extent by two flames, the rays of light from each will be proportional to the square of the distance at which each flame must be placed in order to produce an equal amount of light. It is upon this principle that the actual determination of the intensities and quantities of light depends; the measure for both is, therefore, the distance to which the flames to be compared must be brought, in order to produce an equal amount of light. Practically, however, it is not possible to determine, even approximately, the degree of brilliancy; the degree of light is therefore not observed, but its negation, the *shadow;* and this upon the assumption that the brighter light will produce the deeper shadow, and the weaker light the less deep shadow;

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* A value, therefore, which *diminishes* with the increasing consumption, and is *augmented* by the quantity of light.

the other points remaining as before. In such experiments a board is used, covered with unglazed white paper, before which, at a distance of from 2 to 3 inches, an iron rod is placed, which has been previously blackened by holding it in the candle. Opposite this board, but at the same height, the flames to be compared are so placed that both the shadows (for each throws a shadow) fall close to each other upon the board, and then the stronger flame is so far removed, or the weaker one approached, until both shadows appear equally deep, and lastly their respective distances from the centres of the flames are measured. The squares of these distances give the relative intensities of light; if a flame, for example, has been three times as far removed as another, its intensity will be to that of the latter, as 3^2 to $1^2 = 9 : 1 = 1 : 9$, or 9 times greater. As such observations are simultaneous, and of like duration, they give likewise the relative quantities of light; for unequal lengths of time, this has only to be multiplied with the respective duration. When one of these flames, therefore, burns 3 hours and the other only 2, then the quantities of light evolved will be in the proportion, $3 \times 9 : 2 \times 1$ or 27 : 2. Observations of this kind may possibly give rise to errors, which, however, are easily rectified, so that the results obtained, for all practical purposes, are not the less accurate and trustworthy. One circumstance in particular requires notice, that when two perfectly similar shadows of this kind are observed from one side, the one appears brighter than the other, and the same is the case, the order only being reversed, when they are observed from the other side; so that the rule is, to observe them always from a position exactly opposite the board. Practice is here the best guide in forming rules.*

The simultaneous consideration of the quantities of light (or more generally of the intensities of light i) and of the consumption of illuminating material q, leads to the formula for the *illuminating power* v; for $v = \frac{i}{q}$ is an expression, which in making comparisons shows the quantity of light from an equal amount of combustible matter. The illuminating power, and the price of the material together, show the *cost or value of illumination*, which varies with the market price, and is always in the inverse ratio with it.

All the determinations given in the sequel have been made in the manner described, which is quite as well suited for determining the illuminating power of the different substances, as for that of the dif-

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* In the horizontal reflecting photometer, which has, within a box open at both ends, two mirrors inclined to the horizon in angles of 45° each, or towards each other in an angle of 90°, and forming by their intersection an edge at the centre of the box, an aperture receives a piece of tissue paper let into the top of the instrument, on which is reflected the light from two flames situated at points more or less remote from the respective open ends of the box. In this case it is not the *shadow* but the *light* which the eye of the observer, held directly over the tissue paper, is enabled to observe by means of the equal distinctness given to the fibres of the paper on the two opposite sides of the juncture of the two mirrors. The facility of observing, as well as the directness of the determination, gives to this method of ascertaining the intensity of light a preference over that which depends on the depth of shadows.—AM. ED.

ferent methods of illumination, when these are supplied with the same material. The method is, therefore, doubly important in practice.

It has already been pointed out, that all determinations of the illuminating power are entirely relative, and hence arises the demand for a suitable point of comparison. That flame would doubtless be best suited for this purpose, which would retain a perfectly equal intensity throughout the whole duration of the experiments; such a condition, however, is not completely attained by any known means of illumination. The flame of Carcel's clock-work lamp is, however, of such very uniform brilliancy, remaining unimpaired for several hours after it has been ignited, that lamps, candles, and gas, are very generally compared with it. On comparing two exactly similar lamps of this kind in such a manner, that one was kept constantly burning, whilst the other was freshly ignited for each observation, it was found that the brilliancy which in the beginning was 100, increased in half an hour to 103; in one hour to 116, and in four hours to 117, which it then retained for four consecutive hours. The cause of the very slight change in the intensity of Carcel's lamp depends, as has already been explained, upon the uniform level and superabundant flow of the oil; the increase in the brilliancy with the progressive burning may possibly be accounted for by the diminishing withdrawal of heat from the flame by the neighboring parts in proportion as these become warmer, and, lastly, perhaps, by the excess of oil being too great at the commencement, and becoming reduced to the proper quantity by the decreasing tension of the spring.

Illuminating power of Candles.—It is not remarkable from the nature of candles and the mode in which they disseminate light, that their intensity and consequent power of illumination, even under the same circumstances, should be so very variable. In the beginning, when the wick is freshly snuffed, this variation is comparatively slight, and the intensity increases up to a certain point, when, from an excessive length of snuff, deposit of spongy matter, &c., it constantly diminishes, until the candle is again snuffed or the deposit burnt, and then the process is repeated. Peclet found, by comparison with Carcel's lamp, that the primary intensity of a candle = 100, (6 = 1 lb.), became in 4 minutes 92, in 8 minutes 50, in 10 minutes 41, in 12 minutes 38, in 15 minutes 34, in 20 minutes 32, in 22 minutes 25, in 24 minutes 20, in 28 minutes 19, in 30 minutes 17, and in 40 minutes 14. Another candle, (5 to the lb.) diminished from its original intensity, = 100, in 5 minutes to 76, in 10 to 55, in 15 to 44, in 20 to 39, in 25 to 32, in 30 to 30, in 35 to 24, and lastly, in 40 minutes to 15. Less than half an hour, therefore, is sufficient to reduce the light from a candle to $\frac{1}{7}$ of its original brilliancy. The same diminution was the result of Rumford s observations, namely, $\frac{1}{6}$ after 29 minutes. When, in the sequel, the intensity of candles is compared with Carcel's lamp, the mean intensity of 10 minutes' duration in tallow candles is to be understood, which is about the usual time suffered to elapse between each snuffing; in stearine, wax, and spermaceti candles, however, the highest intensity is taken, which occurs when the wick, without any deposition of snuff, has begun to emerge from the flame. Sometimes, as was done by Schubarth and others, candles are compared with each other, instead of with Carcel's lamp, but always with much greater uncertainty.

Observations of Peclet.

Variety of Candle.	Comparison of the intensity of light.	Consumption of material in an hour.	Comparison of illuminating power.	
			Directly.	With Carcel's lamp = 100.
[Carcel's lamp . . .	100.00	42.00 rapeseed oil.	2.318	100]
Tallow candles, 6^s . .	10.66	8.51	1.253	54.04
" " 8^s . .	8.74	7.51	1.164	50.21
" " 5^s . .	7.50	7.42	1.011	43.61
Wax " 5^s . .	14.60	8.71	1.676	72.30
Stearine " 5^s . .	14.40	9.33	1.543	66.58
Spermaceti " 5^s . .	14.40	8.92	1.614	85.68

Observations of Karmarsch.

[Carcel's lamp . . .	100.00	10.30 rapeseed oil.	2.481	100.00]
Tallow candles, 6^s . .	13.20	10.51	1.256	50.61
Wax " 6^s . .	14.60	9.56	1.527	61.55

Observations of Ure.

[Carcel's lamp . . .	100.00	52.80 spermaceti oil.	1.894	100]
Tallow candles, 3^s and 4^s	8.33—6.25	9.30	0.896—0.572	35.5—47.3
Ditto Palmer's	11.90	15.00	0.793	41.8
Wax candles, 4^s, 5^s and 6^s	9.10	8.10	1.123	59.3
Stearine candles, 5^s . .	9.10	11.00	0.827	43.7
Cocoa-stearine ditto . .	6.25	11.00	0.568	30.0
Spermaceti " 3^s .	9.10	9.20	0.989	52.2

The importance of this tabular view is self-evident. An example will, however, show in what manner it may be used to establish the illuminating value when the market price is taken into calculation. In producing shadows of equal intensity, the tallow candle, six to the lb., was removed 3.265 feet, the wax candle 3.821 feet, and the clock-work lamp 10 feet from the shadow. The intensities, and consequently the quantities of light, are therefore in the ratio of $3.265^2 : 3.821^2 ; 10^2 = 10.66 : 14.60 : 100$ (v. Tab. Pecl.) Whilst the lamp consumed in an hour 42 grms. of oil, the candle flames required 8.51 tallow and 8.71 wax. The illuminating power is consequently in the ratio of $\frac{100}{42} : \frac{10.66}{8.51} : \frac{14.60}{8.71} = 2.318 : 1.253 : 1.676 = 100 : 54 : 72.3$ (v. Tab.) which shows the quantities of light produced by equal quantities of oil, tallow, or wax. Now, when the prices of equal quantities by weight of these substances are as $1 : 1.42 : 4.64$, they will amount for the quantity of light = 100, severally, to 1 for oil, $\frac{100 \times 1.42}{54} = 2.63$ for tallow and $\frac{100 \times 4.64}{72.3} = 6.28$ for wax. When, therefore, Carcel's lamp consumes in an evening 5 cents worth of oil, to obtain an equally good light during the same time from tallow 13 cents would be the cost, and from wax about 31½.

A comparison like the one above is not quite applicable to every-day consumption, as candles are reckoned usually not by weight but by the number constituting a pound. The intensity of light from a tallow candle is, from the above, to the intensity from a wax candle as 10.66 : 14.60, or as 5 : 7 : 7 tallow candles must therefore be ignited to produce the same light as 5 wax candles, each kind being 6 to the pound. This latter is not literally the case ; thus, *e. g.*, a pound packet of the tallow weighed 458 grammes, one of the wax 426 grammes, instead of 500, so that 5 wax candles weigh 355 grammes, 7 tallow candles 534 grammes. The 5 wax candles will cost about 1*s.* 9*d.* and burn 58½ hours, 7 tallow candles will cost about 8⅙*d.* and will burn 53 hours, both with an equal amount of brilliancy, which therefore, for an equal number of hours, will cost 8⅙*d.* in tallow, and $\frac{53 \times 1s.\ 9d.}{58} = 19.2d$ in wax. Besides this, it must be taken into consideration that the ends of candles are of much less value than the actual weight of material which they comprise, and are comparatively valueless when composed of the more costly stearine and wax. Amongst the experiments cited above, those of Ure are less accurate than the others, and more particularly, than those of Peclet. A comparison of wax and stearine candles (of Berlin manufacture) with each other, which possesses much interest, particularly as regards the relative values of 4, 6, or 8 to the pound, has been furnished by Schubarth.

Kind of candles, and whence obtained.		Relative intensity of light.	Consumption in 1 hour in grammes.	Relative illuminating power.
Common wax candles of Tannhäuser	4^s.	103.5	7.877	85.20
	6^s.	91.0	7.176	83.20
	8^s.	100.0	6.562	100.0
Wax candles of Walker . . .	4^s.	132.7	9.398	92.66
	6^s.	120.3	8.082	97.69
	8^s.	113.1	7.132	104.1
Stearine candles of Motard . .	4^s.	117.4	9.427	81.74
	6^s.	111.8	9.383	78.23
	8^s.	121 0	7.877	100.7
Slate stearine candles of Maquet and Ochmichen	4^s.	139.5	10.630	86.11
	6^s.	132.7	9.398	92.66
	8^s.	125.0	8.506	96.54
Stearine candles from the same parties	6^s.	116.1	8.871	85.86
	8^s.	146.0	8.886	108.00
Candles made from Palm wax .	4^s.	124.5	9.880	82.67
	6^s.	115.3	9.178	82.56
	8^s.	167.5	8.813	113.70

Thus it appears, that, with reference to the hourly consumption, it is not the same thing, whether 4, 6, or 8 candles go to the pound. Of the latter, the smallest quantity is consumed, more of the sixes, and most of the fours. Whilst 1 lb. of wax candles, 8 to the pound, burn 62 hours, 1 lb. of sixes burn, on an average, only 55 hours, and 1 lb. of fours only 48 hours. In the same order, 1 lb. of stearine candles will burn 57, 49 and 45 hours. The intensity of the light is, in like manner, variable, and is greatest in candles 8 to the pound, less in sixes, and least in fours, about in the proportion of 15 to 12 and 10. Another result, deduced from the foregoing experiments, according to which the mean illuminating power of wax and stearine candles is nearly the same, without influencing the general conclusions, cannot be made to agree with the very accurate and often repeated experiments of Karmarsch, who found the illuminating power of wax candles to be ¼ greater; and this cannot be satisfactorily explained by the experiment. As a general fact it is evident, that the determination of two points, namely, the intensities of the light and the time during which a candle is capable of burning, is in itself sufficient to determine its value as a source of light in comparison with other candles, without knowing the weight which is consumed in an hour; for the true weight and the nominal weight are always different in a candle, so that a wax candle (8 to the pound, for instance), instead of weighing 66 grms., only weighs 52, and so with others. In this manner, Fyfe has determined the illuminating value of different candles; but his observations are too inaccurate to deserve further notice here. According to Fyfe, a spermaceti candle burns 8 hours, a wax candle 9 hours, with equal intensity of light; in order, therefore, to produce this intensity for an equal length of time, 65 wax candles, or 72 spermaceti candles, (= 8⅛ : 9,) must be burnt. When, therefore, the price of the wax is 3½ times more than that of spermaceti, their illuminating values will be inversely as:
$65 : 3.5 \times 72 = 1 :$ nearly 4. Mohr found the intensity of spermaceti candles $\frac{86}{100}$, that of wax candles, which, the prices remaining the same, accords a 5 times less illuminating value to the wax candles, whilst according to Peclet, instead of 5, it was only 3 times less. This want of coincidence in the results might have been anticipated with certain limits, on account of the fluctuating light of the candles. Although the relative values of different kinds of candles cannot be ascertained with mathematical accuracy, yet such experiments are always valuable as a means of discovering which kind is really the best.

Why, it might be asked, are those means of increasing the steadiness and power of the flame, which have been described with reference to the Argand burner, not applied in consequence of its unstable nature to the light of candles? Inasmuch as the flame of candles becomes gradually lower, mechanical contrivances must be brought into play, either to lower the glass cylinder—for such only can here be meant—or to retain the flame at a constant height. Such contrivances are, however, difficult to combine with the grand advantage of candles, namely, their great simplicity. But supposing this difficulty to be surmounted, glasses for regulating the draught could not even then be used, for as soon as a glass of this kind is applied, the flame gradually diminishes until it is completely extinguished, and this happens more quickly with wax and stearine than with tallow candles. The cause of this is palpable; for, if the chimney is to have any effect at all, ⅔ of the flame at least must enter it; the draught will be very much increased round the flame, just as was the case with lamps, and it will burn with greater brilliancy and steadiness for the first minute. But the current directed against the base of the wick will, in the next minute, cool it and the adjacent parts so much, that the supply of fat will be stopped. The reservoir and lower part of the wick, instead of being filled with a store of melted fat, become empty and dry, the flame will shrink together and retreat to the highest point of the wick into a position therefore which only increases the evil. As soon as the glass chimney is removed, the flame again assumes its original size. The use of such a chimney would, therefore, only be practicable with a supply of hot air.

Illuminating Power of Oils.—The power of lamps depends not only upon their construction, but also, of course, upon the nature of the material consumed in them. In northern countries this material is whale oil, train oil, and especially rape seed oil; in the south, olive oil of inferior quality is used, to which may be added here and there the fluid fats obtained as a secondary product in the manufacture of stearine. The illuminating powers of these oils has not been so repeatedly and accurately examined, as the importance of the subject merits, although the method to be pursued is simple and without many difficulties. It consists in filling one and the same lamp, under similar circumstances, with the different oils consecutively, the illuminating powers of which are to be tried; all differences can in this case only arise from the nature of the illuminating material.

Dr. Ure used a Parker's lamp for his experiments, which are by no means very exact; he found:

	Quantity of light.	Consumption in 1 hour in grammes.	Consumption in 1 hour intensity = 100.
Whale oil	121	47.6	39.5
Southern fish oil	82	50.5	59.0
Olive oil	90¼	53.2	54.4
Oleine from the cocoa nut	81	66.7	82.7

whence it appears, without taking the price into consideration, that the preference must be given to whale oil.

The high price of rape oil in unproductive seasons, gives rise to its being mixed with the cheaper linseed oil, in which adulterated state it is frequently met with in commerce. Linseed oil, on account of the property it possesses of thickening, cannot be used alone in lamps, and it communicates the pernicious property to the mixture of smoking strongly, *i. e.* burning with difficulty and incompletely. The eulogiums passed upon vegetable oil (olive oil) as an economical source of light, induced Karmarsch and Heeren to subject both oils to a strict investigation with reference to their powers of illumination. Two wall lamps of like dimensions and construction with Argand's burners, afforded a means of direct comparison; all precautions were taken to secure accuracy, and the glass chimneys changed about to avoid all possibility of their exerting any particular influence. The first series of experiments gave, as the mean of twelve observations for olive oil, an intensity of 1066 with a consumption of 460.9 grammes in nine hours and a half; for rape oil an intensity = 1000, with a consumption of 428.4 grammes in the same time. In a second series the mean of nine observations showed the intensity produced by olive oil with a consumption of 359.5 grammes in eight hours to be $\frac{980}{1000}$ of the rape oil, of which 367.2 grammes were consumed. According to the former experiments, therefore, the illuminating power of olive oil as compared with rape oil is, as $\frac{1066}{460.9} : \frac{1000}{428.4} = 2.313 : 2.334$, according to the latter, as $\frac{980}{359{,}5} : \frac{1000}{367{,}2} = 2.726 : 2.723$, *i. e.* from like quantities of both oils, an equal quantity of light is evolved, but from olive oil in a shorter time, because it gives proportionally more light, as more of it is consumed.

The importance of purifying the oil from all foreign matters, particularly albuminous matter (mucus), as was noticed above, has been shown by Kaiser, whose experiments unfortunately had reference only to the consumption and not to the intensity of the light. A lamp without wick, like Fig. 19, was supplied alternately with purified and crude oil, and the time and amount of consumption noted. In this manner 2 grammes of purified oil were consumed, 1.82 grammes of crude oil warm drawn, and 1.6 grammes of cold drawn. Hence 100 grammes of the first would burn 50 hours, of the second 55½, and of the last 62½. As long as the quantity of light simultaneously evolved is unknown, it is impossible to form an opinion respecting their relative values.

Illuminating Power of Lamps.—A perfectly uniform light is not to be expected from lamps, on account of their construction, and particularly on account of the action of the wick, the changes, however, which occur in the intensity of the light, are confined to much narrower limits than is the case with candles, where a constant change is occurring, whilst here there is only a gradual diminution. This diminution has already been stated as deduced from experiment, for Carcel's lamp; generally speaking, a single observation or the mere knowledge of the mean intensity of light gives a very imperfect idea of the action of a lamp; good observations must, therefore, take notice of the diminution in the brilliancy during a whole evening, or during about six hours. With this object, Peclet, as well as Karmarsch and

Heeren, have given as an addition to their experiments, tabular statements of this diminution, both of which are here inserted one after the other.

Experiments by Peclet.				Comparison of the diminution of light.						
Kind of lamps.	Dimensions of the wick, breadth or diameter.		Distance of the oil from the margin of the burner.	Intensity of light.						
	Internal.	External.		In the 1st hour.	In the 2d.	In the 3d.	In the 4th.	In the 5th.	In the 6th.	In the 7th.
No. I. Lamp, with flat wick and chimney	Lines. 7.2			100	100	98	98	97	96	96
— II. Astral lamp	4.6	8 8		100	103	90	72	61	42	34
— III. Sinumbra lamp . . .	6.4	11.2		100	102	95	83	81	78	60
— IV. " " with intermittent oil level	"	"	2.8	100	100	90	70	52	41	32
— V. Lamp with inverted reservoir, and Sinumbra burner . . .	3.6	10.0	2.8	100	100	97	95	92	89	86
— VI. Lamp with inverted reservoir	4.4	10.4	8	100	103	82	79	75	72	65
— VII. Girard's Lamp . . .	2.64	6.8	8	100	101	96	84	81	76	70
— VIII. Thilorier's No. 1 . .	6.4	11.2	2	100	106	103	100	94	92	90
— IX. Ditto, No. 4	2.64	6.8	2	100	101	101	101	100	98	96

Compared with each other with reference to their illuminating power, the same lamps gave the following results:

Number of the lamp.	Average intensity of light during seven hours, Carcel's lamp = 100.	Consumption in one hour in grammes.	Quantity of light from 100 parts of oil, Carcel's lamp = 100.	Number of the lamp.	Average intensity of light during seven hours, Carcel's lamp = 100.	Consumption in one hour in grammes.	Quantity of light from 100 parts of oil, Carcel's lamp = 100.
Carcel's lamp	100	42.00	100.0	No. V.	41	18.00	95.4
No. I.	12.5	11.00	47.5	— VI.	90	43.00	87.8
— II.	31	26.71	48.7	— VII. . . .	63.7	34.77	76.5
— III.	56	37.14	63.0	— VIII. . . .	107.7	51.14	90.3
— IV.	85	43.00	82.8	— IX.	45.0	17.26	109.2

The observations of Karmarsch and Heeren were made upon exactly the same principle, and are to be understood in the same manner. The first column in the following table gives the dimensions of the lamps used by them.

Sort of lamp.	Breadth of the wick, or diameter of the burner.		Average intensity of light from twelve experiments.	Consumption of rapeseed oil in one hour in grammes.	Quantity of light from an equal quantity of oil, Carcel's lamp = 100.
	Inner.	Outer.			
	Lines.				
No. I. Carcel's clock-work lamp	6.8	9.2	100	40.64	100
— II. Kitchen lamp	3.2 (thick.)		6.65	8.05	33.58
— III. Lamp with flat wick	8.2 (broad)		15.13	9.40	65.71
— IV. Lamp with chimney	7.6		19.37	12.33	63.82
— V. Table lamp with circular oil vessel, and semi-circular wick	12.5		32.64	20.88	63.54
— VI. Astral lamp	6.2	9.4	44.98	28.70	63.72
— VII. Sinumbra lamp	5.2	8.8	52.50	26.74	79.78
— VIII. Lamp with flat wick, and inverted reservoir	8.4 (broad.)		21.50	14.90	54.80
— IX. Wall lamp with inverted reservoir, and semi-circular wick	13.0	"	39.33	20.15	79.35
— X. The same, with round wick	7.4	10.0	52.54	29.33	72.81
— XI. Liverpool lamp with inverted reservoir*	6.0	9.2	41.80	26.78	63.45
— XII. Wall lamp with constant oil lever and regulator†	5.8	8.0	82.46	35.44	111.60
— XIII. Hydrostatic lamp	7.4	9.2	92.44	38.94	113.90

With Lüdersdorff's vapor lamps the same observers found:

Dimensions.	Intensity of light in the middle of the burning time.	Consumption of material in an hour.	Illuminating power.
No. I. With twelve holes 0.4 lines apart in a circle of 1 inch diameter	130.7	560 grms. of illum. spirit.	36.2
— II. With twelve holes 0.4 lines apart in a circle of 13.6 lines diameter	69.6	315 " " "	34.2
— III. With eight holes 0.4 lines apart in a circle of 10.9 lines diameter	52.8	295 " " "	27.7
Carcel's lamp	100.0	155 rape-oil	100.0

Lastly, an observation of Ure's upon Parker's lamp may be given:

Lamps.	Intensity of light.	Consumption of whale-oil per hour in grammes.	Quantity of light from the same quantity of oil.
Mechanical lamp	100	52.7	100
Samuel Parker's lamp	121	45.1	141

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* See p. 199.

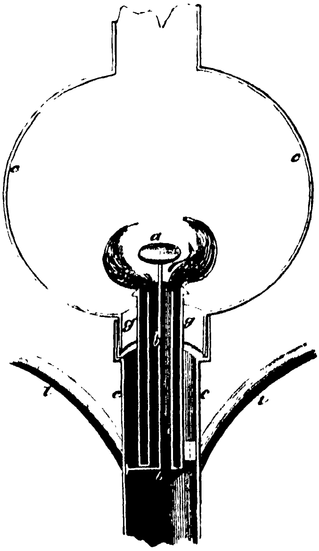
† This lamp, of French invention, combines the advantage of the inverted reservoir with that of a contrivance similar to Caron's stop-cock, which obliges the oil to rise to such a height in the burner, that, when the opening is unimpeded, and the flame extinguished, it still continues to flow out slowly.

The first table presents some remarkable facts with reference to the diminution of the intensity of light. Those lamps, in the burners of which the oil level gradually sinks, generally show the greatest diminution, as in No. II.; it is but very slight in No. I., where it might naturally be expected that it would be strongest. In the same manner, it was anticipated that the light of the lamp No. III. would show a less diminution, when, with the same dimensions, the level of oil in its burner is rendered constant by an annular reservoir, after the fashion of the inverted vessels in No. IV., and yet the table shows the contrary. It is evident that in both cases (No. I. and No. *III.) other influences preponderate, which are propitious to the* uniform brilliancy of the flame. *On the whole, the diminution of light* in six hours amounts to $\frac{1}{2}$, $\frac{1}{3}$, and even $\frac{4}{5}$ of the original intensity; it is only imperceptible in Carcel's and Thilorier's lamps, and both these produce their light with the least consumption of oil, whilst the lamp with a flat wick requires the largest quantity.

The irregularities and apparent contradictions in the action of lamps, can only be properly understood and explained by weighing the influence of different secondary causes. The whole art of constructing lamps depends upon the single, but important condition of establishing a proper relation between the current of air, and the flow of oil simultaneously consumed. Although the mobility of the wicks and chimneys admits of a partial approach to this state of things, yet even the better kind of lamps are still very far removed from it. The position of the wick, downwards, can never exceed a certain limit, for it must always project so far from the burner that, in a certain time, as much oil shall enter into combustion, as is requisite to produce the amount of light necessary: a circumstance which indicates that it is preferable to adapt the draught to the position of the wick, rather than the reverse. The width and height of the glass place the draught quite under control; yet, nevertheless, the quantity of air conducted to the flame in lamps is, without exception, too great; the flame has, consequently, to warm a portion of this air at the expense of its own temperature and intensity; and from this portion it can derive no advantage. This necessary evil is connected with the material of the chimney, for glass is the only substance that can be used. From fear of fracture, which is not always well-founded, the glasses are seldom made sufficiently narrow—though undoubtedly they are then exposed to a much higher temperature. The draught may likewise be lessened by contracting the mouth of the burner, through which it (the draught) enters the chimney. When, according to Peclet, 100 grammes of oil produced an amount of light = 1000, with a burner in which the space for the internal draught was 6.4 lines wide, this quantity was increased to 1014 when the draught aperture was 4.8 lines, to 1093 when it was 3.6 lines, and 1209 when only 2.4 lines in width. Too small draught apertures, on the contrary, give rise to too much friction, and require an increased power of current. The proposition for supplying the internal and external draught apertures with dampers which can be moved according to circumstances, would certainly be desirable, but has never yet been put into practice. Holthouse found, that an excessive height of chimney, for example 3 feet to $\frac{7}{8}$ inch in width, caused the flame to flicker, but that the greatest steadiness was obtained when, the width remaining the same, the height was 7 inches. The aim of recent improvements has been directed to the breaking of the draught, and throwing it in upon the flame rather than to these points; a part of the subject which has already been touched upon in speaking of the chimneys with shoulders, Fig. 29*a*. Amongst these improvements, which have, therefore, reference solely to the burner, and not to the other parts of the lamp, is an older one, forming the principle of the so-called Liverpool-lamp.

The Liverpool Burner.—The original Argand burner *g*, Fig. 69, is supplied with oil by the tube *i*. At its lower aperture a wire *b* is fastened, which rises through the axis of the burner to a few lines above its upper margin, where the projecting end is furnished with a screw. This is intended to support a round copper plate *a* (in the shape of a button) of equal diameter with the wick. It is difficult, at first, to establish the proper relation of distance between *a*, and the margin of the burner, but it is easily found, experimentally, by screwing the plate backwards and forwards. As the result of this arrangement, the internal draught is forced from its original perpendicular direction, and broken against the plate *a*, whence it is propelled at a sharp angle, nearly horizontally, against the flame, which thus assumes a globular, instead of its ordinary cylindrical form, and (as is shown in the figure) is forced into contact with the external current. The form of the flame makes it necessary to have the peculiar bulging chimney *c*, and this is supported by the case *e* of the burner. Complete combustion, together with intense brilliancy and whiteness, characterizes the flame; but there is nevertheless a certain want of uniformity, which, however, does not exist in the nature of the principle, and can be avoided by a proper regulation of the draught.

Fig. 69.



The lamps constructed by Benkler and Ruhl, in Wiesbaden, since the year 1840, depend entirely upon the same principle, causing the draught to impinge at an angle upon the flame. The apparent novelty of the invention, the surprising brilliancy and peculiarity of the flame, and partly, the solid and elegant workmanship of the lamps themselves, led the public, at least for a time, to confound these advantages with the more essential one, namely, the economical consumption of the oil, and created in a short time such an enormous demand for this invention, that, at the end of the year 1841, Wiesbaden witnessed the growth of a manufactory where, in its prime, with sixty workmen, 2,400 lamps were constructed monthly. Some hasty experiments, which were published by the Physical Society of Frankfort-on-the-Main, in favor of the invention, tended very much to augment this over-estimation of its value, which the accurate observations and quiet reconsideration of the last year have at length brought back to its proper limits.

Fig. 70.

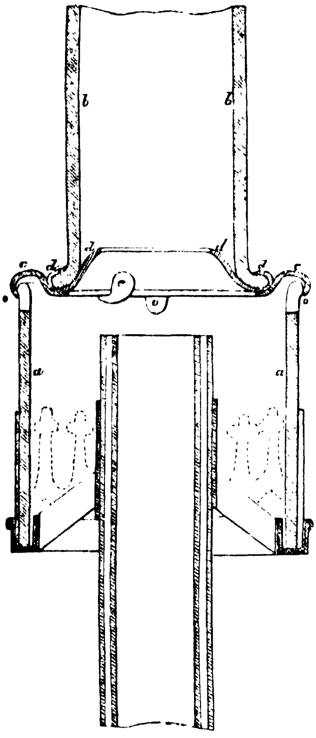


Fig. 71.

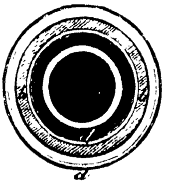


Fig. 72.

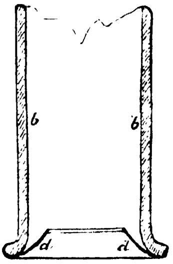


Fig. 70 is a sketch of the general plan of Benkler's burner. Fig. 71 is the ground plan; and Fig. 72 represents the upper distinct parts. The shoulder of the chimney is here formed at the junction of two pieces; a narrower glass *b*, above the flame, and a wider glass *a*, which is below it. Just at this junction is placed the most important part of the arrangement, which consists of a conical ascending brass ring *d d*, with an aperture of the same diameter as the wick. This flat open cone is immovably fixed to the upper glass *b*, by bending up its outer edge, Fig. 72. The connection of *b* with *a* is effected by a so-called bayonet joint. For this purpose, on the lower margin of the plate *d*, there are two tongues *e*, and these correspond with two cuts in the ring *c*, with which the margin of *a* is encircled. When, therefore, *d* is so placed upon *a* that the tongues and cuts correspond, a simple turn of *d* is sufficient to bring the tongues under the ring *c*, and thus secure the whole. The apertures *o o* are made round *a*, to increase the draught from without. The principal addition, therefore, in Benkler's lamp, is a sudden contraction in the chimney, at a certain distance from the flame, the aperture being of the same diameter as the wick, and this is produced by the insertion of a metallic ring, or cone.

The action of such a contrivance is easily understood. The external and internal currents of air and the flame must pass through the aperture of *d*, where a rapid contraction results. The outer current is driven against the axis of the flame at a sharp angle, and thus forces the flame itself into the inner current, so that an intimate mixture of air is effected with the products of decomposition of the oil. The flame becomes narrower, and three times as long, when, by keeping back all the air which has no part in the combustion, and by giving a proper direction to that which has, the highest and whitest brilliancy, and considerable evolution of heat are attained. A perfectly white heat is produced; for, in consequence of the well-ordered combustion, the suspended particles of carbon are more intensely heated than in any other lamp. Notwithstanding the intensity of the heat, the chimneys —in corroboration of what was stated above—stand well. A very short portion of the flame, that which produces the least light, is naturally situated below the cone *d*, but the longer portion—the essentially luminous part, is above and throws a shadow from *d* downwards, which is perceptible in standing and hanging lamps, but is of no moment in the determination of the intensity of light, as it only occurs in the direction of the edges of *d*. As the cone *d* has no other object than that of producing a sudden contraction, chimneys are now made in one piece with an inward bend in the proper place, something like the one represented in Fig. 33. The first inaccurate experiments of the Frankfort Physical Society stated the illuminating power of lamps, with Benkler's cone, to be twice that of lamps without it. Karmarsch and Heeren, however, settled the matter by numerous and very carefully conducted observations, in which they took care to afford the lamps,—which, without the appendage *d*, were converted into common Argand's lamps,—every condition necessary for complete combustion. In this manner, 3 lamps, amongst others, were tried, of which No. I. had a breadth of burner = $\frac{7}{8}$ inch, No. II. = $\frac{9}{16}$ inch, and No. III = $\frac{7}{16}$ inch. The results were as follows:

	Intensity of light.		Consumption.		Consumption for an intensity of light = 1 tallow candle.		
	With	Without	With	Without	With		Without
	Cone.		Cone.		Cone.		
No. I.	1334	739	19.50	12.62	100.0	:	95.0
— II.	656	336	8.94	5.37	100.0	:	105.2
— III.	392	146	5.75	3.37	100.0	:	80.0

Two quite similar lamps, with inverted reservoir and $\frac{7}{8}$ inch width of burner, showed an intensity of light, without the cone, = 1000, and the consumption was = 14.56; whilst with the cone, the intensity was = 1334, and the consumption 19.5; whence the relation of illuminating power is as $\frac{1000}{14.56} : \frac{1334}{19.5} = 68.4 : 68.7$. The examples quoted, as well as the other numerous results of the above observers, prove, beyond a doubt, that with wider burners (above ½ inch), in Benkler's lamps, the production of an equal amount of light is attended by as large a corresponding consumption of oil as is the case in well arranged ordinary Argand lamps; with narrower wicks, it appears, however, that they are somewhat more economical. But in all cases, the intensity of the light, with Benkler's appendage, was considerably (sometimes doubly) greater than in lamps without it; but the consumption is then nearly in the same ratio, so that there results but little difference in the illuminating power. Benkler's lamps are excellent for producing a very white light, quite equal to the best gas light (hence called gas lamps), and on account of the steadiness of the flame, which is quite unaffected by draughts of air in the vicinity, or by the motion in carrying, &c. The narrow burners are also preferable on account of the light they evolve being perfectly uniform during 4 or more hours, whilst wider burners show a rapid diminution and often begin to smoke, if no subsequent regulation is effected by means of the wick. A lamp with a wick $\frac{3}{16}$ of an inch in diameter, with a flat oil vessel, and no inverted reservoir, gave at first an intensity of light = 185, in an hour = 240, in another hour = 268, and after a third hour, still = 235. The intensity of another lamp, on the contrary, the wick of which was ¾ of an inch in diameter, diminished from 748 and 869 in the first and second hour, to 634 and 603.

In localities where several of Benkler's lamps are burning simultaneously, in the form of a chandelier or otherwise, as in large rooms, workshops, &c., the evolution of heat from the lamps raises the temperature very perceptibly. A middle-sized lamp, the chimney of which is 1 foot high, with a contraction 0.6 of an inch in width, immediately melts a bar of zinc held over it. The temperature at that spot cannot, therefore, be less than 360° C., (680° F.) according to which 1.5 cubic feet of air (at 360° C.) must pass through the cylinder in one minute, and this is very much *less* than the quantity which actually passes.

Another very advantageous peculiarity of Benkler's lamp, is, that we are enabled to burn more oil in the same time with the same wick, *i. e.*, the wick actually concerned in the combustion is much higher. For producing an equal intensity of light, therefore, Benkler's lamps may be of smaller dimensions, and are consequently less costly. On the other hand, the carbonization of the wick is so considerable, that massive wicks must never be used. Lastly, it must be stated, that train oil and unclarified oil, contrary to the assertions of the inventor, cannot be used in these lamps without inconvenience and deposition of carbon on the wick any more than in other lamps.

When it is recollected, that the wick and the cone *d* are of the same diameter in Benkler's lamp, it becomes obvious that, by raising the former, more oil must be brought into the sphere of combustion, but that, at the same time, the external draught is diminished, and in proportion as the distance of *d* from the wick is lessened. In the highest position, when the outer draught entirely ceases, the disproportion and the great cooling influence exerted by the ring upon the summit of the wick give rise to a singular phenomenon. The still-existing internal current of air is only just sufficient to keep up the blue weak flame below the ring, whilst the flame above is extinguished, and its place occupied by a smoking current of gas, which can be re-ignited at the apex by a candle, where it again comes in contact with the external air. This slightly luminous point flickers over the current of invisible gas proceeding from above the ring, whilst below it assumes the form of narrow flames.

The proof afforded, by practice and experiment, of the same amount of light being evolved from equal quantities of oil in Benkler's lamps as in those of ordinary construction, appears strikingly opposed to the great luminosity and beauty of their flame. A great many of those improvements, also, the object of which was a greater intensity of the flame, have failed in consequence of this palpable contradiction. For the advantage of the increase of light, (produced by means similar to those in Benkler's lamp,) when carried beyond a certain point, is removed or counterbalanced by an evil which arises at the same time. This consists in the diminution of the size of the flame, consequently the diminution of the surface radiating light. In an ordinary lamp, this surface is extensive and but slightly luminous, whilst, in Benkler's, it is small and more powerfully luminous in proportion.* Hence it is evident how, in the extension of the flame, the Liverpool lamp is superior to Benkler's, in which the reverse is the case, *i. e.* it is contracted. For the same reason, taller glasses, *i. e.* such as cause a greater draught, cease to be of greater advantage, because they diminish the size of the flame as much as they increase its brilliancy.

Among the general circumstances influencing the action of lamps, the position of the wick is also of importance, because the consumption of oil does not increase in proportion to the size of the flame, and the latter is immediately dependent upon the position of the wick. According to Peclet, the quantity of light produced by equal quantities of oil was

	In a lamp with a flat wick.	In the hydrostatic lamp.	In the sinumbra-lamp with intermitting level.
At the greatest height of the flame without its smoking	100	100	100
At a medium height	64	74.4	92
At its least ditto	43	25.5	45.5

This maximum of flame is not advisable for use, because the least thing causes the flame to smoke and flicker, and there is too much charring of the wick. The explanation of the better action of larger

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* The flame of the former is somewhat cylindrical, that of the latter acutely conical. Supposing that an ordinary flame, 1 inch in diameter, and 1.5 inch in height, gave as strong a light as one of Benkler's, 0.5 in diameter, and 3 times the height, the corresponding surfaces would be in the proportion of about 19 to 10. In addition to this, the imperfect transparency peculiar to each flame, increases in Benkler's with the diminution in size. Thus, in the latter, more of the light from the posterior half is suppressed by the anterior part than in ordinary flames.

flames, moreover, depends upon the existence of a more correct proportion between the supply of air and of oil. Much also depends upon the width of the annular space in the burner for the wick. Where the spaces for the oil are very large, or the oil is contained in open vessels, the wicks become charred down to the surface of the oil, and finally remain in the flame like the snuff of an unsnuffed candle, whilst in narrow burners, a white uncharred ring always remains above the margin, but the intensity of the light of the flame soon diminishes. We endeavor to combine the advantages of both by preserving this space wide, except at the distance of a line from the margin, where it is made narrow.

Illuminating Power of Gases.—The inconvenience arising from gas-burners not being portable, is greatly compensated by the decided advantages of great cheapness in the illuminating material, and the constancy and brilliancy of the light. In fact, in gas illumination, the object to which the numerous improvements in the burners of lamps and their supply of oil are directed is already attained. The wick, with all the imperfections and deficiencies attendant upon it, is entirely dispensed with, as also the difficulty of regulating the supply of illuminating matter is reduced to the simple task of maintaining a constant pressure. Whilst with candles and lamps, the simultaneous production and combustion of the gas are in a condition of mutually conflicting dependency, the combustion of illuminating gas, when passing freely through the apertures, is conducted in such a manner as to attain the greatest perfection. To determine the illuminating power of gas, apparatus (as the gas-meter described at p. 182, which was used in the following experiments) for measuring the amount of gas consumed is employed. According to Brande, to produce the light of 10 wax candles, 2.7 cubic feet of olefiant gas, 5.1 cubic feet of oil-gas, and 13.75 cubic feet of coal-gas are requisite per hour; hence the illuminating power of oil-gas is 2.6 times greater than that of coal-gas, but only half that of olefiant gas. From another determination, 6.85 cubic feet of coal-gas and 1.9 of oil-gas per hour yield as much light as a Carcel's lamp, which consumes 42 grammes of oil, and gives 3.6 instead of 2.7 times the illuminating power of oil-gas, a difference which does not depend upon erroneous observation, but as shown by Christison and Turner, upon the different nature of the gases themselves. By their observations, they were led, with regard to the density, to the following results.

Specific gravity			Relation of illuminating power		
Of coal-gas.	—	Of oil-gas.	Of coal-gas.	:	Of oil-gas.
0.659	—	0.818	100	:	140
0.578	—	0.910	100	:	225
0.605	—	1.110	100	:	250
0.407	—	0.940	100	:	354
0.429	—	0.965	100	:	356
0.508	—	1.175	100	:	310
0.529	—	0.986	100	:	272 average.

According to a report made by Hedley to the British parliament, the illuminating power of coal-gas, in twelve principal districts of England, amounts to between 4.408 and 1.645 times that of a tallow candle (6 to the pound), but ordinarily about two or three times, when the consumption varies from 2.3 to 1.5 cubic feet (per hour), and the specific gravity from 0.58 to 0.412. The common price of 100 cubic ft. is 7*d.* (= $1.50 per 1000), in some places not quite 6*d.* (= $1.20 per 1000); in Leipzic this quantity of gas costs rather more than 6*d.* (1840). The two-fold greater illuminating power of oil-gas presents great advantages; far less extensive apparatus, gasometers, &c., are required; hence less capital is necessary for the production of an equal supply of light.

With the same burner and gas, the amount of light depends upon the height of the flame, which practically, the pressure being nearly constant, is regulated by the position of the cock; or in fact by varying the size of the aperture in the burner. According to Christison and Turner, the advantage increases with the height of the flame, but to a limited extent only, and for a simple jet in the following proportion:

Length of the flame in inches.	Intensity of the light from equal quantities of		Coal-gas.		Oil-gas.	
	Coal-gas.	Oil-gas.	Intensity of the light.	Gas consumed.	Intensity of the light.	Gas consumed.
1	—	100	—	—	22.0	33.1
2	100	122	55.6	60.5	63.7	78.5
3	109	159	100.0	101.4	96.5	90.0
4	131	181	150.0	126.3	141.0	118.0
5	150	174	197.8	143.7	178.0	153.0
6	150	—	247.4	182.2	—	—

Thus the point at which further advantage ceases to result on raising the flame of oil-gas is 4 inches, whilst for coal-gas it is 5 inches, which in general requires the flames to be higher. The consumption of gas and the intensity of the light increase together, but the latter in the greatest proportion up to these points. This occurs to a still greater extent with Argand's burners, for which, with the same consumption of gas, these observers found the intensity of the light to be

	100	282	560	582	582	504	
at a height of	$\frac{1}{2}$	1	2	3	4	5	inches.

According to Fyfe's experiments upon different burners, in which he probably used a better kind of coal-gas, the increase is as follows:

Argand-burner.	With 24 apertures of $\frac{1}{40}$ of an inch, the diameter of the perforated ring being $\frac{7}{8}$ of an inch	—	100	121.8	—	188.5	—	236.6	235.4
	With 42 apertures of $\frac{1}{50}$ of an inch, the ring being $\frac{21}{20}$ of an inch in diameter	100	136.6	—	176.2	—	194.8	—	242.3
	Height in inches . . .	1	1.5	1.75	2	2.5	2.75	3	3.5

With a bat's wing he found the intensity of the light in the highest position of the flame to be 117, at a medium height 105, at its lowest point, with the same consumption, 100. Lastly, his experiments give a view of the intensity of the light produced by the same quantity of gas in different burners, when separately compared at the most advantageous height of the flame.

Burners.	Simple jet.	Bat's-wing.		Fish-tail burner.	Argand-burners,	
		Small.	Large.		With 24 holes.	With 42 holes.
Quantity of light from the same amount of gas .	100	135	164	138	183.5	182.3

According to the observations of Hedley already quoted, which were made in the gas-works at Sheffield, the intensity of the light of a simple 4 inch jet is to that of a 3.5 inch Argand flame (from 14 apertures) as 1 : 4.4 to 4.8, the amounts consumed being as 1 : 3 cubic feet, which corresponds to a greater amount of light from the Argand burner, by from 1.47 to 1.6 for the *same quantity of gas*. From the general report of the same engineer upon the principal gas-works in England, it is found (in the case of coal-gas) the average specific gravity being 0.476, that a simple jet, 4 inches in height, consumes on an average 1 cubic foot (English) per hour.

[*American Experiments on Illumination.*—A number of comparisons have at different times been made in Philadelphia and its vicinity to ascertain the relative values of several materials employed in this country for purposes of illumination : some of these, such as lard, rosin, and camphine, or other similar compounds, being produced in great quantities, both for home consumption and for exportation, some account of the results may very properly follow what has already been shown by European inquirers.

The materials operated on here have been coal gas, rosin gas, sperm oil, lard oil, crude lard, Dyott's pine oil, Greenough's chemical oil, Carr and Gould's camphine, and the trials have been made on several varieties of burners and lamps.

Some of the results are contained in the following statements.

1. Comparison between the Carcel lamp, the solar lamp of Cornelius, the camphine lamps of Carr, Dyott, and Gould, and an Argand gas burner. These comparisons were made by a sub-committee from the Committee of Science and Arts of the Franklin Institute, and appear in its journal for February, 1843.

"The Carcel lamps were of four different sizes, Nos. 1 and 3 were burned with fall strained oil, at 90 cents per gallon; Nos. 2 and 4 with winter strained oil, at $1 per gallon.

"The solar lamp, No. 2, and the semi-solar, with winter strained; No. 1 with fall strained oil.

"The following table gives the result of these experiments; the economical value being estimated as the intensity divided by the expense, or the relative quantity of light for the same expense.

"Table, showing the relative intensities, the quantity consumed, the duration of experiment, the cost of material, the expense per hour, and the economical value of different lights.

		Intensity.	Quantity consumed in pints.	Duration of experiment in hours.	Cost of material per pint.	Time of consumption of 1 pint in hours.	Expense per hours in cents.	Quantity of light at same expense.
Gas, . . .		1.					1.4875	1.
Carcel	No. 1 .	2.152	.92	5.8	11.25	6.32	1.78	1.8
	" 2 .	1.1	.766	7.	12.5	9.14	1.27	1.2
	" 3 .	.93	.766	7.	11.25	9.14	1.23	1.1*
	" 4 .	.69	.422	6.15	12.5	14.60	.86	1.2
Solar	" 1 .	2.13			11.25		1.85	1.71
	" 2 .	1.4	.481	4.05	12.5	8.42	1-48	1.4
Semi-solar .		1.152	.6	4.05	12.5	6.75	1.85	.93
Camp.	Carr .	1.8	.25	2.50	7.8	10.	.78	3.4
	Dyott .	1.69	.28	2.63	7.8	9.40	.83	3.
	Gould .	1.75	.31	2.66	7.8	8.53	.91	2.86

"The consumption and expense in this table were determined by an independent experiment. The solar lamp, No. 1, was introduced from after experiments.

"The following experiments were instituted by the committee to determine the comparative values of sperm and lard oil, as burned in the Carcel lamp, which, from its construction, requires a better oil for its satisfactory exhibition than ordinary lamps.

"The experiments were conducted in two similar Carcel lamps, and were continued, the first during eight, the second for nine hours.

"The lamp which was used in the first experiment for the sperm, was, in the second, used for the lard oil, and *vice versâ.*

"*Experiment* 1.—The oils used were lard-oil, at 80 cents per gallon, and fall pressed sperm oil, at 90 cents per gallon. The experiment lasted eight hours, and the intensity was examined every half hour.

	11 h. 40 m.		5 h. 05 m.	5 h. 30 m.	6 h.	6 h. 30 m	7 h.	Average.
Sperm oil	1.	no change until 5 o'clock.	1.	1.	1.	1.	1.	1.
Lard oil	.72		.5	.46	.374	.41	.396	.63

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* An after experiment with this lamp demonstrated to the satisfaction of the committee, that its less economical value was owing to its being used with too high a chimney. When tried with a better chimney, it gave the same result, as to economical value, with No. 2.

"Oil consumed, sperm 13.7502 oz.; lard oil, 12.5 oz.; 7,2727 : 4,9253 = 1 : 0,6772.

"*Experiment* 2.—The lamps were reversed; that is, after being emptied and carefully drained, the one which had been used with sperm oil was filled with lard oil, and *vice versâ.*

	11 h.	4 h.	5 h.	h. m. 5 30	6 h.	h. m. 6 30	7 h.	h. m. 7 30	8 h.	Average.	Average of both.
Sperm oil	1.	1.	1.	1.	1.	1.	1.	1.	1.	1.	1.
Lard oil	.86	1.81	1.5	.83	1.	.86	.66	.52	.35	1.09	.86

"Duration of the experiment, nine hours. Oil consumed, sperm 13.5 oz.; lard, 14.5 oz."

From the above two experiments, the following results are deduced,

$$\frac{100}{13,75} : \frac{,63}{12,50} : = 7,2727 : 4,9253 = 1 : 0,6772$$

$$\frac{100}{13,5} : \frac{1,09}{14,5} = 7,4077 : 7,517 = 1 : 1,014,$$

or the relative values of equal weights are on an average 100 to 84½.

"After the conclusion of the experiment, the lamp containing the sperm oil was compared with the gas standard, and gave the following comparative intensity—gas 1., Carcel 1.2; and as it was the lamp marked No. 2, in the Table, it demonstrates the admirable steadiness of these lamps, when burned during considerable periods of time.

"The irregularity and diminution of light shown by the lard oil, and its consequent less economical value, was owing to the fact of the formation of a long and hard crust upon the wick, which finally reduced the light so far as to induce the committee to close the experiment. But further experiments, with lamps of other constructions, would be necessary to enable us to decide upon the general question of the comparative values of lard and sperm oil, as burned in such.

"In consequence of the representation made to the committee that the solar lamp heretofore used in their experiments, (marked No. 2, in the Table,) was not a fair average specimen of that kind of lamp, two new series of experiments were undertaken with a lamp selected by the makers, and in the presence of those interested in both lamps. The following were the results.

"*Experiment* 1.—Oil furnished by the makers of the solar lamp.

	1 h.	h. m. 1 30	2 h.	h. m. 2 30	3 h.	h. m. 3 30	4 h.	h. m. 4 30	5 h.	h. m. 5 30	6 h.	h. m. 6 30	Average.
Carcel lamp	1.	1.	1.	1.	1.	1.	1.	1.	1.	1.	1.	1.	1.
Solar lamp	.85	1.	1.	1.	1.1	1.2	1.06	1.1	1.1	.85	.975	1.1	1.03

"It was evident, from the irregular behavior of the Carcel lamp, that the oil was not favorable to its use.

"*Experiment* 2.—The same lamps were used, with oil furnished by the agent for the Carcel lamp.

	12 h.	h. m. 12 30	1 h.	h. m. 1 30	2 h.	h. m. 2 30	3 h.	h. m. 3 30	4 h.	h. m. 4 30	5 h.	h. m. 5 30	6 h.	Average.	Average of 2 experiments.
Carcel	1.	1.	1.	1.	1.	1.	1.	1.	1.	1.	1.	1.	1.	1.	1.
Solar	.957	.87	.87	1.	1.	.99	.975	.975	.975	975	.96	.96	.97	.95	.99 "

2. *Greenough's Patent Chemical Oil, Gas, and Sperm Oil.*—In 1841, a comparison was made at the Franklin Institute between an Argand gas burner three-fourths of an inch diameter with 18 jets, and Greenough's chemical oil lamp, of which the following is a description.*

"The lamp consists of an inverted bell-shaped reservoir, through the centre of which passes a tube, open at both ends, the upper end of which is about one and a half inches above the reservoir, while the lower extremity has a free access to air, as in the ordinary Argand lamp.

"This tube, of course, passes air-tight through the reservoir. Concentric with this, and surrounding it, is another metallic tube, starting about one-sixteenth of an inch below the upper edge of the wick, and passing down nearly to the bottom of the reservoir, where it terminates. Into the space between these two tubes, the wick, itself secured upon another tube, passes, and rises about three-fourths of an inch above the upper edge of the inner air-tube. In consequence of this arrangement of the wick, the lamp, when filled, may be inverted, or even rolled over the floor, without losing any of its contents.

"The top of the reservoir is made flat, and upon it rests a slightly conical tube, a little more than two inches in height, expanded below into a flat zone, around the circumference of which apertures are provided for the introduction of the air, which is delivered at the upper end of the tube, around the outer circumference of the flame. Along the axis of the inner air-tube passes a metallic stem, which carries, at its upper extremity, a button, or reverberator, of a diameter rather larger than that of the tube upon which the wick is secured. This button may be raised or lowered at pleasure, by means of the stem, and by it the height of the frame is regulated, and perfect combustion insured. The glass chimney is about one foot in height, swelling slightly at the part opposite the flame, and thence gently tapering to its upper extremity.

"By means of the contrivances thus described, a constant and steady access of air is secured to the flame, while the effect of any draught, or sudden current, is in a great measure counteracted. The lamp thus burns steadily, and without any apparent flickering irregularity."

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* See Journal of the Franklin Institute, January, 1842, vol. iii. p. 50, New Series.

A comparison with an Argand gas burner, consuming 4.5 cubic feet of gas per hour, while the Greenough's lamp consumed ⅝ of a pint of the chemical oil, resulted in showing the intensities to be as 702.21 for gas, and 1482.25 for the chemical oil. At $1 per gallon for *chemical oil*, and $3 50 per thousand feet for *gas* (the price then paid), the cost of the former was 0.9 of a cent, and of the latter 1.575 cents, per hour.

Now 702.25 : 1482.25 : : 1 : 2.11, which shows that 2.11 times as much light was given by 0.9 cent's worth of the chemical oil, as by 1.575 cents' worth of gas; consequently, for equal quantities of light, the cost will be for chemical oil 1, and for gas $2.11 \times \frac{1.575}{0.9} =$ 3.692. At $2.50 per 1000 feet for gas, it will be as 1 to 2.617.

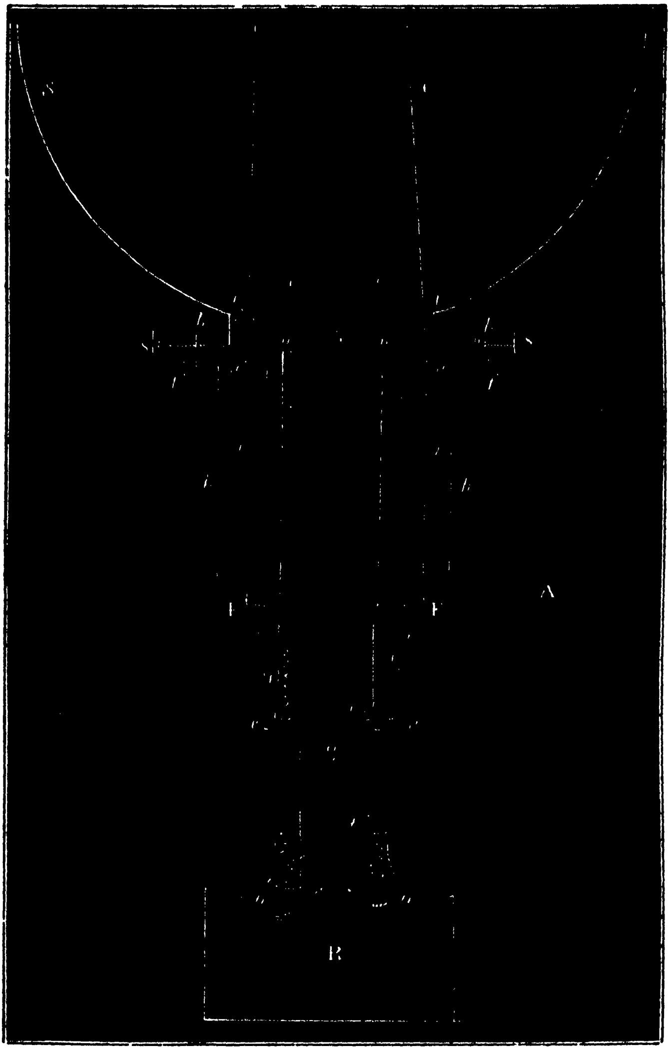
The result proves that the gas then used ought, in order to be on a level in point of cost with the chemical oil, to have been sold at $\frac{3,50}{3,692} =$ 94.8 cents per 1000 cubic feet. At the same time a comparison was made between the Argand chemical lamp of Greenough and "a remarkably fine Argand lamp with an adjustable chimney, by means of which the draught of air could be regulated to every height of wick." This lamp, burning sperm oil, gave an intensity as compared with the chemical lamp as 1 to 2.26.

The lamp of Greenough is adapted to burn any of the camphine class of burning fluids. A comparison between two lamps of the same pattern, one burning Greenough's "chemical oil," and the other Dyott's pine oil, showed the intensities from the former to be ⅛ greater than from the latter.

Cornelius' Lard Lamp.—This lamp does not differ widely from some of the forms of Argand oil lamps, which have adopted the so-called solar principle in the burner. Like all Argand burners, it has an interior and an exterior current of air, and besides the contracted ring over the flame, has a tube attached to the same going down a considerable distance into the lard destined to keep it fluid, and at a high temperature.

The accompanying figure represents, in section, one of the ordinary forms of table lamps on Cornelius' plan. *A* is the body of the lamp containing the lard, *R* is a receptacle for any waste which may find its way through the central tube *t*. The air to supply the central tube finds admission through a ring of holes *o o* in the shoulder of *R*. Outside of *t t* comes the wick bearer *n n*, the upper part of which has the thread of a screw cut to receive the lower end of the wick instead of depending, as in most Argand lamps, on the adhesion of the web to the brass, or on projecting points in the bearer. A spiral groove passes around *t*, serving to elevate and depress the wick as in ordinary Argand burners. *FF* is a frame composed of a tube *e e* with a ring encircling its lower part, from which proceed upwards several strong wires *h h* to a ring of metal *b*, at the top of which are the two screws *s s*, which confine the basis of the chimney *C*. The ring *b* rests on a depressed flanch *ff* of the body of the lamp on which it can revolve horizontally. In the tube *e e* are several holes *i i i i*, through which lard passes to the wick, and along one side is the longitudinal

Fig. 72,.



slot *g g* which receives a projecting pin *p* from the wick-bearer, by which it is caused to revolve whenever *s s* are carried round horizontally. By this means an inwardly projecting pin from the bearer is caused to traverse the dotted spiral groove and elevate or depress the wick *w w*. The ring *b* is itself depressed forming a flanch in which rests the lower edge of the solar cap *c c*, with its tube *l l* going down to *z* in the lard, between the upper part of the tube *e e* and the wires *h h*. On the flattened part of this ring *c c* rests the base of the glass chimney

C, kept in place by the ring *r r* which comes over the outward flanch of glass and is screwed upon *c c* by a thread cut on the outside.

The air passing to the outside of the wick enters a circle of holes as seen at *a a* through the lower edge of the solar cap *c c*.

The circle of metal *c c* is called the deflector, and must be always above the level of the top of the wick. The wicks used in this lamp are about twice as thick as those of ordinary Argand oil lamps, and should be trimmed to about one-eighth of an inch above the burner-tube.

The shades of these lamps are either glass globes, roughened by grinding on the inside, or truncated cones of paper, resting on light wire frames at a suitable distance above the body of the lamp. The latter is preferable for reading, and the former for the general illumination of apartments.

3. *Oil, Rosin-Gas, and Crude Lard.*—In December, 1844, the editor was associated with Messrs. J. C. Cresson and G. W. Smith in an examination and comparison, on behalf of the U. S. Treasury Department, of rosin-gas and oil, as materials for furnishing light to the light houses; and on that occasion a solar lard lamp of the kind above figured was employed as a standard. The report of this investigation will be found at length in Senate Document No. 166, Twenty-eighth Congress, 2d Session. The experiments showed that one of Cornelius' solar lard lamps, burning at the rate of 0.1356 of a pound of crude lard per hour, produced a quantity of light represented by 1.448;—that one of Coston's solar Argand gas burners, consuming 2.707 cubic feet = 0.1046 of a pound, avoirdupois, of rosin-gas per hour of sp. gr. 0.8093, or 43 per cent. superior in density to coal gas, gave a quantity of light represented by 1, while one of the Argand oil lamps of the kind commonly used in the light-houses of the United States, burned per hour 0.069943 of a pound of sperm oil, ($\frac{2}{3}$ summer and $\frac{1}{3}$ winter strained,) and gave a quantity of light represented by 0.4973.

These data afford the means of computing the relative quantities of light from equal weights of materials.

$$\text{Thus: } \frac{1.448}{0.1356} : \frac{1.}{0.1046} : \frac{0.4973}{0.069943} = \overset{\text{Lard.}}{1068} : \overset{\text{Gas.}}{956} : \overset{\text{Oil.}}{711}.$$

The two following tables are computed from the data furnished by the experiments, in which 70 lbs. of rosin produced 486 cubic feet of gas, and from the ascertained cost of the several materials at the time of making the experiments.

In computing the cost of gas and other materials for a given establishment, as a single light-house, it is necessary to take into account not only the *materials* out of which gas is made, but also the interest on the cost of gas apparatus, the annual repairs of apparatus, renewal of retorts, &c., together with the fuel for heating the retorts. Admitting a gas apparatus for a light-house to cost $1500, the interest on its cost will be 24.6 cents per day,—the annual repairs of building at $100 per annum will cost 27.5 cents per day; other repairs, as retorts, grate bars, soapstone, &c., 17.81 cts. per day. Rosin and heating materials on the western waters were computed to cost 25.22 cts. per day, and on the Atlantic 18.66 cts. Hence, the total cost of gas per night on the Atlantic comes to 88.57, and on the western waters to 95.03 cts. The calculations are based on a consumption of 162.4 cubic feet of gas per night of 12 hours.

"For a given amount of light on the Atlantic and Gulf of Mexico, the following comparative table of the expenses of the several materials has been computed. Lard being 5.8 cents per lb., oil 91.6 cents per gallon, rosin 65.8 cents per barrel, of 300 lbs.

Material from which light is obtained.	Number of burners to give the same quantity of light now used at Christiana light-house.	Cost, in cents, per night.	Cost, in dollars, per annum.	Relative cost, that of oil being 100.	Cost, per annum, for the light furnished by 2,671 oil lamps, burning at the rate of that tried by the committee.
Lard . .	3.45	32.49	118.59	31.9	$31,643
Rosin gas .	5.00	88.57	323.28	86.8	86,348
Oil . . .	10.01	101.95	372.12	100.	99,292

"The last column is computed from the number of lamps actually in use in the light-house establishment in 1842.

"At the Cincinnati prices of $1 25 per gallon, the oil, per night, would amount to 1.113×125=139.12 cents; while, at 4.75 cents per pound, the lard would cost 5.602×4.75=26.61 cents per night.

"Table of the cost of light from lard, gas, and oil, at Cincinnati prices. Lard 4.75 cents per lb., oil $1 25 per gallon, rosin $1 50 per barrel.

Material.	Number of burners.	Cost, in cents, per night.	Cost, in dollars, per annum.	Relative cost, that of oil being 100.	Cost, per annum, for the light, equivalent to that of 2,671 oil lamps.	Cost, per annum, at prices on the *Atlantic*, as per preceding table.
Lard . .	3.45	26.61	97.13	19.13	$25.916	$31.643
Rosin-gas	5.00	95.03	346.85	68.31	92.553	86.163
Oil . .	10.01	139.12	507.79	100.00	135.493	99.292

"Hence it appears that at Cincinnati prices of rosin and oil, the relative cost of gas light and oil light is greatly more in favor of the former than on the Atlantic border."]

The superiority of the flat flames over the simple (round) ones, explains an observation which has been made with regard to the Argand burners. When the apertures in it are placed so far apart as to form a circle of distinct jets, the effect is ⅓ weaker (with the same current of gas) than when the jets (of ⅛ to ⅛ inches) unite into a single flat ring.

It must also be remarked, that the action of glass-chimneys upon gas flames, to which they are not so requisite, is quite different from that exerted upon the flame of the wick of a lamp. For the mass of the jet of gas, as it leaves the burner, is in far more correct relation to the air, which at the same time has free access by reason of the hot current, than occurs with the gas produced at the burning margin of the wick.

Gas has little tendency to smoke; Argand wick flames never burn without smoke unless a chimney is used; the latter require a strong draught; with the former, the glasses serve rather to steady the flame than to ensure its perfect combustion. Hence they are always made shorter than the glasses of oil-lamps. When increased to a certain extent, which is soon attained, the draught of air begins to cool the base of the flame, and consequently to mix with the gas. A diminution of the light is thus produced, which depends upon the combustion of too much carbon simultaneously with the hydrogen; hence but little is momentarily separated in the flame. A striking proof of this is yielded by the well-known experiment in which a closed tube of wire-gauze (through which a flame will not ignite) is adapted to a gas-burner by means of a suitable mouth-piece. The same current, which without the case of wire-gauze yields a perfect flame, becomes intimately mixed with air in the interior of the case, and on its exit burns with a pale blue light, because the separation of carbon in the flame has then completely ceased. This phenomenon gives an important hint on the general management of the draught in illumination. It is seen in the same way when the gas is allowed to escape with too great velocity. If this velocity exceeds the proper limits, the flame is extinguished by being cooled too much; when urged to a certain point, the current will not ignite for a distance of several lines from the aperture, but then burns, with a pale flame, because during this time the gas has become mixed with air.

Busson and Rouen have recently, with great ingenuity, converted the cause of this evil into the principle of a new system of illumination with the oil of turpentine, oil of bituminous marl, coal-tar oil, oil of rosin-gas, &c.; in short, with such oils as appear from their composition to be fluid, volatile hydrocarbons. When speaking of Lüdersdorff's lamp, it was shown how, on account of the great amount of carbon which these oils contain, they were best burned when mixed with alcohol, since, alone, they yield an extremely smoky flame. The two inventors, therefore, allow the oils to escape in the form of a jet of vapor, under a pressure varying, according to circumstances, of from 4 to 24 lines (mercury), by which means the above phenomenon is produced, and by the admixture of air the excess of carbon is removed, but without injury to the order of combustion. In this manner brilliant flames, free from soot, are produced.

Comparison of the Various Methods of Illumination with each other.—In the preceding remarks, we have laid down the particulars requisite for judging of the value of the various methods of illumination and their practical details. But the true value is not clearly seen until in its determination the cost is compared with the effect. In the following sketch (by Peclet), the value expended each time is determined;—the price, for example, of a pint of oil (0.9 lb.) being fixed at about 5*d.*; of 1 lb. of tallow candles at 7*d.*, wax candles at 2*s.* 2*d.*, stearine candles at 1*s.* 4*d.*; a pint of illuminating spirit (0.8 lb.) at 8*d.*; of 100 cubic feet of coal-gas at 7*d.*; and lastly, of 100 cubic feet of oil-gas at 2*s.* 3*d.* Of course the price depends upon the locality, consequently the value of the means of illumination is different at each place.

Means of illumination.	Intensity of the light.	Consumption of illuminating material per hour.	Illuminating power, Carcel's-lamp = 100.	Price of 100 grammes of illuminating matters.	Cost of the light per hour in pence.	Cost of a light of the same intensity per hour, in pence.
Tallow candles, 6 to lb.	10.66	8.5	54.04	1.5	0.125	1.169
Wax " 6 "	14.60	9.6	61.57	5	0 461	3.155
Stearine " 5 "	14.40	9.3	66.58	3.2	0.298	2.066
Kitchen-lamp . .	6.65	8.0	33.60	1.4	0.083	1.246
Lamp with flat wick .	12.50	11.0	47.50		0.114	0.912
Astral-lamp . .	31.00	26.7	48.70		0.280	0.893
Sinumbra-lamp . .	56.00	37.1	63.0		0.385	0.687
Lamp with inverted reservoir . .	90.00	43.0	87.8		0.446	0.495
Hydrostatic-lamp .	45.00	17.26	109.2		0.179	0.398
Carcel's-lamp . .	100.00	42.0	100.0		0.435	0.435
Vapor-lamp . .	130.70	151.0	36.2	1.3	2.013	1.207
		C. F.		per 100 C. F.		
Coal-gas . . .	127.00	8.70	—	7.0	0.580	0.456
Oil-gas . . .	127.00	2.43	—	19.2	0.630	0.367

Thus illumination with wax lights is the most expensive; then come stearine candles and the vapor lamp, which are also very expensive, as is well known. However, there are certainly few cases in which the opinion of the public and the scientific estimation of the value differ so materially from each other, as is the case with regard to the means of illumination in general, occasional deceptions, such as occur in Benkler's lamp, not being taken into consideration. Thus, a glance at the last column shows that the kinds of illumination, which, on account of their supposed cheapness, are partly used by the wealthy, and exclusively by the poor, are the very ones which, for the production of a certain degree of brilliancy, are of the greatest expense, provided we exclude articles of luxury, as wax, &c. A given amount of light yielded by tallow candles costs from $\frac{8}{3}$ to twice (according to the price), by the kitchen lamp nearly 3 times, and by the lamp with the flat wick, more than twice as much as when obtained from Carcel's lamp. Moreover, we not unfrequently hear good lamps confounded under the trivial name of great oil-consumers, with such as evidently consume to less advantage. The foundations of these views are more than mere errors, and are derived from different sources. First of all, we must take into consideration the cost of the means of illumination, independent of the expense of the material used to yield the light, because this is greatest in the better kinds of lamps, &c., but small in candles, the kitchen lamp, &c. Thus the poor are frequently subjected to a loss, which although each time exceedingly small, by its daily recurrence, in the end amounts to a considerable sum,—merely because they are unable to procure or lay out, at once, the sum required for good lamps. Another reason is, that lamps (especially the better kinds) cannot be made in every variety of size corresponding to the varying amount of light required by the numerous wants of ordinary life. In this manner one of the most common cases arises, in which a simpler means of illumination, as candles, study-lamps, &c., is preferred, merely because larger and better constructed lamps give far more light than the space and number of persons employed require. Carcel's lamp, when most advantageously yielding light, is an article of luxury for 2 persons, because it gives light enough for 8 or 10, and is, consequently, more expensive than the study lamp, notwithstanding the imperfect consumption of oil in the latter, or than tallow candles, which are so especially adapted to all cases where smaller quantities of light are required. It may be urged to the reproach of art, that little attention has been paid to practically applying the numerous principles of the improvement of illumination to circumstances where small quantities are required.

Lastly, the table shows that gas-light deserves the preference, not merely for its beauty and whiteness, but also for its cheapness. But it is, of course, only applicable when the consumption is sufficient to make up for the expense of the works. However, we have recently learned to combine lighting with other trades, so that, by the diminution of the expense, it also becomes applicable where a smaller quantity only is required, as in a manufactory. Thus retorts are placed in the fire of steam-boilers, and produce the gas without any interference with the ordinary working of the machine, and in this manner the expense of firing is avoided.

[The foregoing remark relative to the *cheapness* of gas applies to European prices of that article. At the enormous rates charged in this country, (2, 3, 4, or 5 dollars per 1000 feet,) it is evident from the above cited American experiments that other materials, especially lard, and the camphine compounds, are far more economical than gas.]

GROUP II.

PROCESSES OF MANUFACTURE CONCERNED IN THE PRODUCTION AND APPLICATION OF THE ALKALIES AND EARTHS.

The more powerful salifiable bases—the hydrated oxides of the light metals, therefore, or the alkalies and earths—are gifted with extraordinary chemical forces, the action of which may as easily be directed towards affecting the decomposition and transmutation of other substances, as to the production of intimate combinations in the formation of salts.

Those of the salifiable bases in question, which are sufficiently plentiful, or which can be manufactured at a sufficiently cheap rate, give rise, therefore, to a series of industrial employments, which are founded chiefly upon this energetic chemical action.

I.—OF THE ALKALIES.

Amongst the different salifiable bases of this class, *soda* and *potash* —known in commerce in the state of carbonates—are the only two used in manufactures, and are consequently of pre-eminent importance. But besides the direct and interesting application of these bodies, certain other branches of manufacture, as the production of sulphuric acid, which have not the production of potash or soda for their direct object, are, nevertheless, so intimately connected with this part of the subject, that a description of them cannot be well passed over here without detriment to the general view of the whole.

SULPHUR.

Native Sulphur.—In volcanic districts, as those of Toscana and Naples, in Italy, and those between Cattolica and Girgenti, on the south coast of Sicily, large masses of native sulphur are found deposited in layers of lime and clay marl. It is more than probable, that this sulphur is formed originally from the gaseous sulphuretted hydrogen, which, mixed with sulphurous acid, aqueous vapor, air, and sulphur, in a finely divided state, issues from all parts of the soil in the form of currents of gas, which are there called *fumaroles*. The glowing lava which simultaneously comes in contact with the ascending current of sulphuretted hydrogen from the interior, and with the atmospheric air, causes a partial combustion of the former to sulphurous acid and water. But the sulphurous acid thus formed is decomposed in contact with the remaining portion of sulphuretted hydrogen into water and sulphur, and this is partly carried up with the current of gas, and partly sublimed in the cracks and crevices of the rocks.

Far the largest proportion of sulphur is brought from those districts; Sicily alone furnishes nearly 1,540,000 cwts. yearly; Naples, and the Solfatara of Tuscany, less; the latter only 20 to 30,000 cwts.

Purification.—It is usual to separate the sulphur, by distillation, from earthy impurities on the spot, which always constitute at least one half of its weight. A furnace is used for this purpose, Fig. 73, which is sufficiently wide to receive two rows of earthen pots *A A*—the vessels for distillation—which are arranged in pairs, somewhat raised above the sole of the furnace, upon the supports *b*, so that the necks of the pots can be conveniently let in to the top of the furnace. Thus the mouths of the pots are free, and having been charged from without, they are closed by the lids *c* cemented on, and the distillation begins. The sulphur vapors pass over by the lateral tubes *a*, to the receivers *B*, where they condense to liquid sulphur, which flows through *o* into a vessel *C* filled with water, and there becomes completely solid.

Fig. 73.

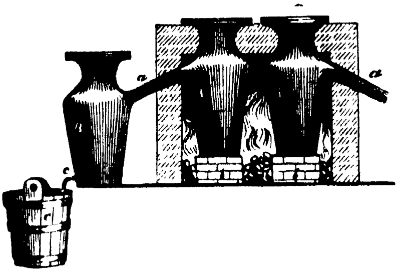
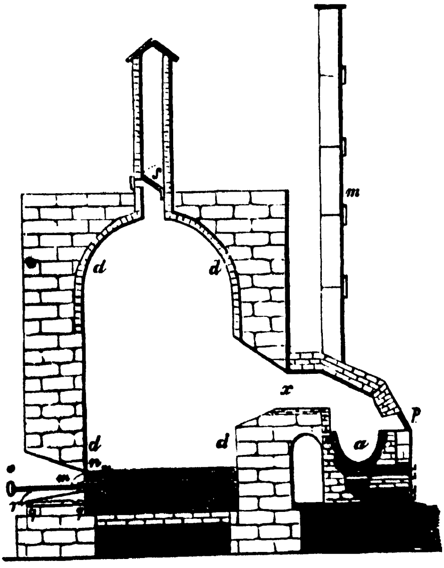


Fig. 74.



Refinery.—The purification effected in the manner described above is so imperfect, that the product, *crude sulphur*, still contains a small per centage of earthy matter, and this makes a second purification, by distillation, necessary; this is generally performed at the sea-ports. A very suitable apparatus, invented in 1815, by a manufacturer, Michel, at Marseilles, and now everywhere used, Fig. 74, affords the double advantage of producing consecutively, without interruption, *flowers of sulphur*, (pulverulent sulphur,) and *sticks of sulphur*.

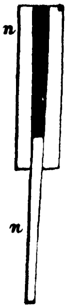
The iron vessel *a*, which is large enough to contain a charge of from 10 to 12 cwts. of sulphur, is walled into a furnace, the interior of which has no other outlet than the arched channel *x*, leading to the chamber *d d d*, which has a capacity of from 6 to 7000 cubic feet. The boiler and the chamber together form, therefore, a retort and receiver upon a very large scale. The firing for the boiler *f* is maintained by a draught through the ash-pit *c*, by means of the chimney *m*. At *p* there is a door for charging and emptying the boiler.

The chamber itself has a separate outlet, in which a valve *s*, opening outwards, is situated.

Soon after the heat is applied, and the sulphur has become liquid, (at a temperature of about 150°=302° F.), it catches fire;* but this is extinguished of itself, as soon as the oxygen of the air in the chamber is converted into sulphurous acid. When the boiler has attained a temperature above 316° (633° F.), the mass begins to boil, and give out vapors, which pass over to the chamber through *x*, and condense against the cold walls. As long as the temperature of the walls is below the fusing point of sulphur, 108°, (258° F.,) the sulphur can only condense in the solid form. The sulphur, therefore, forms small, microscopical crystals, and these deposit in the form of a yellow dust (flowers of sulphur). The constant condensation of the flowers of sulphur heats, however, the walls of the chamber, and they acquire, at length, a temperature of 108° (258° F.) When this period arrives, on the third day, liquid sulphur only can be present in the chamber. If the production of flowers of sulphur is to be continued, the operation must be stopped during the night, that the chamber may have time to cool. If not, the flowers of sulphur are removed from the chamber by a door for the purpose, and the heat being kept up, sulphur continues to distil over, and collects at the bottom in the fluid state, as is represented in the figure. This second period has also its limit, like the first; for as soon as the walls of the chamber have attained the temperature of 316° (601° F.), which occurs on the seventh day, the condensation diminishes so rapidly, that a stop must be put to the process.

The sulphur can be drawn off through an aperture *n n*, made at a few inches above the floor of the chamber. It is only requisite to push in the stopper *h*, which can be made to assume any position by means of the spring *m* and its handle *o*. The sulphur flows through the gutter *r*, which is kept hot as far as *q* by charcoal, into the wooden somewhat conically bored moulds, Fig. 75. The solidified sticks of sulphur can be easily removed from the moulds by the pestle *n*.

Fig. 75.



The production of sulphur from the bisulphuret of iron (Fe S_2), a mineral disseminated throughout all formations, as *iron pyrites*, and *cockscomb pyrites*, depends upon the

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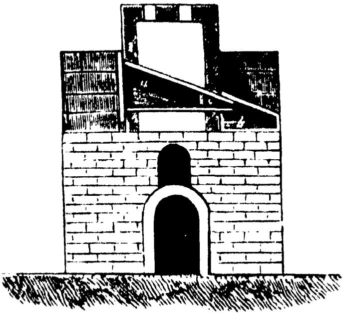
* Violent explosions are not uncommon.

property possessed by that mineral of being decomposed at a red heat into sulphur, and a compound of the same constitution as magnetic pyrites, $7\,FeS_2 = 6\,FeS, FeS_2 + 6\,S$. The mineral thus parts with 23 per cent., or $\frac{3}{7}$ of its sulphur.

In Silesia, Bohemia, and Saxony, the decomposition of iron pyrites is mostly carried on in conical clay tubes *a*, which are placed in rows, from twelve to twenty-four, in a gallery furnace (Galeerenofen), (Fig. 76 is a side view). Both the wide and narrow ends of the tubes project out of the sides of the furnace; the former for the purpose of charging the tubes with broken pieces of iron pyrites, from 70 to 100 lbs. at once; the other to open into an iron receiver *b*, filled with water; the narrow mouth is stopped by a perforated plate of clay, that the ore may not fall into the water (from the inclined position of the tubes *c*). Not more than $\frac{1}{4}$ of the sulphur contained in the pyrites is actually obtained; as in attempting to expel all the sulphur present, the residue would melt, and the tubes would require to be broken up each time in order to remove it for future operations. These consist in roasting it, when, by the absorption of oxygen, green vitriol (sulphate of iron) is produced.

Fig. 76.



The crude product, called *drop-sulphur*, requires to be subjected to a second distillation, on account of the impurities which it contains, more particularly to free it from arsenic (derived from arsenical pyrites = sulphuret of arsenic + sulphuret of iron, which nearly always accompanies iron pyrites), and this is effected in cast-iron retorts, in the purifying furnace. Sometimes, instead of employing the furnace, the pyrites is roasted in heaps or "meiler," in a square brickwork space, over a layer of wood. By covering the heap with earth, the sulphur vapors can be forced to pass through a lateral tube into the condensing chamber. In uncovered heaps of this kind, deep grooves are often made in the upper colder parts, in which a portion of the expelled sulphur collects.

The purified sulphur still contains some selenium, arsenic, and bituminous particles.

Here and there copper pyrites (sulphuret of copper) is made use of in the same manner; but the sulphur obtained from pyrites is always the smaller portion of that which is brought into commerce, by far the larger portion coming from Sicily.

Pyrites is now much used instead of native sulphur for burning in the sulphuric acid chambers, and the manner in which it is used will be described under sulphuric acid.

Within the last few years two patents have been enrolled for obtaining sulphur from what have hitherto been thrown away as waste products of manufacture. The first plan was patented by Mr. Newton, and applies to the sulphurous acid evolved during roasting from the sulphurets of iron, copper, lead or zinc; the second is the invention of Mr. Lee who converts the sulphuretted hydrogen gas obtained by an acid from alkali-makers' waste, or from the sulphurets of potassium, sodium, or calcium, first into sulphurous acid by burning; and this sulphurous acid is then resolved into solid sulphur. The mode of converting the sulphurous acid into solid sulphur is alike applicable, from whatever source the acid may have been obtained in the first instance. The following description of the process and apparatus, which have been partially carried out in Ireland, where it is so important an object to reduce the freight of the sulphur hitherto conveyed to this country in the form of pyrites, is taken from the Repertory of Arts, vol. v. p. 20, 1845, and from a memorandum drawn up by Mr. Lee himself.

The sulphurous acid, in whatever manner it may be evolved, is decomposed by passing through a fire of common coal or coke, which fire maintains at a red heat a flue or chimney filled with bricks in such a manner that interstices are left through which the products of combustion are carried.

These products consist of some undecomposed *sulphurous acid gas*, some *sulphuret of carbon*, *sulphuretted hydrogen*, *carbonic oxide*, *and carbonic acid gases* with *vapor of sulphur*. In passing through the heated bricks in the flue or chimney, these gaseous compounds react upon each other so as to produce solid sulphur. The sulphurets of carbon and hydrogen are decomposed by the carbonic acid gas and undecomposed sulphurous acid gas, producing sulphur and aqueous vapor, and the carbonic oxide gas formed at the same time, as well as that produced by the passage of the sulphurous acid gas through the fire, decomposes a further portion of the sulphurous acid gas in its passage through the heated bricks. Whenever a deficiency of sulphurous acid gas occurs in this part of the apparatus, which is easily detected by the escape of sulphuret of hydrogen or carbon, it is supplied as wanted. Thus the process is conducted quite as easily as the manufacture of sulphuric acid. It is absolutely necessary that the bricks should be at a full red heat. The sulphur vapor is cooled down to a temperature of 350° F., and conducted through an apparatus (similar to the muriatic acid condensers to be described hereafter), in which it is exposed to an extensive heated surface, on which it liquefies and filters down to a pan at the bottom from which it is run off. That part of the sulphur which escapes liquefaction is collected in powder in an apparatus constructed on the principle of the chamber for collecting lamp-black.

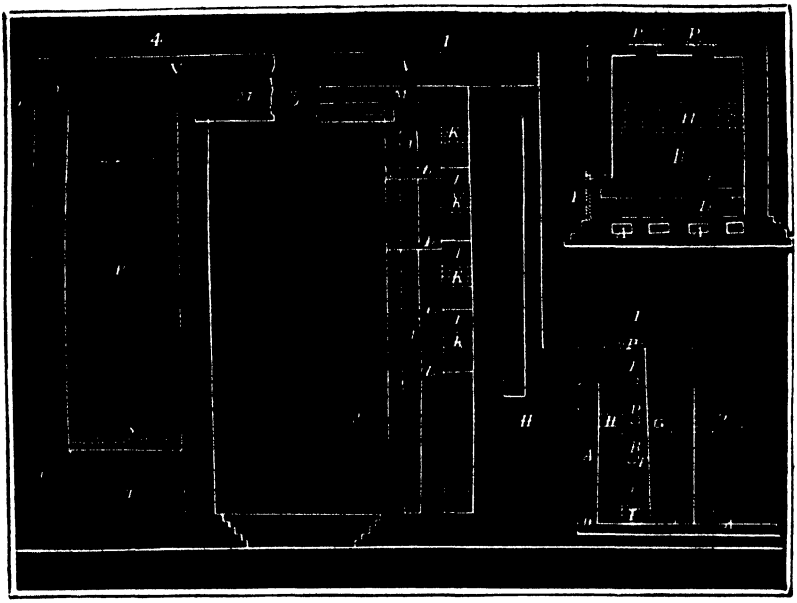
The following drawings represent that part of the apparatus by which the sulphurous acid is decomposed.

Fig. 77, 1, is a longitudinal section.

Fig. 77, 2, is a transverse section of 1, through the dotted lines I, I.

Fig. 77, 3, is a sectional plan through the dotted lines 2, 2, Fig. 77, 1.

Fig. 77.



A is the flue through which the sulphurous gas passes, when it is generated to the fire-place *B*; *C*, the grate bars; *D*, the ash pit; *E*, the door closing the ash-pit; *F F F*, are holes closed by fire bricks, and through which the fire is stirred; *G*, is the fire-brick grating communicating with the flue *A*, through which the sulphurous acid gas enters the fire; *H H'*, are the flues carrying away the sulphur vapor and gaseous matter from the fire into the chimney or flue *I*, and constructed on the principle and similar to the grating *G*. The chimney or flue *I* is constructed of common brick or stone, cased inside with fire-brick, in the interior of the walls, which are of great thickness. *J* is a space filled with ground coke or furnace ashes, or any other suitable material that is a bad conductor of heat. *K K K* are brick arches or fire piles thrown across the chimney or flue *I*, and placed about two inches apart, upon which are piled fire-bricks, or fragments of fire-brick constructed in a way to form tortuous passages for the sulphur vapor and gaseous matter to traverse; they are placed in the chimney at intervals of 18 to 24 inches. *L L L* are openings into the chimney, through which to ascertain its temperature, and are closed by an iron or brick stopper when not used; *M* is the flue carrying away the sulphur vapor and gaseous matter to the condenser hereafter described; *N* is the door at the bottom of the chimney for cleaning the chimney out; *o o o o* are doors for closing the brick grating *G*, in which are registers for admitting atmospheric air when necessary; *P P* are doors through which the coke is supplied to the fire-place *B*; *Q* is a damper for regulating the supply of sulphurous acid gas to the flue *A'*.

Figs. 77 and 78, 4 and 5, represent the apparatus in which the sulphur vapor, or part of it, is condensed and liquefied, and *M* is the flue in connection with the same flue *M*, Fig. 78, 1.

Fig. 78.

Fig. 78, 4, is a sectional elevation.

Fig. 78, 5, is a horizontal section through the dotted lines 3, 3, Fig. 78, 4.

The sulphur vapor and gaseous matter enter that part of the apparatus shown at Fig. 77, 4, and which is called the condenser, by the flue *M*. *R* is the chamber or body of this condenser, filled with broken glass, bricks, stone, or coke, so as to expose extensive surfaces for condensing the sulphur vapor, on the principle of the condenser so extensively used by the alkali makers for condensing muriatic acid gas; *S* is an iron grating to support the materials with which the condenser is filled, and through which the liquefied sulphur runs into the iron pan *T*, placed underneath to receive it; the gaseous matter and uncondensed sulphur vapor also pass through this grating, and are carried out of the condenser by the flue *U*, into an apparatus constructed of brick or stone, and on the principle of the chambers used in the manufacture of lamp-black, and in which the remainder of the sulphur is collected in the form of powder or flour brimstone: a draught is produced by connecting with this part of the apparatus last described a chamber of sufficient capacity to command any draught that may be required.

The following is an estimate of nett profit realized by this process.

	£	*s*	*d*
100 Tons of Pyrites at 13*s*., the present price at the mine averaging 38 to 40 per cent. of sulphur, and 2 per cent. of copper	65	0	0
Expense of 60 tons of coal at 12*s*.	36	0	0

Carriage of sulphur to place of shipment and freight to market		36	0	0
Labor		20	0	0
		157	0	0
Produce 30 tons of sulphur at £5 10*s*.	£165			
2 tons of copper at £80	160			
Gross value	325			
Deduct expenses, &c.	157			
Nett profit	168]			

OIL OF VITRIOL (SULPHURIC ACID).

Sulphuric acid, as an article of manufacture, is either produced directly from sulphur (English oil of vitriol), or is separated, ready formed, from green vitriol (Saxon, fuming or Nordhausen oil of vitriol).

English Sulphuric Acid.—Theoretical Process.—Sulphur, in order to be converted into sulphuric acid, must take up 1.49 parts of oxygen = 3 equivs. When it is burnt in the air, which is easily effected at a temperature of 300° C. (572° F.), it combines with only 2 equivs. of oxygen = 0.99 parts; the compound formed, sulphurous acid ($S O_2$), must therefore assume another equiv. = 0.497 parts in order to become sulphuric acid. Sulphurous acid possesses the property, when in contact with moist air, of gradually combining with this additional portion of oxygen, and by the agency of platinum sponge, which then exerts the same power as in the platinum lamp, this combination rapidly ensues; but this property of platinum sponge has not yet been turned to account on a large scale, partly on account of the tediousness of the process, and partly from the costliness of platinum. A body is, therefore, employed, which combines small cost, with the property of purveying oxygen from the air with rapidity, and on a large scale: such a body is the *deutoxide of nitrogen, or nitric oxide* ($N O_2$). This gas, when brought into contact with the air, becomes converted by the assumption of 2 equivs. of oxygen into a red vapor, into *peroxide of nitrogen*, ($N O_4$), which, (in the presence of moisture and sulphuric acid,) parts completely with that half of its oxygen, which it had taken from the air to the sulphurous acid, so that 1 equiv. of peroxide of nitrogen, and 2 equivs. of sulphurous acid become converted by this exchange into 2 equivs. of sulphuric acid, and the original 1 equiv .of nitric oxide. For $N O_4$, or $N O_2 + O_2$ and $2 S O_2 = 2 S O_3$ and $N O_2$. This latter, therefore, only acts as a purveyor of oxygen, and is re-obtained entire at the completion of the process. It might, therefore, be used a second and a third time, and indeed with a given quantity of nitric oxide an unlimited amount of sulphurous acid might be oxidized to sulphuric acid, if it were not necessary practically to employ air instead of pure oxygen, which contains 75½ per cent. by weight, and 79 per cent. by volume of nitrogen.

As often, therefore, as 100 lbs. of sulphur are burnt, and the 299 lbs. of sulphurous acid produced are oxidized to sulphuric acid, 49.7 lbs. of oxygen enter into combination, and 648 lbs. = 4074 cubic feet (at 0° C.) of nitrogen are separated, and this must be removed from the chambers where the acid is produced, in order to make room for a fresh mixture of gases, which cannot be done without removing at the same time the nitric oxide with which it is mixed; a separation of the two gases from each other being impracticable. The manufacturer is consequently obliged always to sacrifice the valuable nitric oxide, in order to get rid of the useless and impeding nitrogen; and hence he is forced to reproduce it in the same quantity, simply on account of this mechanical difficulty.

The manufacturing process for sulphuric acid is older than the theoretical explanation of what actually occurs. Although generally known before the end of the 17th century, the manufacturing process takes date from the invention of the *sulphuric acid chambers*, the first of which was erected in 1774, by Roebuck, of Birmingham. Besides *air* and *water* (vapor), therefore, a supply of *sulphurous acid* and *nitric oxide* must constantly be kept up in them.

The sulphurous acid was nearly always obtained in the first instance by the combustion of sulphur in furnaces constructed for the purpose; and crude sulphur from Sicily was employed without being submitted to further purification, until, in the year 1841, the disputed sulphur question between the English government and Naples, notwithstanding its peaceable adjustment by the mediation of France, raised the price of native sulphur to such an extent, that manufacturers were forced to seek other sources of supply. Success was soon the reward of English industry; and the enormous stock of iron and copper pyrites which occurs in Ireland and the coal districts, was worked for sulphurous acid.

This pyrites is frequently roasted in perpendicular furnaces 7 feet high without any combustible matter, the pyrites itself being combustible, and giving out sufficient heat to decompose and ignite the subsequent charges. Whilst fresh matter is added above, the calcined stones are removed from below, so that there is no interruption to the roasting process. From time to time the mass is stirred about through doors at the sides to cause it to sink more rapidly. The pyrites in burning affords sulphurous acid, and leaves a residue of basic sulphate of iron $(Fe_2 O_3, SO_3)$ mixed with the matrix of the vein, so that in all, the residue contains about 3 per cent. sulphuric acid. From the purer varieties of pyrites this residue can be used for preparing sulphate of soda (in the soda works), or for fuming sulphuric acid.*

Horizontal furnaces are also employed for roasting, like that in Fig. 79. *A* is the door for introducing the ore, *a* the principal grate; whatever falls unburnt through this, collects in the second grate *b*,

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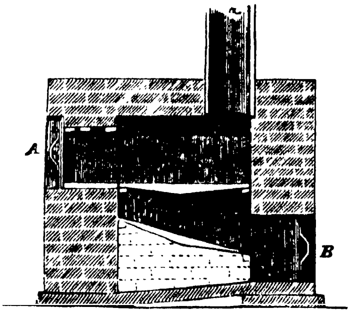
* Pyrites is most completely decomposed into oxide of iron and sulphuretted hydrogen, by conducting a current of aqueous vapor over it at a red heat, a process which has been put in practice in England.

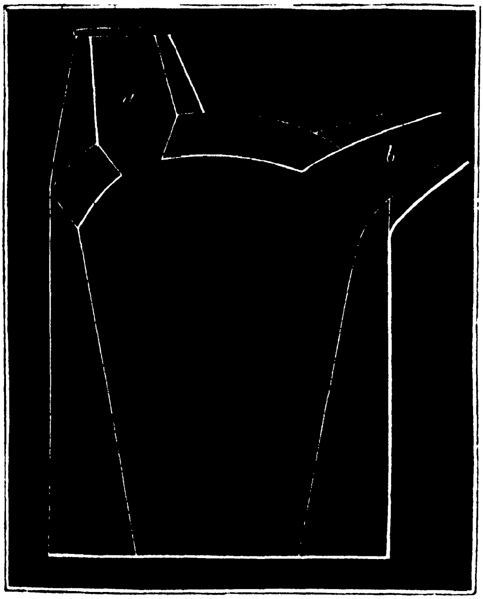
and is removed afterwards through *B*. The draught is regulated by *B* and *A*, whilst the sulphurous acid is conducted by *x* to the chamber. Since Sicilian sulphur has been again imported, the use of pyrites has lost much of its interest.

g. 79.



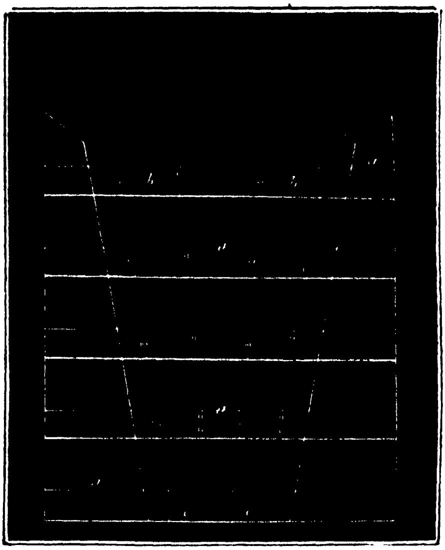
[The present plan of using the pyrites consists of a square furnace strongly bound round with iron somewhat similar to the Figs. 83 and 84, about 10 feet high and 4 feet wide inside at the top, and 3 feet at the bottom. The opposite sides of the furnace are similarly constructed. Thus Fig. 80 is perfectly plain; the opening *a* is only temporary to allow the gases of the coke or fuel which is burnt in the furnace at first to bring it up to a sufficient heat to pass off into the atmosphere; the other opening *b* is a flue about 12 inches square for the passage of the sulphurous acid to the chamber. In this flue the ordinary nitre cups are placed. Fig. 81 represents the two other sides where *a a a* show the iron straps for strengthening the furnaces, *b b* are the doors for charging the furnace with the pyrites broken into small pieces; the doors lower down are intended to allow the workman to keep the materials free and as open as possible for

Fig. 80.



the passage of the air and gas; *c c* are the openings through which the residue is drawn out.

Fig. 81.



The residue, after dissolving out crude soda, tank waste, or refuse from black balls, which contains amongst other substances, sulphuret of calcium, has also recently been turned to account; it is decomposed by carbonic or muriatic acids, and the sulphuretted hydrogen collected in gas-holders. From these it can be conveyed to the chambers where, when ignited, it gives rise to sulphurous acid and water. This process, the invention of Mr. Gossage, has not come into general use, from the difficulty of managing the gas, and the fall in the price of sulphur.]

For the production of nitric oxide, the old plan was to ignite a mixture of 8 parts sulphur, with 1 of saltpetre, when sulphurous acid and nitric oxide were produced, and sulphate of potash remained. The former results from the excess of sulphur, as in all probability $KO, NO_5 + S = KO, SO_3 + NO_2$. Instead of this process, a trial was made (in France) to use the vapors which are evolved when treacle is heated with nitric acid; a mixture, therefore, of nitric oxide with peroxide of nitrogen. Oxalic acid is here obtained as a secondary product; it, however, does not realize a sufficiently high price, which was anticipated, to compensate for the expense of the process. It has, therefore, been found generally more advantageous to employ nitric acid at once, which is evolved from cubic or common nitre, *i. e.* nitrate of soda or potash, by means of sulphuric acid, and the heat of the sulphur furnace. Nitric acid, namely, forms with sulphurous acid, nitric oxide, and sulphuric acid, for $NO_5 + 3\ SO_2 = NO_2 + 3\ SO_3$. When fluid nitric acid is exposed in saucers to the action of sulphurous acid in the chambers, the result is precisely the same. In fact, the apparatus for sulphuric acid, Fig. 85, is calculated for this mode of procedure. A mean produce of 150 cwts. is obtained in twenty-four hours, and this can be increased to 200 cwts. The production of this mass of acid is effected in five large rooms, or *chambers*,* made of stout sheet-lead, *C*, *E*, *G*, *I*, and *M*, the first of which is 13 ft. wide, 20.8 ft. high, and 24 ft. long, with a capacity of 6490 cubic feet; the second of the same length and width and 20 ft. high, 6240 cubic feet in capacity; the third, and largest is 100 ft. long, 26 ft. high, and 52 ft. wide, and its capacity is 135,200 cubic feet; the fourth is 22 ft. wide, 25.2 ft. high, and 28 feet long, with a capacity of 15,523 cubic feet; lastly, the fifth is of the same length and width, and 24 ft. high, having a capacity of 14,784 cubic feet; together, therefore, they have a capacity of 178,000 cubic feet. As leaden walls of these dimensions, on account of the weight and flexibility of the metal, are incapable of supporting themselves, the chambers are enclosed on all sides by a scaffolding of beams, and below with a coating of boards (see Fig. 82), so that, in case of repairs being necessary, they are accessible from underneath. The joints of the different sheets of lead, on account of their immense length, are preserved air-tight with the greatest difficulty. Common solder (an alloy of tin and lead) would soon be destroyed; although Richmont has recently invented a plan of connecting sheet-lead without solder, namely, with simple lead, and the use of the oxyhydrogen blow-pipe; yet this is found to require too much time, and in preference the sheets are turned over each other at the margin, and covered with white-lead paint. *A* is a furnace for burning crude sulphur to sulphurous acid; two of these are required for supplying the chambers; their height is twelve ft., and the surface of the sole comprises 144 square feet. The double case of the furnace leaves room for cold air to pass between, which serves to regulate the heat. The draught of the furnace, a most important point, because upon it depends not only the supply of the furnace with air, but also the supply afforded to the chamber itself, is safely managed by a damper at the door of the furnace, and the chimney *O*, with its regulator *P*. This latter is a horizontal cross plate, or partition, let into the drum, with nineteen round apertures, which together are equal to the section of the chimney. Of these, any number can be closed by means of leaden covers introduced through the door *g*.

From the furnace *A* the gases—a mixture of sulphurous acid, nitrogen, and unchanged atmospheric air—pass through the large cast-iron tube *B*, which is 4 feet wide, and enters the chamber *C* at the top, through a leaden collar. The height of this aperture above the sole of the working space of the furnace is a point of some im-

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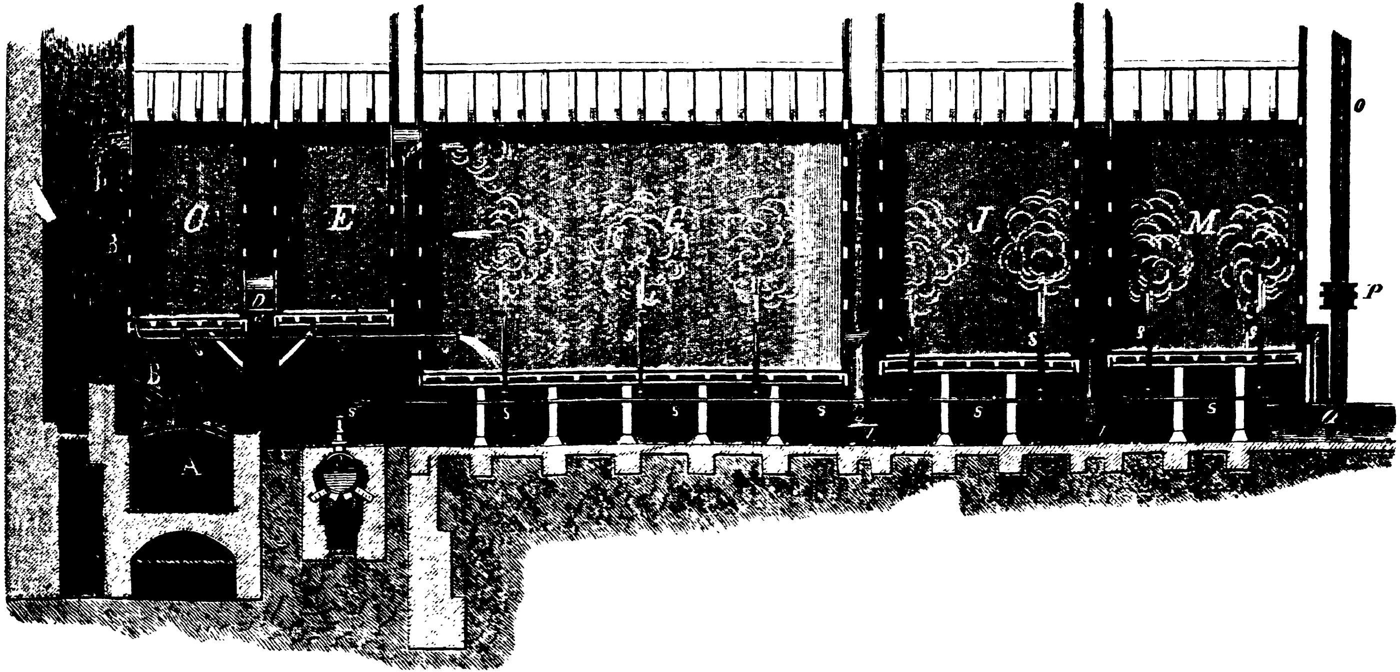
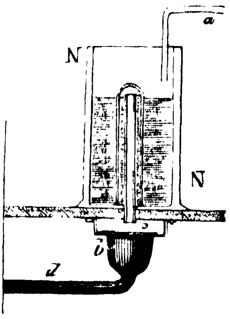
* The chambers in reality do not stand in a line, one by the side of the other, but, to economize space, they are arranged in pairs one behind the other, namely *F* behind *C*, and *I* behind *M*, so that the front ones in the drawing would in reality not be seen. Tennant's manufactory at St. Rollox, Glasgow, produces yearly 160,000 cwts. of acid in 20 chambers, each of which is 70 ft. long, and 38,000 cubic feet in capacity.

Fig. 82.



portance, and to produce a good draught it should be about 30 ft. high. From the first chamber, the gases pass on to the second *E*, through the short tube *D*, there to decompose (according to the method here given as an example) the nitric acid which is exposed in flat glass saucers.* It is found beneficial in practice to allow the concentrated nitric acid to flow in at intervals (about 600 lbs. in twenty-four hours) of about half an hour each, therefore each time 12 lbs. The nitric acid is caused to flow from a series of glass carboys, connected together to form one large reservoir, through the narrow tube *a*, into the vessel *N*, Fig. 83, (outside the chamber,) in which the bell-shaped vessel *b* with the wide exit tube *c* together form a syphon. The width of *a* is calculated to let just 12 lbs. of nitric acid flow out in half an hour, and this will then stand at the level *n*; at this height *c* fills of itself, and in a few moments empties the vessel into the tube *d*, from whence the acid is conveyed to the saucers, to flow off on to the floor of the chamber *E*, when it has become sufficiently weak. The sheet-lead is there protected by a layer of dilute sulphuric acid. The sulphuric acid here formed, which contains a large proportion of nitric acid, is made to flow through the small tube *u* back into the first lower chamber *C*, and this is done with no other object than to subject the acid a second time to the current of sulphurous acid, by which the nitric acid is decomposed. In the two first chambers a portion of sulphuric acid is formed, but only in a subordinate manner, whilst the nitric acid is converted into nitric oxide, which, mixed with the gases from the furnace, enters through *F* the large chamber *G*, the actual seat of the sulphuric acid formation, simultaneously with aqueous vapor, and the process is completed in the chambers *I* and *M*; the last portions of sulphurous acid being there converted into sulphuric acid which is condensed. A boiler *R* supplies a current of vapor, which by the pipe *s* is disseminated in the back chambers *G*, *I* and *M*. The chambers *I* and *M* receive the gases through the tubes *I H* and *L K*, 2½ feet in diameter, which are furnished with the receivers *r* for collecting whatever may condense. All the sulphuric acid that is formed in the two front chambers *C* and *E* flows from *C* through the tubes *g g* into the middle chamber *G*, which is consequently placed lower than all the rest. To keep the fluid on the floor of this chamber in constant agitation, and in more intimate contact with the gases, the fluid acid from *g* is allowed to fall from a height of 6 ft. The walls of the chamber *G*—as may be seen in Fig. 84, which shows at the same time the mode of attaching the walls to the scaffolding—dip into sulphuric acid on the detached floor of *G*, a contrivance which tends to simplify the operations.

Fig. 83.



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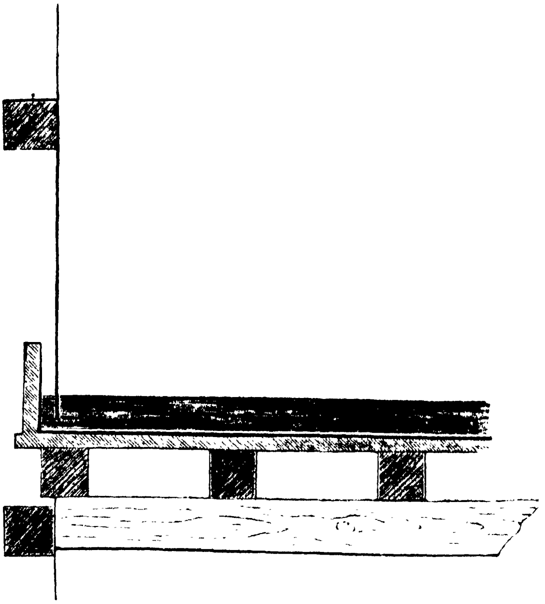
* When the nitric acid is formed in the furnace *A* from saltpetre, the first chambers and the saucers are useless.

At the most important spot *i* in the chamber *G*, the steam-pipe enters in the middle of the current of gas, that a complete intermixture may take place.* Below the exit tube *O*, is a so-called refrigerator, for instance, a vessel *Q* in which the escaping gases must pass over two layers of water, and deposit any residual portions of sulphuric acid.

Fig. 84.



Instead of using several chambers, connected with each other in the manner described, it has sometimes been found preferable to separate (as in Fig. 85) one roomy and very long chamber by partitions into a number of compartments, and in such a manner that the gases by ascending and descending are forced to mix intimately with each other. Although by this means a saving of lead for the walls is effected, yet the sulphurous acid can scarcely undergo so complete a conversion.

Fig. 85.

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* Perhaps the gases would become more intimately mixed, if they were always allowed to enter at the bottom of the chambers, for (their temperature being much higher than the enclosed air) they have a tendency to collect at the top. This is more particularly the case in the apparatus Fig. 85.

From this description, it appears that the production of sulphuric acid in these chambers may be a continuous process. This was by no means the case upon the old method which was consequently defective. The new method was introduced in the year 1774. On the old plan, no constant current of air was supplied to the chamber, but a mixture of sulphur with twenty or more per cent. of saltpetre was burnt—originally upon a kind of carriage, which was pushed into the chamber through a door—and steam was admitted at the same time. As soon as it was thought that the acid originally on the floor of the chamber had absorbed the newly-formed portion, the residual gas was allowed to escape by the chimney, and the chamber again filled with air, for a fresh operation. In this manner only so much sulphuric acid could be formed as would correspond with the quantity of air (oxygen) in the chamber, and this would naturally depend upon the capacity of the latter. All the sulphurous acid produced in excess, as well as in the opposite case, a quantity of nitric oxide which had as yet taken no part in the production of acid, was therefore lost, each time that fresh air was admitted into the chamber.

Within the last few years, two very important improvements have been introduced in the manufacture of sulphuric acid from sulphurous acid, which are both alike applicable to any process wherein this latter acid has to be dealt with.

The arrangement of a series of chambers is an important point, however, which we will describe before proceeding to these processes. Figs. 86 and 87 show the ground plan of the arrangement adopted in one of the largest alkali works in England, where the chambers 4, 2, and 3 are connected together by leaden pipes *A A A*, and 1, 5 and 6 by *B B B*. The burners *D* are large flat ovens constructed of iron, and a thin sheet of air is allowed to enter below the door, which is kept at a proper elevation by screws. Another arrangement, Fig. 88, consists of a series of chambers all of the same size, placed alongside of each other, but instead of being connected by lead pipes or flues at the end, the following plan is adopted. The chambers 1, 2, 3, 4, &c., are attached together by leaden passages the full size of the chambers themselves, constructed in the same way as the chamber.

No curtain is employed in these chambers; and the use of this plan, to mix the gases, is now generally abandoned.

The first of the improvements alluded to is that patented by Mr. Bell, consisting (Fig. 89) of the above series of chambers, to the last of which a number of coke columns are attached. *A* is the section and *B* the ground plan of this arrangement. *C* is the last chamber, and *D D D D* are the coke columns. At the end of the last column *E*, a steam jet similar to that described further on, is attached, and this jet effects the draught through the whole range of burners, chambers and columns. The columns are four feet square, and the total length of coke piling may be 200 feet or more. Mr. Bell recommends 120 feet. In every other respect, this process is similar to that already

Fig. 86.

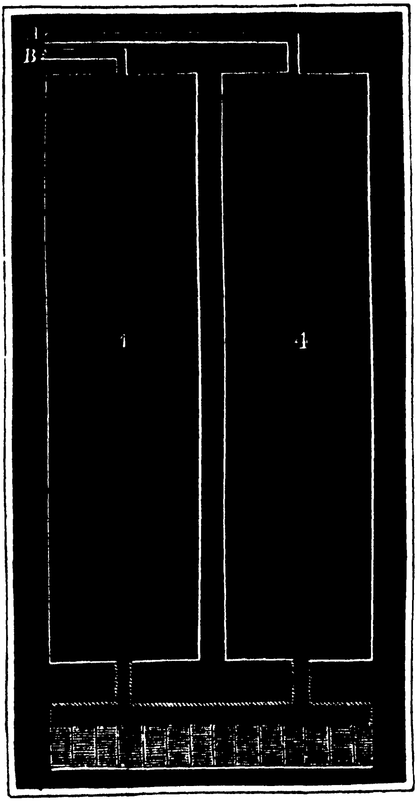


Fig. 87.

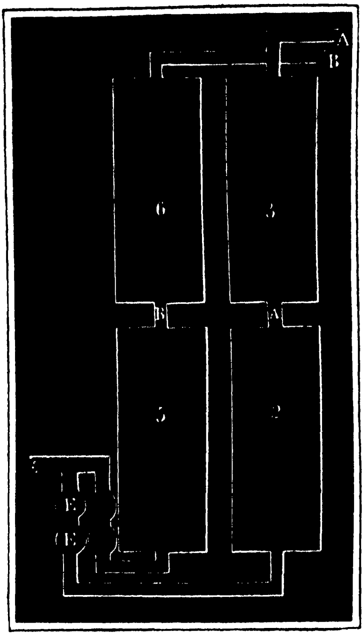
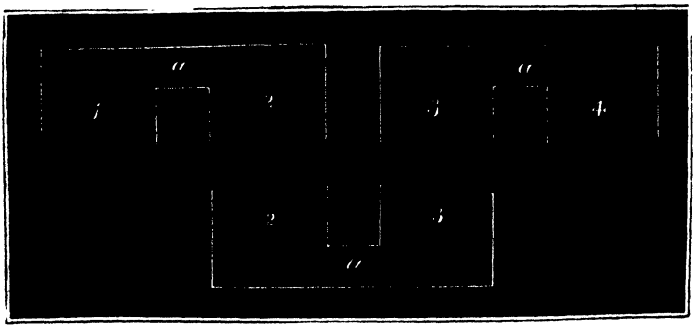


Fig. 88.



in practice. The advantages held out by this plan are the perfect control of the draught under all circumstances, the increased quantity of sulphur which may be profitably burnt in the same time in the same chamber room, and the saving of nitrate. The condensing power of the coke column is very great, and enables the manufacturer to dispense with chamber room, or increase his make, while the stream of acid which runs from the condensers, carries back to the chambers all nitrous gases which had escaped.

The other improvement is that proposed and carried out by Gay-Lussac, which consists in attaching three coke columns *C*, *E E* in Figs. 87 and 91 to a series of chambers. In Fig. 90 *D* represents the flat iron burner with a door at *A* for the charging of the sulphur, and another at *B* for the insertion of the nitre pots, where the heat is not so high as to destroy the nitrous acid compounds, *F* the flue leading to the coke column *C*, whence the gases enter the chamber *G*, and previously ascend and descend the colums *E E*, Fig. 91, before making their final escape to the chimney. The cistern *h* is filled with sulphuric acid of 1.75 to 1.80 specific gravity.

The chamber is worked with an excess of nitrous acid, and a good draught. The waste gases of the chamber in passing through the columns *E E* meet with streams of sulphuric acid from the cistern *h*, which absorb all the escaping nitrous acid; and this acid thus charged with nitrous acid, is forced up into another cistern above the column *C*, by a peculiar contrivance; it then descends the column *C* when the sulphurous acid of the burners completely *denitrate* the sulphuric acid, and where, in fact, a large quantity of sulphuric acid is made. The saving of nitrate by this plan is very great, indeed; it has been found that as much as forty tons of sulphur can be burnt per week in these chambers with no larger consumption of nitrate than three per cent., and an excellent produce of sulphuric acid maintained at the same time. The following is the manner in which the acid is supplied to the cistern above the coke columns, Fig. 92.]

Fig. 89.

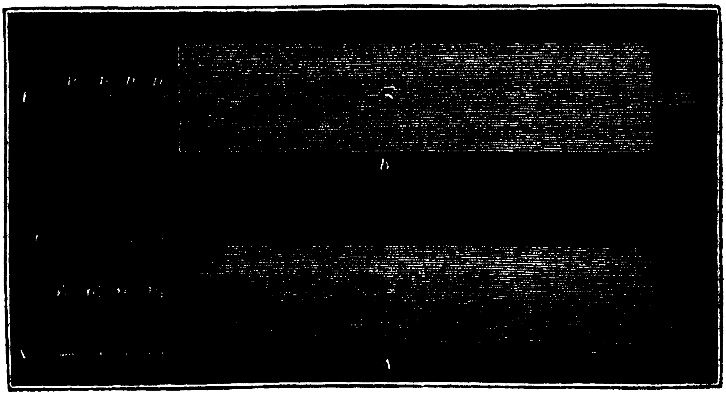


Fig. 90.

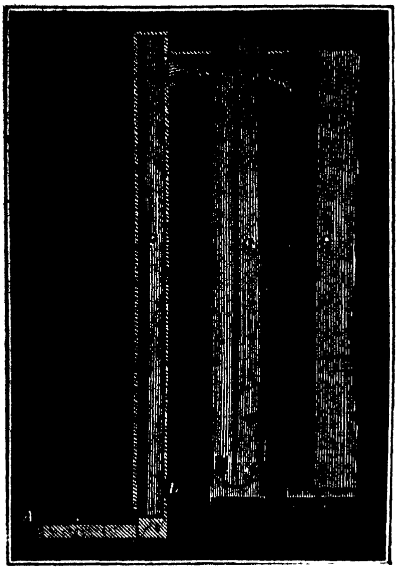
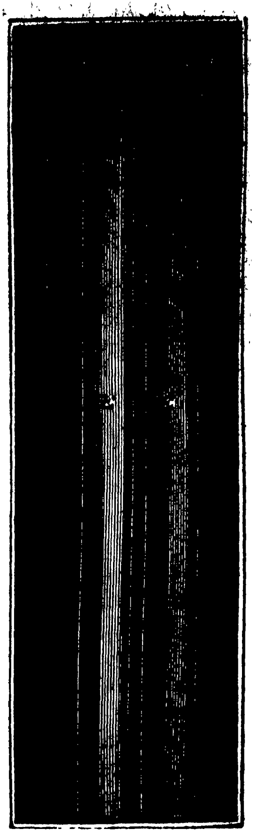


Fig. 91.



A is a strong leaden cistern.

B is the shaft of an air-pump.

C is a safety valve.

D is the pipe reaching from the bottom of the cistern *A* to the cistern *E* at the top of the coke columns.

The valve *C* is opened and the cistern *A* is filled with the sulphuric acid from the concentrating furnace pan already described, or some conveniently situated reservoir. As soon as this is done, the valve is again closed, and the air-pump set in motion, which forces the air into the cistern at the top, and thus causes the acid to ascend up the pipe *D* to the cistern *E*. As soon as the cistern *A* is emptied, the valve *C* is again opened, and the operation repeated as often as necessary to maintain a supply of acid to the coke columns.

As the escape of vapors from a vitriol chamber should always be the same, it becomes of essential importance that a perfect regularity should be obtained in the supply of acid for absorbing the nitrous gas; this is well effected by the following contrivance which is represented by Fig. 93.

Fig. 92.

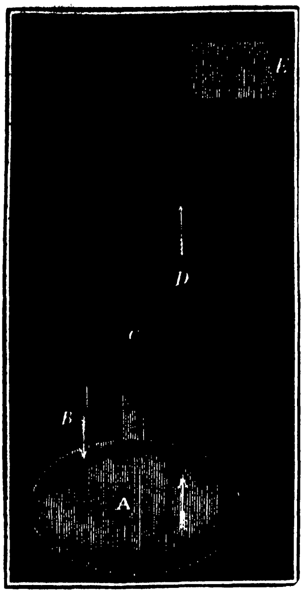
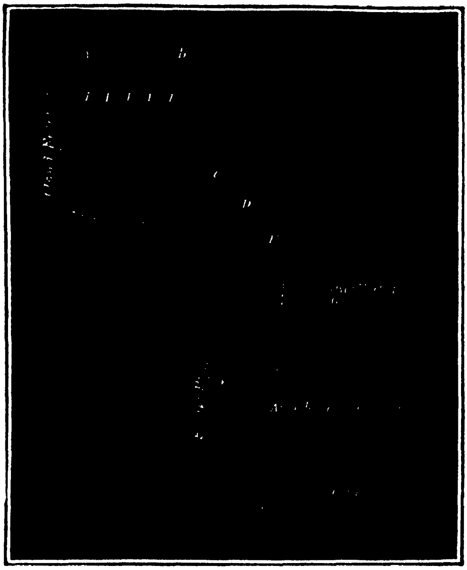


Fig. 93.



It is evident, that if the reservoir which holds the acid be open, it will be impossible to obtain a regular flow of acid, as the level of this will be continually varying; thus, when the reservoir is full, the weight of acid would cause it to run out very quickly; but as the level descends, the acid would run more slowly; it is, therefore, necessary to make use of a closed reservoir. This reservoir is filled with sulphuric acid 62° Baumé (1.760 sp. gr.) by means of a funnel *A*, the air escaping through the small tube *B*; near the bottom is a leaden cock *C*, which must be perfectly tight, and which dips into a small leaden vessel *D* that has a small glass tube *F* at the bottom to let out the acid. The section of this tube must be somewhat smaller than that of the orifice of the cock. When the reservoir is full the funnel *A*, and the tube *B* must be well closed with corks, the cock *C* is then opened. The acid flows faster through the cock than it can escape through the glass tube *F*, so that the acid rises in the vessel *D* covers the orifice of the cock, prevents the air from entering, and soon stops the flow of acid on account of the partial vacuum in the upper part of the reservoir. As soon as the acid has run out of the vessel *D* sufficiently to uncover the mouth of the cock, air enters again through the cock, the acid flows, and the vessel fills as before. This will go on as long as there is acid in the reservoir, and the flow of acid through the tube *F*, will be almost perfectly regular as the utmost difference of level in the vessel *D* is so very small.

A partial vacuum being formed in the reservoir, it is necessary to support its cover; this is done by means of 5 or 6 bars of iron *E*, covered with lead, resting on the bottom and soldered to the cover.

Now it is equally important that the acid should be distributed uniformly over the whole surface of the coke. This is well effected by means of cones of progressive sizes, one placed above another in the top part of the column. These cones being all, except the middle one, truncated, receive at the top the acid that flows on the surface of every one of them, and falls in a number of circular streams that cover the whole surface of the coke. If the acid fell on the cones in a regular stream, there could not be a sufficient quantity of it to cover all these surfaces; it is, therefore, necessary that a certain volume of acid be supplied suddenly at regular intervals. This object is obtained by means of the oscillator *G*. This oscillator consists in a sort of leaden box with a partition in the middle that divides it into two equal parts; this is supported on an axis on which it oscillates, the contrivance being so arranged, that while one side pours out the acid that it has received, the other receives its supply of acid, and only falls to pour it away when the calculated quantity has been supplied. Every time the oscillator falls, its contents run into an S pipe, and from thence into a short pipe, placed just above the tops of the cones and fitting closely on the upper one; this pipe being suddenly filled with the acid, the acid escapes, and runs along all the cones.

The oscillator should deliver the acid at least twenty times per hour. For a daily consumption of one ton of sulphur, 1800 parts of acid 62° Baumé (1.760 sp. gr.) will be required, and proportionately for a larger or smaller consumption.

Theory of the Process.—The transfer of the oxygen of the air to the sulphurous acid by means of nitric oxide is, however, by no means so simple a process as it appears, and as was at first supposed. Nitric oxide has a great tendency to combine with sulphuric acid and form a sulphate of nitric oxide (NO_2, 2 SO_3),* which again has a strong tendency to unite with hydrated sulphuric acid, (probably NO_2, 2 SO_3 + SO_3, HO;) so much so, that the formation of sulphate of nitric oxide is very much favored by the presence of hydrated sulphuric acid. This is the case in the chambers, where this compound is frequently found in inch thick crystaline layers—like ice on window panes—covering the walls, or falling sometimes as fine snow flakes or even in more minute division as a pale cloud, for sulphurous acid and peroxide of nitrogen are immediately converted—but only in presence of aqueous vapor—into sulphate of nitric oxide.

Aqueous vapor, therefore, and sulphuric acid, are essential requisites for the rapid formation of this compound. In the chambers, however, sulphate of nitric oxide is not permanent—its production not being the ultimate object—it is decomposed by the current of

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* The difficulty attending the analysis of this compound explains the want of accordance, and the different views of chemists concerning its nature. Prevostaye considers that the compound must be viewed as a combination of common anhydrous sulphuric acid with a sulphuric acid, in which 1 equiv. of oxygen is replaced by peroxide of nitrogen, namely $SO_3 + SO_2$, NO_4.

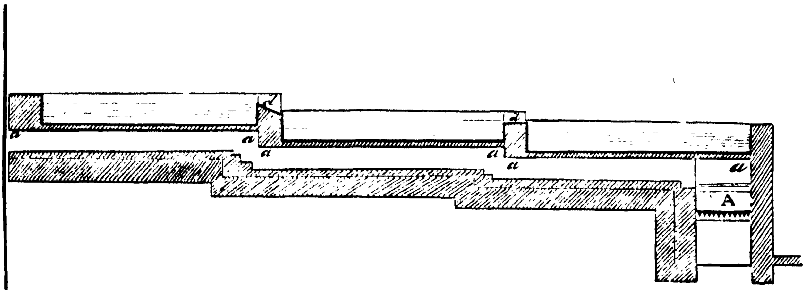
aqueous vapor into *hydrated sulphuric acid* which dissolves, and *nitric oxide* which is evolved with effervescence, and can again be converted into peroxide of nitrogen.

Formerly the formation of the crystals in the chambers was considered as something remarkable, and only of casual occurrence, until it was proved by the more recent researches of A. Rose, De la Prevostaye, Gay-Lussac, Gaultier, and others, that the production of sulphuric acid is solely due to the decomposition of the sulphate of nitric oxide.

It is not a matter of indifference what strength the acid is at first allowed to assume, but it has been found desirable to draw it off from the middle chamber in which it collects when it has attained the strength of 52° B. (sp. gr. 1,558) or when it contains 54 per cent. of hydrated sulphuric acid. Stronger acid would absorb too much sulphurous acid; and if it were much weaker (up to 46 per cent. hydrated sulphuric acid) it would take up too much nitric oxide. Thus from every cwt. of acid from the chamber, 39 lbs. of water must be separated in order to obtain the commercial acid, which should contain about 93 per cent. of hydrate, (66° B.)

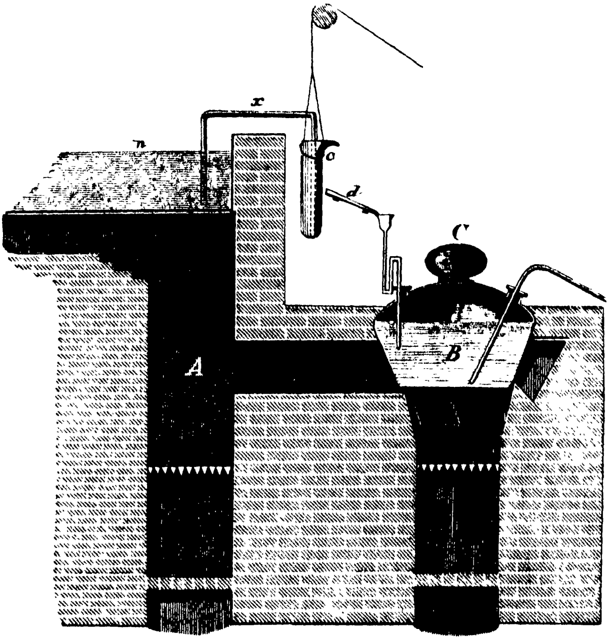
The Concentration.—The concentrating apparatus in which this separation is effected consists of leaden pans and a platinum retort. The former, Fig. 94, are erected over a fire *A*, and supported by iron plates *a a* against which the flame beats; *d d* are incisions through which the lower pans are filled. The evaporation precipitates a little sulphate of lead and oxide of iron (anhydrous), whilst the boiling point of the fluid attains a height, at about 65 per cent. of hydrate, which endangers the pans from the great heat, and causes a useless loss of acid by evaporation. When, therefore, about 11 per cent. of water has been evaporated, with which nitric oxide, nitric and sulphurous acids pass off, the acid is conveyed (having a specific gravity therefore of 1.7) through the syphon *x* into the platinum retort, Fig. 95, the fire under which is closely approximated to the firing of the pans *A*. The syphon *x*, which is here represented as closed, is worked without a stop-cock by the vessel *c* on filling the retort in a remarkably simple and ingenious manner. When this vessel is lowered with its spout to the gutter *d*, the outer limb of the syphon—

Fig. 94.



which is constantly full—becomes lengthened below *n*, and acid consequently flows out. The danger and great loss by breakage attending the use of glass vessels, have induced the manufacturers very generally—notwithstanding the great cost—to make use of platinum retorts. These are made (nearly all in Paris) to contain from five to twenty cwts. and cost from about £1,700 to £2,600; all the joints in the retorts are soldered with gold. During the boiling, the contents of the retort separate into commercial acid and some acid water, which is conducted by the tube in the capital, and its spiral leaden continuation to one of the pans, where it is used to concentrate a quantity of weak acid from the chamber. If the heat were further increased, the boiling point would suddenly rise to 326° C. (619° F.) and hydrated sulphuric acid would distil over, which of course is not desirable.

Fig. 95.

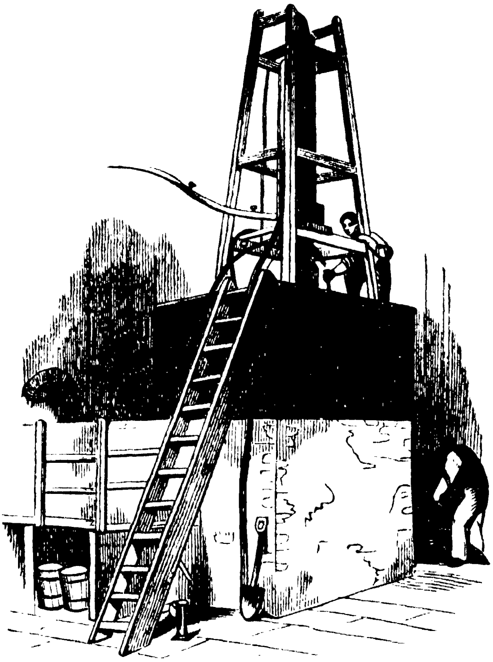


With reference to the quantity of lead taken up by sulphuric acid in different states of concentration, experiments have lately been instituted by Anthon, which prove how very objectionable the practice must be of concentrating the acid in leaden pans beyond the prescribed limits. Anthon found in acid thus concentrated and afterwards cooled down to 68° F. the following quantities of sulphate of lead:

Acid of sp. gr. 1.724 contained $\frac{1}{480}$th sulphate of lead
" " 1.791 " $\frac{1}{80}$th " "
" " 1.805 " $\frac{7}{320}$ths " "

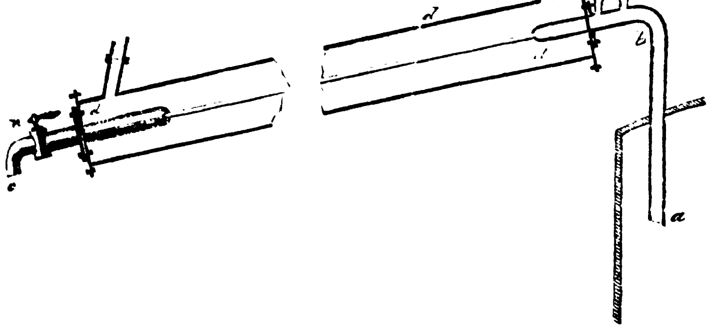
The annexed wood cut (Fig. 96) shows the manner in which the platinum still is erected in the concentrating house of the vitriol works.

Fig. 96.



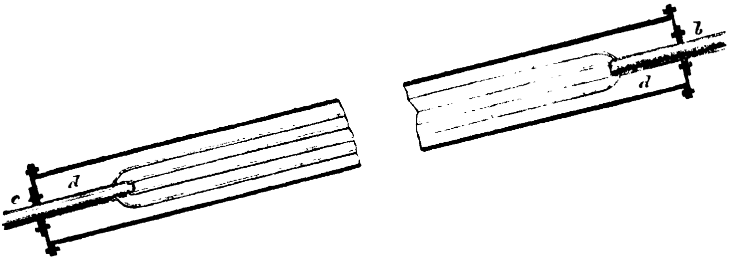
The high price of platinum vessels renders it very much to the interest of the manufacturer that they should be in constant use; yet it is impossible to draw off so powerful an acid at that temperature into the glass carboys, in which it is sent out, and leaden coolers cannot be used. Hence arises the necessity for the platinum syphons, Figs. 97

Fig. 97.



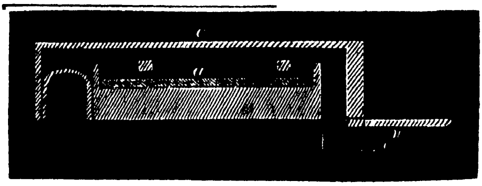
and 98, which at the same time answer the purpose of coolers. The syphon *a b c* is let into a wide tube *d d*, which is supplied with a current of cold water through *e*, The water, after becoming warm, flows off at *g*. The cooling is, therefore, effected by surrounding the hot acid in *b c* with a current of cold water passing in an opposite direction, the effect of which is very much increased by making the longer limb in four distinct tubes, as in Fig. 98. To fill the syphon, the cock *n* is stopped, and acid is poured first into *o*, and then into *o'*, until it runs down into the retort through *b a*. When *o* and *o'* are now close, and *n* opened, the syphon comes into play.

Fig. 98.



The process of concentrating sulphuric acid in a series of open leaden pans by applying the heat below, has been abandoned in most manufactories, in consequence of the great waste of the pans themselves (v. p. 240), and the loss of acid, where the chambers have been worked with an excess of sulphurous acid. Two modifications have been introduced with great advantage. One of these modifications consists in covering the leaden pan with a movable hood of sheet-lead, suspended from a wooden framework, constructed in the same way as the ordinary sulphuric acid chamber; and this improvement generally effects a saving of 10 per cent. of acid. The other modification is shown in the drawing, Fig. 99, by means of which a larger quantity of acid is concentrated in the same time, and the leaden pans protected from the serious corrosion to which they are liable under both the other systems. This arrangement consists of a leaden pan *a*, built in brickwork, and enclosed in a furnace *b*, when the heat from the furnace *c* is applied from above, and passes along, with all the fumes, into the flues *d*. The advantages of this latter plan are too obvious to require any notice.

Fig. 99.



Produce.—In a manufactory like that described, from 100 lbs. of sulphur, 308, 310, or even 320 lbs. of concentrated commercial acid, according to the management of the process, may be obtained, of 66° B. (= 1.815 specific gravity), and for the production of this quantity, from 10 to 12 lbs. of nitric acid are requisite, whilst upon the old plan the produce would not have exceeded 150 to 200 lbs. of sulphuric acid. As the commercial acid is not pure hydrate (SO_3, HO), but, on account of about 7 per cent. residual water, is probably a mixture of SO_3, HO, with some SO_3, 2 HO, the mean produce of 310 lbs. will correspond with 288 lbs. of actual hydrate. Now as 100 lbs. of sulphur in becoming sulphuric acid, require 150 lbs. of oxygen (= 3 equivs.), and 56 lbs. (= 1 equiv.) of water, which, according to theory, would give 306 lbs. of hydrate, we see to what a high state of perfection this branch of manufacture has arrived, when only (18 per cent. of hydrate =) 6 per cent. of sulphur have been lost in the process.

The manufactory described at page 232, is capable of burning 40 tons of sulphur per week, with a produce of 3 of oil of vitriol for 1 of sulphur, and a consumption of only 3 lbs. of nitrate of soda for every 100 lbs. of sulphur.

To produce this mean quantity of acid (310 lbs.) 48 cwts. of sulphur are burned, on an average, daily, therefore, 2 cwts. per hour, which take up 2 cwts. of oxygen from 8.5 cwts. = 12.500 cubic feet of air, in order to be converted into 4 cwts. = (about 2323 cubic feet) of sulphurous acid; in which case there will remain 6.5 cwts. of nitrogen from the air, = 8660 cubic feet. On its arrival in the chamber, the sulphurous acid requires 5650 cubic feet of air, in order, by the separation of another quantity of nitrogen (4436 cubic feet), to combine with 1 cwt. of oxygen = 1184 cubic feet, and become converted into sulphuric acid. From the sudden condensation of the latter, which is almost equivalent to its complete removal, the chamber, upon the old plan, was exposed to the risk of being crushed in—inasmuch as it was closed for a time.

The excess of air which enters the chambers being left out of calculation, there will pass through them altogether in an hour (2322 + 8660 + 5650 =) 16532 cubic feet of the mixture of gases,* so that, during the lapse of twenty-four hours, their contents will be changed four or five times. The gases which escape carry with them the nitric oxide, which is at the same time generated, about 5 or 6 lbs. in the hour (to 2 cwts. of sulphur). To regain this, at least the greater part of it, the gases, in escaping from the chamber are brought into contact with a current of strong sulphuric acid, in the form of rain, which absorbs nitric oxide with great avidity, as described at page 235.

Impurity.—English commercial oil of vitriol is not sufficiently pure for all purposes: it contains, besides hydrochloric acid (from the common salt of the impure saltpetre), traces of nitrous acid, nitric acid, and particularly nitric oxide, which are detected by the purple color which it assumes with green vitriol. On distilling the acid, sulphate

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* At a temperature of 0° C. (32° F.)

of nitric oxide being less volatile, is contained in the residue. The presence of the oxides of nitrogen is objectionable to the manufacturer, on account of their communicating to the acid the property of attacking platinum. To get rid of that portion which would otherwise reach the platinum retort, $\frac{1}{10}$ to $\frac{1}{2}$ per cent. of sulphate of ammonia may be added before the heat is applied; the ammonia, and the oxides of nitrogen, are then converted into water and nitrogen gas (Pelouze). Besides these impurities, there are also sulphate of lead, (which is not separated by sulphuretted hydrogen, but only by dilution,) anhydrous persulphate of iron (as a white deposit, which vanishes on dilution), selenium, and arsenic (from the sulphur, or pyrites) in the acid, which is likewise frequently colored brown by straw, or cement that has fallen into it.

Fuming Oil of Vitriol.—Of those sulphates which part with their acid at a red heat, without decomposition of the latter into sulphurous acid and oxygen, the persulphate of iron is the only one that can be used in the manufacture of the fuming acid. This substance is always evolved when green vitriol, a cheap, easily obtainable salt, is heated to redness. The starting point of the manufacture is, therefore, green vitriol, (hence the name, *oil of vitriol,*) or crystallized proto-sulphate of iron, ($FeO, SO_3 + 7\,HO$,) 6 equivs. of its water being driven off, before decomposition ensues; the seventh equiv., which is more intimately combined, is only expelled when that process begins. In the vitriol manufactories, the impure vitriol obtained by evaporation of the mother liquors, which has no commercial value, is subjected to two consecutive operations, the one of which removes its water, the other its acid.

The Furnaces.—Both these operations are effected simultaneously in the same furnace, the arrangement of which, as constructed at Hermsdorf, is seen in profile at Fig. 100. The furnace used at Radnitz, in Bohemia, is represented at Fig. 101. In the gallery furnaces

Fig. 100.

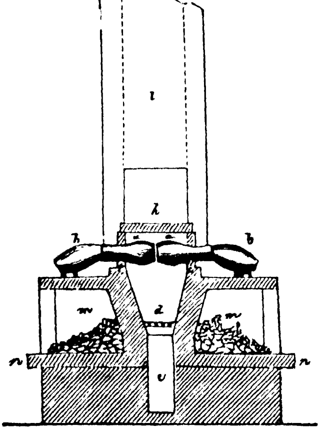
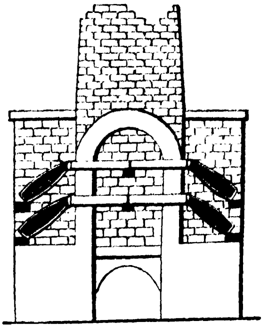


Fig. 101.



(Galeerenöfen) in general, as represented in Fig. 100, the same firing heats two rows of vessels *a a*, in which the decomposition is effected; these pots are walled in at the necks *c c*, and in such a manner that the movable receivers *b b* can easily be inserted, and made tight by cement. If, on the contrary, the necks of the retorts *a* were inverted into the receivers *b*, the cement would be liable to fall into the acid. The grate *d* is carried throughout the whole length of the furnace to the chimney *l*; *e* is the ash-pit, and *m* the drying chamber for separating the water from the vitriol, which is heaped up upon the projecting plate *n*. The walls *c c* are overlaid at top with plates of clay *h*. The Bohemian furnace is not essentially different from the one described, except that it is calculated for a double range of retorts. The retorts are 1½ feet long, and 4 inches wide at the neck; the receivers are of the same length, and are 1½ inch wide at the mouth; both retorts and receivers are from 5 to 6 lines thick, and composed of crucible ware. The furnaces accommodate from twelve (as in Fig. 101) to thirty retorts on each side, which are placed three inches apart.

Process of Distillation.—When the retorts are charged, each with about 2 to 2½ lbs. of calcined vitriol, a flame-fire is made with dry pine wood. The first portions that pass off, consisting of very weak sulphuric acid, and much sulphurous acid, are not collected. As soon, however, as the gray, fog-like vapors of anhydrous sulphuric acid appear, the receivers are connected, each containing about an ounce of rain-water, and the distillation begins. The heat is kept up until the retorts have been exposed for some time to a white-heat, in all about thirty-six hours; as long, indeed, as acid passes over. When this ceases, and the receivers have become cool, they are at once removed, the retorts emptied, and charged anew, which is done by means of iron shovels; the same receivers are again adapted (without having been emptied), and the process is then repeated. The acid in the receivers is not so saturated with anhydrous sulphuric acid, as to attain the strength of commercial oil of vitriol, until this process has been repeated four times. In this manner, 45 to 50 per cent. of the dry vitriol is obtained as acid, which is sent out in stoneware jars, with screw stoppers, covered with cement. The residue is a reddish-brown earthy mass, called *Colcothar*, or *Caput mortuum vitrioli*, and may be used as a paint.

When anhydrous vitriol (FeO, SO_3) is heated to redness, the protoxide is converted into peroxide, by taking from a portion of the sulphuric acid, the requisite quantity of oxygen, the former becoming reduced to sulphurous acid. For $2\ FeO, SO_3$, or $2\ Fe + 2O + SO_3 + SO_3 = Fe_2\,O_3, SO_3 + SO_2$.

Basic persulphate of iron is, therefore, formed, which, at a still higher temperature, parts directly with its acid. From the great tendency which protoxide of iron has to combine with oxygen, or to be converted into peroxide, mere exposure to the air, or slight roasting, is sufficient to effect this conversion, when $2\ Fe\ O, SO_3$, or $2\ Fe + 2O + 2\ SO_3 + O$ (from the air), become $Fe_2\,O_3 + 2\ SO_3$, or ⅔ basic persulphate of iron, which at a high temperature parts with the whole of its sulphuric acid without any formation of sulphurous acid, and, therefore, without loss. This is the case in the vitriol works, where vitriol is employed that has become nearly entirely peroxidized by exposure to the air; for every portion of oxygen taken up, five portions more anhydrous acid are obtained. The chambers *m*, therefore, besides separating the water from the vitriol, roast it also to a certain extent. The amount of produce proves what is here stated; for whilst protosulphate of iron ought to produce 30.3 per cent., and the persalt 53.3 per cent. of dry acid, 50 per cent. of oil of vitriol is obtained, which is equivalent to much more than 30.6 per cent. of anhydrous acid.

Since English sulphuric acid has become so cheap, manufacturers in Germany have begun to use it in the vitriol works, either for dissolving colcothar, (to form persulphate of iron,) which is then decomposed in the manner described, or for replacing the water in the receivers. In the latter case, the product is of course contaminated with all the impurities of the English acid.

Fuming oil of vitriol is an oily, brownish fluid of 1.9 specific gravity. Its chief constituent is the hydrate $2\,SO_3, HO$; in the weaker acid this is mixed with the simple hydrate SO_3, HO, in the stronger it contains anhydrous sulphuric acid SO_3 in solution. The latter substance is so volatile, that it escapes even at ordinary temperatures from the oil of vitriol, and uniting with the moisture of the atmosphere, is condensed in the form of a visible cloud to SO_3, HO. Hence the fuming. Together with selenium, and earthy particles, sulphurous acid is never missing amongst the impurities, and is only gradually evolved on dilution, destroying, for instance, the spongy platinum in the platinum lamp, when fuming acid is used to supply it.

COMMON SALT.—SEA-SALT.

Occurrence.—Sea-salt, or culinary salt, (chloride of sodium NaCl,) is not an artificial product, but is found even lavishly prepared and stored up in the earth by nature. Nevertheless, the manner in which it is obtained is interesting, and the more so, as it is the source of the most important compounds of soda. As a rock—*rock-salt*—for so it is called by mineralogists—forms a distinct member in the series of stratified rocks, occurring with limestone, clay, chalk, gypsum, marl, stinkstone, slate, and not unfrequently with bituminous formations. The great deposit of salt which extends from Upper Austria through Styria, Salzburg, and Berchtesgaden, as well as that of Wimpfen, in Würtemberg, are the most extensive and productive in Germany.* From the section of the latter, Fig. 102, it will be seen how the gypsum is enclosed by a deep layer of shell-limestone, containing the rock-salt as a separate mass. It is highly probable that the rock-salt

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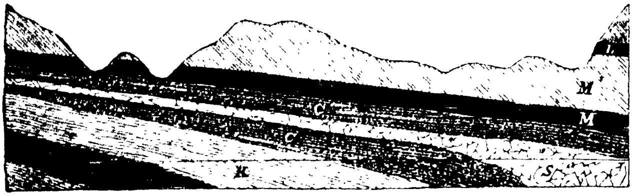
* The chief deposit of rock-salt in England is at Northwich, in Cheshire, where the mineral occurs in two beds, one above the other, and separated by about 30 feet of clay and marl, intersected with veins of rock-salt. The two beds together are not less than 60 feet thick, and probably extend 1½ miles, and are 1300 yards broad.

in this, and similar basins, has been deposited from saline lakes, and this explains why it should occur in more defined and rounded masses, as compared with the enormous extent of the other members of the same formation. In the high lands of Asia, and Africa, and America, there are often extensive wastes, the soil of which is covered and impregnated with salt, without having ever been covered by other deposits. Salt lakes themselves are not uncommon, and occur on the banks of the Wolga, in South Africa, in England, in the neighborhood of the Caspian Sea, and west of the Rocky Mountains, in America. In the water of one of these lakes near Symphe-ropol, in the Crimea, Göbel found 16.12 per cent. chloride of sodium, 2.444 sulphate of soda, 7.55 chloride of magnesium, 0.276 chloride of calcium, and 0.7453 sulphate of potash. The simultaneous occurrence of soluble sulphates, or other chlorides, as well as the corresponding compounds of bromine and iodine, which has everywhere been observed, is of equal importance as regards the history of its origin, as also of the mode of obtaining sea-salt. Lastly, the water of the ocean—which, from the geological processes concurring in its formation, is necessarily a solution of salt—contains chloride of sodium as its chief saline ingredient. On account of the unequal amount of evaporation, however, the water of the sea has not always the same composition; thus there has been found in 1000 parts:

Fig. 102.



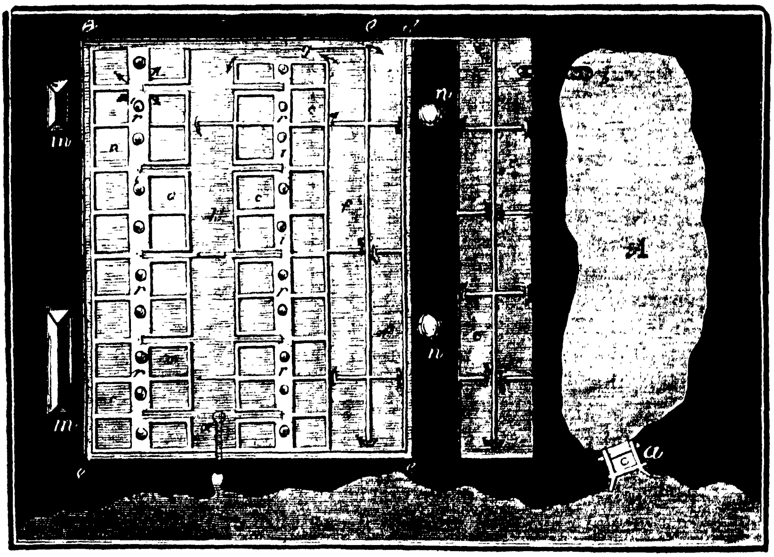
	Clemm. (N. Sea).	Marcet.	—
Chloride of sodium	24.84	26.66	25.00
" magnesium	2.42	5.15	3.50
" potassium	1.35	1.23	—
Sulphate of lime	1.20	1.50	0.10
" magnesia	2.06	—	0.58
" soda	—	4.66	—
Carbonate of lime and magnesia	—	—	0.20
Total amount of salts	31.87	39.20	29.388

to which must be added 6.2 vol. per cent. of carbonic acid, traces of proto-carbonate of iron and manganese, phosphate of lime, silica, bromides and iodides of the metals, some organic matter, and ammonia.

Production of Salt from Sea-water.—It is seldom that artificial evaporation is had recourse to for separating the salt from sea-water;

when it is practised, the same mode is adopted as will be described hereafter with reference to the brine springs; sometimes, as in Siberia, frost is made subservient to this object—for salt water separates on freezing, into ice (containing no salt), and a strong saline lye; but most generally evaporation is effected by the air and sun in the "*salt gardens*," Fig. 103, which are laid out upon a clay soil on the sea-coasts of southern climates, and being secured from the influence of the tides, are cultivated during the summer months, from about March to September. These salt gardens are nothing more than a series of very shallow ponds, intended to spread the water over a very large surface with hardly any depth of liquid, so that by increasing as much as possible the evaporating surface, the drying action of the air may be more fully exerted, and salt may be deposited in the hindermost pools, whilst the foremost ones are constantly supplied with fresh sea-water. Advantage is taken of the flow of the tide to fill the collecting pond *A*, through the flood gate *a*, to the height of from 2 to 6 feet, in which the evaporation begins, but the principal object of this first pond is, to allow the water to deposit its mud. The pipe *b* then carries the clear water from the collecting pond to the perfectly horizontal but very shallow front pool *c*, *c*, *c*, from whence, by means of a second pipe *d*, it is circulated through a channel *e*, *e*, 16000 feet long, from this it enters the ponds *f*, *f*, *f*, and lastly runs through the open channel *g* to a third series of ponds *h*, *h*, *h*. At this point, the evaporation has proceeded so far that the salts begin to crystallize in the hindermost reservoirs *o*, *o*, *o*, of which there are four rows. From the reservoirs *h*, *h*, numerous channels *i*, *i*, branch out, which supply the crystallizing ponds *o*, *o*. The manner in which the water arrives

Fig. 103.



in these through the gutters in the sides, is clearly shown in the drawing. The saline incrustation with which the surface of *o*, *o*, *o*, becomes gradually covered, is broken up and collected with rakes into small heaps *r*, *r*, *r*, on the sides, and from these the mother liquor runs off into the ponds, *o*, *o*, and *h*, *h*. When no more salt separates by crystallization, the lye is allowed to run off through *x* into the sea. The salt as at first collected, would contain too much impurity, chiefly consisting of chloride of magnesium, the smaller heaps *r*, *r*, are, therefore, made up into larger square (*m*, *m*), or round heaps (*n*, *n*), which are allowed to remain for a time covered with straw. The rain is thus kept off, and the moisture of the atmosphere suffices to liquefy the chloride of magnesium, which is thus gradually separated from the saline mass.

Although the entire surface of the ponds amounts together to many hundred acres, yet the process depends so entirely upon the sun and wind, that in wet weather the evaporation sometimes entirely ceases. The following analyses of sea-salt show the nature and amount of its impurities.

Locality.	Salt.	Sulphate of magnesia.	Chloride of magnesium.	Sulphate of lime.	Water.	Insoluble matter, (clay.)	
Salt from St. Ubes in Portugal,							
I. Sort . . .	95.19	1.69	—	0.56	2.45	—	Berthier.
II. " . . .	89.19	6.20	—	0.81	3.60	0.20	
III. " . . .	80.09	7.27	—	3.57	8.36	0.20	
Salt from Figueras . .	91.14	3.54	0.70	0.33	4.2	—	
" Eymington .	93.70	3.50	1.10	1.50	—	0.20	Henry.
" " (cat salt)	98.80	0.50	0.50	0.10	—	0.10	

Rock-salt.—The mode in which salt is obtained from the deposits of rock-salt depends very much upon the locality, upon the depth of the deposit, the price of fuel, the rate of wages, &c. &c. In some places, it is a mining operation, and is carried on by means of shafts and horizontal galleries, as at Wieliczka in Galicia (where the layer is 500 miles long, 20 miles broad, and 1200 feet deep), near Liverpool, in England, and in other places. It depends upon the degree of purity of the rock-salt, whether it can at once be brought into the market, or must first be purified by solution and recrystallization. Near Liverpool, for instance, it is obtained as clear as glass and colorless; in general, however, it varies throughout the mass, is often colored red, either from clay or bitumen, and particularly from the same kind of infusoria, which are still found inhabiting salt-lakes. Rose has also observed a particular kind of carbo-hydrogen $C_2 H_8$ in the rock-salt of Wieliczka, which is enclosed in a high state of condensation, and is evolved on dissolving the salt with a peculiar crackling sound. Henry found in the rock-salt from Chester 98.3 per cent. chloride of sodium, 0.05 chloride of magnesium, 0.65 gypsum, and 1 per cent. of insoluble matter. In other places, as at Wimpfen, fresh water is let down through a bore extending to the middle of the salt bed, and pumped up again as a saturated solution. For this purpose pumps and pipes descend the whole depth of the bore. The solution of salt is raised in the pipes, whilst between these and the sides of the bore fresh water flows down. Thus a wide cavity is gradually left in the bed of salt, in which fresh water and a solution of salt are contained. Now, as 1 cubic foot of the saturated solution weighs 12.8 lbs. more than the same volume of fresh water, the latter will chiefly occupy the surface of the fluid in the cavity. The pump must, therefore, work from the bottom of the cavity, and the suction pipe be sufficiently deep for that purpose. The valves, however, may be placed much higher up, because the fluids on the inside and outside will balance each other, and the solution of salt will be as much below the level of the water as its specific gravity is greater.* At 1200 feet depth of bore, for instance, the saturated solution of salt will of itself stand at 1000 feet, and the pump will only have to raise it 200 feet.

Natural Brine Wells.—Salt wells, which may thus be artificially constructed, are also frequently found ready formed in nature, wherever a spring, during its course, has come in contact with a bed of rock-salt. It is rare, however, that these are so highly saturated as the artificial springs, although this is actually the case with that of Lüneburg, which contains 25 per cent.; but they are generally very slightly impregnated, or have become weakened by an after addition of fresh water. This difference in the strength, and many other circumstances attending the occurrence of salt, will be seen from the following tabular view:

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* Specific gravity of the saturated solution = 1.2046. 100 parts of saturated solution contain:

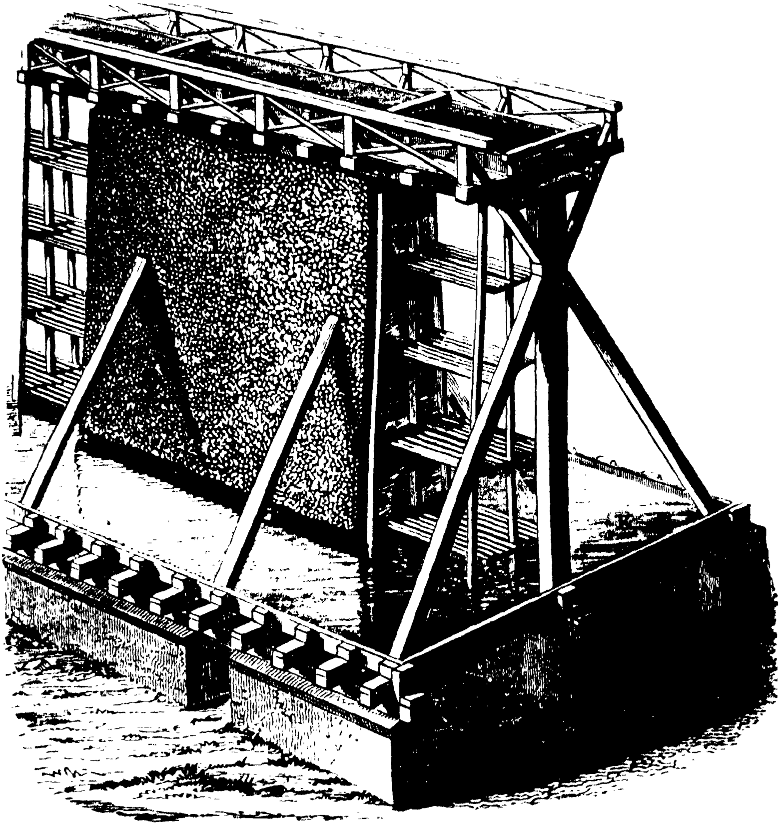
At 1°	26.53	Chloride of sodium according to	Unger, Gay-Lussac.
— 17°	26.40	" "	Gay-Lussac.
— 18.8°	26.75	" "	Karsten.
— 25°	26.30	" "	Kopp.
— 100°	28.22	" "	Unger, Gay-Lussac.
And at every temperature	27.00	" "	Fuchs.

	1	2	3	4	5	6	7	8	9	10
Brine springs.	Schönebeck.	Dürrenberg.	Rodenberg (Boring).	Artern.	Nauheim.	Soden (Spring VI c.)	Kreuznach.	Salzhausen.	Rodenberg, (Schaft.)	Schwalheim.
Salt (chloride of sodium)	9.623	6.599	5.173	2.829	2.506	1.475	1.415	0.913	0.633	0.155
Chloride of potassium .	0.007	0.008	—	0.004	trace	0.037	0.006	0.009	—	—
" magnesium .	0.083	0.092	0.166	0.038	0.085	—	0.023	0.080	—	0.023
" calcium .	—	—	—	—	0.203	—	0.261	—	—	—
" ammonium .	—	—	—	—	—	—	—	—	—	—
" lithium .	—	—	—	—	—	trace	trace	trace	—	—
Bromide of magnesium .	—	—	trace	—	—	trace	—	—	—	trace
" sodium .	—	—	—	—	trace	—	—	0.00003	trace	—
Iodide of magnesium .	—	—	trace	—	—	—	trace	—	trace	—
Sulphate of potash .	0.014	0.004	trace	0.004	—	—	—	—	—	—
" lime . .	0.339	0.250	0.515	0.158	0.005	0.011	—	0.080	0.222	—
" soda . .	0.249	0.208	—	0.092	—	—	—	—	0.036	0.008
" magnesia .	0.012	0.004	0.005	0.004	—	—	—	—	—	—
Carbonate of lime .	0.026	0.056	0.010	0.042	0.150	0.126	0.003	0.057	0.018	0.056
" magnesia .	—	—	trace	—	0.048	0.024	0.001	—	trace	0.005
" protox. iron .	0.001	0.001	—	0.012	0.004	0.004	0.005	0.001	—	0.001
" soda . .	—	—	—	—	—	—	—	—	—	—
" manganese .	—	—	—	—	trace	—	—	—	—	—
Phosphate of alumina .	—	—	—	—	—	—	trace	trace	—	—
Alumina . . .	—	—	—	—	—	0.005	—	—	—	—
Silica	—	—	trace	—	0.007	0.004	0.013	0.001	—	0.002
Crenic and apocrenic acid	—	—	—	—	—	trace	—	trace	trace	trace
Organic matter . .	0.001	0.012	—	0.017	—	—	trace	trace	—	—
Carbonic acid . .	—	—	$\frac{1}{15}$ vol	—	0.162	0.211	—	0.027	$\frac{1}{4}$ vol.	0.296

Constituents of the Brine.—With the exception of Nos. 6 and 10, all the brine springs mentioned in the foregoing table are boiled down for obtaining salt. The impossibility, from the lowness of its price, and cost of carriage, of conveying salt to a distance, and the different advantages of locality, sufficiently explain, why in some places very weak brine, and in others brine containing 10 times as much salt, may both be worked with advantage. Thus, for instance, the salt-works at Salzhausen can only be carried on in consequence of fuel being obtained without cost; the refuse of the brown coal works upon the same spot supplying a source of heat.

Borings.—It is sometimes possible, by a suitable arrangement of the borings, to bring the brine to the surface by means of natural hydrostatic pressure (Artesian). The raising is then effected without the use of machines, and without diluting the brine with fresh water. Borings are also frequently made for the purpose of obtaining the brine nearer to its source, as at Rodenberg, in the principality of Schaumberg, where a very weak spring (0.6 per cent.) was obtained at an 8.5 times greater state of saturation (5.1 per cent.) by means of a boring. The new salt-work at Prussian Minden is peculiarly adapted to give an idea of the importance of such undertakings. The new boring there, is 4½ inches in diameter, and was begun in the lias, and had attained in May, 1843, a depth of 2515 feet under the surface, and 2105 feet under the level of the sea, having passed through the new red sandstone formation, and arrived still unfinished at the Muschelkalk. 84 cubic feet of brine containing 4 per cent., issue from it per minute; therefore, 567,670 cwts. of salt in a year; the shaft at Schönebeck affords in the same time from 20 to 25; the spring at Artern, 211 cubic feet of brine.

Fig. 104.

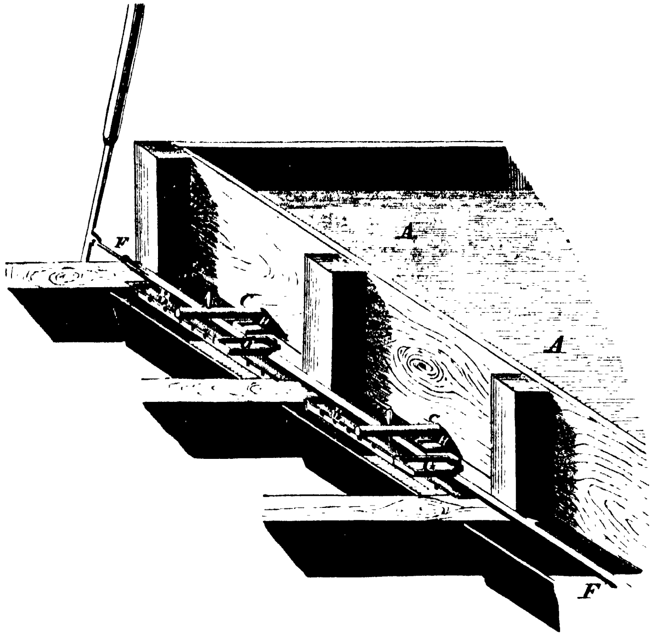


The Graduation.—The greater number of brine springs are far too dilute, with the present price of salt, to repay the cost of evaporation by means of fuel. At Salzhausen, for instance, the production of 1 cwt. of salt presupposes the evaporation of 339 cubic feet of brine; at Schönebeck the annual produce of 575000 cwt. of salt is obtained by the evaporation of 19 mill. cubic feet of water. In all the brine springs, therefore, which are far removed from a state of saturation, the greater portion of the water is removed by evaporation in the air, "graduation," the smaller portion by "boiling."

The graduation house is intended to distribute the brine in the form of rain, and expose it to the air in this state, whilst the action of the latter is increased by stopping and retarding the single drops as they fall.

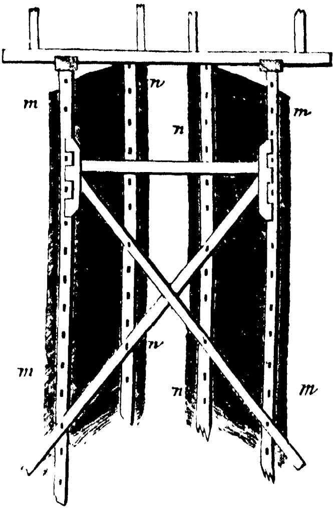
The brine is caused to fall from the trough or cistern *A*, Fig. 104, into the tank *K*; the retardation is effected by means of a wall of twigs or thorns *L*, *L*, and its distribution in the form of rain by means of a series of perforated tubes and plugs (Geschwindstellung), Fig. 105.

Fig. 105.



The motive power raises the brine into a large reservoir, generally placed in a tower, whence it must be enabled to flow freely into the troughs *A*, as it is wanted. By means of the horizontal pipes *C*, *C*, *C*, the brine is conducted in a thin stream to the dropping channel *B B*, which extends throughout the whole length of the graduation, and from thence it falls drop by drop upon the wall of twigs *L L*. This structure is composed of fagots of black-thorn, placed between the lathwork *l l*, in a horizontal even manner. The protecting board *I I* prevents the wind, which must pass through the thorns, from giving a wrong direction to the drops which are constantly falling on the outer side. That the air may exert its full influence, the whole structure for graduation is erected in an airy situation, and in a direction at right angles to that of the prevailing wind. It is obvious that this arrangement must expose the *extended surface* of the brine for a *longer time* to a constant current of air. If the wind changes, and threatens to carry the brine away from the wall and over the structure, the graduation must be reversed to the opposite surface of the wall of thorns, and this is done by a simple movement of the lever *E:* for which purpose *E* is attached to the wooden rod *F F*, supporting the boxes *G G*. The lever brings the wooden rod forward, and with it the boxes *G* are moved into a position just under the horizontal pipes, so that their narrow lips at the back project over the cross channels *H H*. Thus the brine is intercepted above the channels *B*, and carried to the other side, and opposite surface of the thorns, by a channel precisely similar to *B*. That the whole arrangement of spigots, channels, &c., may be easily managed, planks for walking are laid on both sides of *A*, and these are furnished with a railing. The erection for graduation here described, as it is practised in Salzhausen, is known as the "*one-walled*" graduation house, and is used in small works where building material is scarce. The walls of thorns are, however, frequently made in pairs, Fig. 106, and sometimes the outer surfaces *m m* only are used—"*surface graduation;*" at others, the inner surfaces *n n* are employed at the same time—"*cubic graduation.*" This latter practice does not quite double the effect, but (from observations made at Dürrenberg) it increases it in the ratio of 5 : 8 or 9. In each of these operations the brine must be allowed to fall 3, 4, 6, or even 8 times through the thorns. For this reason, the graduation houses are partitioned into several compartments, the foremost of which serves for the first, the second for the next fall, and so on. At Schönebeck, the effective thorn surface comprises 390,000 square feet, and evaporates, on an average, during the day 3.7 cubic feet of water from each square foot; therefore, in the year (= 258 working days) the whole evaporates above 44 millions of hogsheads, of 63 gallons each.

Fig. 106.



According to an old-fashioned plan, the graduation was effected by distributing the brine over flat, inclined wooden surfaces, ("*Pritschen*,") or over ropes stretched backwards and forwards for a length of several 10,000 feet.* The thorn walls, introduced into Saxony from Lombardy, in the year 1559, have in Germany superseded every other plan. It is easily understood that graduation proceeds best with a moderately warm wind and sunshine, that a moist, calm atmosphere is less favorable to it, and that in rainy weather it is altogether

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* Thus, for instance, at Moutier, in France, where salt is crystallized during the whole summer without any evaporation by fire, solely by graduation, the hot brine is caused to pass ten or more times over these ropes.

stopped, whilst the wind, when it acquires a certain force, is liable to carry the brine entirely away from the brine cistern. Frost is also prejudicial; for Berzelius observed, that below—3° (27° F.) sulphate of magnesia, with a portion of chloride of sodium, became converted into chloride of magnesium, and Glaubers'-salt—SO_3 MgO + Cl Na = Cl Mg + SO_3, Na O—and that this decomposition is not reversed when the weather becomes warmer. Salt is, therefore, not only lost in this manner, but the quantity of chloride of magnesium is increased, which is detrimental to the boiling process. Graduation is, consequently, limited to the more propitious time of the year, and can then only be practised during 200 to 260 days; and the quantity of brine allowed to flow over the thorns must be proportioned to the power of the wind. Nevertheless, a considerable loss is unavoidable during the graduation, (12.4 per cent. at Schönebeck), which is partly occasioned by small drops being blown away, and partly from salt evaporating with the water, which is probable, judging from similar observations made with boracic acid. At Nauheim, a glass plate, removed to a distance of 600 feet from the building, and placed upon a high pole, was found covered, after some time, with a thin incrustation of salt.

The changes which the brine undergoes in passing through the thorns are various. The carbonates of the earths are dissolved in the brine as bicarbonates; all the free carbonic acid, and the half of that combined with the earths, escapes, partly in passing through the pumps, and still more during graduation; and the earths are deposited as insoluble simple carbonates, whilst the greater portion of the gypsum crystalizes in consequence of the diminished amount of water.* In consequence of these depositions, the thorns become gradually covered with a thick coating (*thorn stone*), consisting of carbonates of lime, magnesia, manganese, and protoxide of iron, with traces of metallic chlorides in variable proportions, which, inasmuch as it at last fills up the interstices, and stops the draught of air, renders it necessary to renew the thorn wall every 5, 6, or 8 years. In the brine cisterns, precipitates of like composition fall as a fine mud, sometimes accompanied by a grayish, thick, scum-like mass, filled with bubbles, which is nearly entirely composed of living infusoria evolving large quantities of pure oxygen. The principal change which takes place in the brine, is naturally the progressive evaporation of the water; and the manner in which this progresses, although variable on account of locality, and the weather, may be seen from the following general view of the graduation at Dürrenberg.

1 cubic foot of brine contains		100 lbs. of salt are therefore dissolved	For every 100 lbs. of salt are therefore evaporated	
In the beginning . .	2.5 lbs. salt	in 38.3 cub. ft. of water		
After the first graduation	3.9 " "	" 24.7 " "	in the first graduation	13.6 c. f.
" second "	5.6 " "	" 16.6 " "	" second "	8.1 "
" third "	8.0 " "	" 11.3 " "	" third "	5.3 "

Whilst, therefore, the evaporation diminishes, the loss in gradua-

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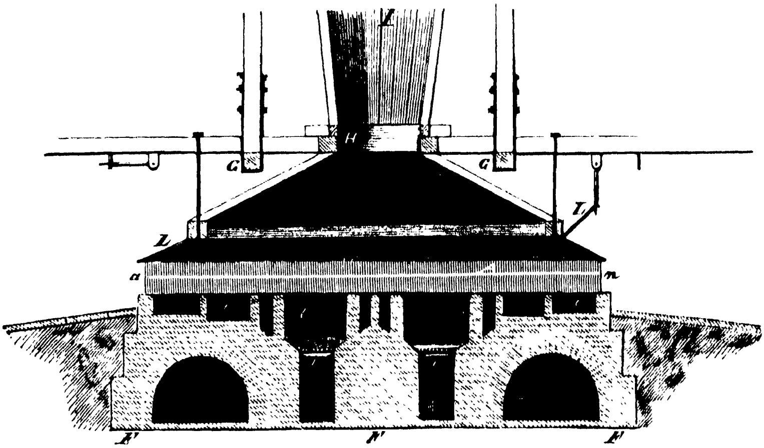
* Gypsum, according to Berthier, is most soluble in a brine of specific gravity 1.033, and is, therefore, not deposited at first from very weak brine.

tion increases with the strength of the brine, so that, at last, a period arrives when the loss of salt by the wind, and the advantage of further removal of water, compensate each other. Upon this, and upon the price of fuel, the extent to which graduation is carried must depend. In general, the *brine fit for boiling*, should not contain more than 23 per cent.; at Nauheim it contains 16.47, at Rodenberg 16.38, at Dürrenberg 22, at Schönebeck 17.5, at Artern 21.0 per cent. of salt; all natural or artificial brine of this, or still greater strength, as, for instance, that of Lüneburg (25 per cent.), Reichenthall (23 per cent.), or Wimpfen (25 per cent.), can of course be boiled down at once.

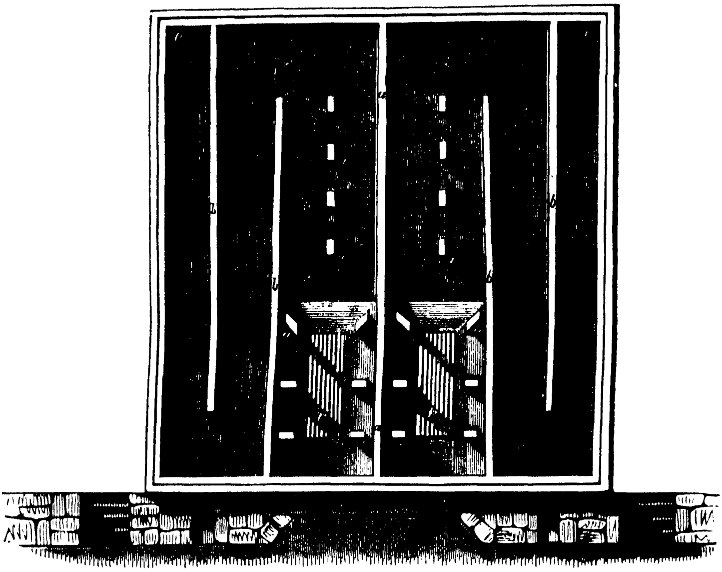
The Boiling.—As graduation only goes on during the fine season of the year, and the boiling during the winter, the concentrated brine is collected in large reservoirs, protected from the frost, and is supplied from thence to the *pans* in the boiling houses, which are thus rendered independent of the irregular progress of graduation. Their mode of construction will be seen in Fig. 107, which is a perpendicular section, and Fig. 108, which is the horizontal cross section at the height of the bottom of the pan. The pan *A* is a flat, four-sided vessel, of sheet-iron, with a flat bottom, somewhat deepened towards the middle, and several fathoms in length and breadth. Some are above 60 feet in length and half that width, others 20 feet square. The bottom of the pan is supported by the small pillars *a a a*, and the pieces *C C C*, which are built upon the foundation *F*, and form at the same time the flues *c c c*. The middle wall *d* divides the pan into two halves, each of which has its own grate, so that the pan is heated by two separate fires. The flues are calculated to disseminate the flame as uniformly as possible, which passes out behind at *e* to the drying chambers, which it heats, and then escapes by the chimney. This kind of firing is called a "*circulating hearth;*" another kind, in

Fig. 107.



which the flues proceed in a radiating manner from the grate, is called a "*radiating hearth.*" It is essential to rapid evaporation, that there should be a free circulation of air above the surface of the fluid. This is effected by a roof-shaped hood of boards *G G*, Fig. 107; *the steam or vapor trunk*, which, hanging from above, opens into the roof of the chamber, where (at *H*) it is connected with the vapor chimney *I I*. The lower margin with which the steam trunk appears to rest upon the pan, is only a series of wooden shutters *L L L*, which can be turned back as occasion may require, in the manner represented on the right hand in Fig. 107. The external air thus passes in a constant current over the surface of the fluid, and becomes saturated with aqueous vapor, which is carried off in the form of a visible cloud through *I*, where it partly condenses and collects. This liquid which collects, has been found by experience to contain, particularly during the boiling of the brine, about 1 per cent. of salt. To preserve this, and to prevent its running back into the pan, conducting tubes leading to a tank are fixed at *H*.

Fig. 108.



The process of boiling consists of two distinct operations; it begins with the further purification and evaporation of the brine up to the point of saturation—the *schlotage;* and finishes with the crystalization of the salt—the *soccage*.

The Schlotage.—When the pans have been rather more than half filled (up to *n n*, Fig. 107) with clear brine from the reservoir, in which a deposit is also formed, the brine is brought rapidly into a state of violent ebullition, and the evaporated portion is replaced from time to time by fresh brine. The surface soon becomes covered with a dirty brown scum, consisting of decomposed crenic and apocrenic acids, and a bituminous matter,* which, with the salts precipitated at the same time, collects into a thick mud, and is partially removed by means of rakes; but some attaches itself to the bottom of the pans (the *scale*). After 12 or 15 boilings, it increases often to the thickness of an inch, and must then be broken up with chisels. The salts are chiefly gypsum and sulphate of soda, probably in combination forming an insoluble double salt, which encloses a considerable quantity of chloride of sodium, and small portions of other metallic chlorides; as will be seen by the following analyses:

Contains	Mud from Moutier.			Panstone or scale.	
	at the beginning.	in the middle.	at the end.	Moutier.	Rodenberg.
Gypsum	28.0	41.1	10.1	11.8	34.7
Sulphate of soda . . .	24.5	52.6	25.7	20.6	7.0
Common salt . . .	47.5	6.2	64.2	63.4	57.6
Sulphate of magnesia . .	—	—	—	3.3	—
Chloride of magnesium . .	—	—	—	0.8	0.5
	Berthier.				Pfannk.

Both these depositions are, therefore, a new and increasing source of loss during the boiling. In the meantime, the solution of salt becomes more concentrated, by the constant evaporation and renewal of the brine, until at last it crystalizes. Imagine a pan containing 1600 cubic feet of brine (therefore, 176 cwts. of salt), to be refilled as often as ¼th is evaporated, after the first addition there will be 176 $+ \frac{176}{4} = 221$ lbs. of salt in the pan, after the second addition 176 $+ 2\frac{176}{4} = 286$ lbs., and so on. When, therefore, at the expiration of 20 or 24 hours, a scum of crystals begins to form over the surface, the fire is lessened, until the temperature of the brine falls to 90° (194° F.), or 75° (167° F.), when with slow evaporation the *soccage* begins and lasts for several days.

The Soccage.—During this time the surface is interspersed with small floating crystals which gradually grow into the well-known 4 sided funnels, and soon sink to the bottom when agitated by the vapor in making its escape. When the pan is kept at a high temperature, the crystals have no time for growing, and salt of a finer grain falls to the bottom; at the lowest possible temperature they remain floating a longer time, and produce salt of coarse grain. In the former case, the process is rapid, in the latter more slow. The process, however, or the temperature of the soccage is not entirely at the command of the workman, because the chloride of magnesium is always a source

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* Sometimes mentioned as organic matter in the analyses.

of obstruction when little or no sulphate of soda is present. Both salts mutually decompose each other in the pan, giving rise to chloride of sodium and sulphate of magnesia ($Cl\,Mg + So_3\,NaO = Cl\,Na + SO_3\,Mg\,O$). This has been observed in an interesting manner with the brine from Rodenberg. The more concentrated brine which contained chloride of magnesium but no Glauber's salt (see Analyses 3), became constantly covered all over its surface, at the ordinary temperature of soccage, with a continuous scum of salt, which could not be permeated or broken up by the vapors, and when removed was immediately reformed and entirely prevented evaporation. Thus no coarse-grained salt could be produced as it is required in commerce: the evil could only be remedied by reducing the temperature, which of course was attended by loss of time. An effective remedy was accidentally found for this evil, by mixing the weaker brine (in which there is no chloride of magnesium, but Glauber's salt) with the former, which is no doubt explained by the chloride of magnesium and sulphate of soda being mutually decomposed in the mixture into chloride of sodium and sulphate of magnesia. The result was the same when sulphate of soda was added at once without diluting the brine by the addition of so much unnecessary water. During Sunday, when all work is stopped, the crystals may be seen growing large at the bottom (*Sunday salt*), for the salt not being quite so soluble in the cold, a portion is forced to crystallize, as soon as the temperature is lowered, and this attaches itself to the other crystals already in the pan. It is evident, that the purity of the salt must diminish gradually towards the end of the process of soccage; thus Berthier found in the salt of Moutier:

	Salt.	Chloride of magnesium.	Gypsum.	Sulphate of magnesia.	Sulphate of soda.
At the beginning . . .	94.64	—	1.56	—	3.80
In the middle	93.59	0.61	—	0.25	5.55
Towards the end . . .	85.5	2.0	—	12.5	—

For this reason the soccage must be stopped before all the salt is deposited. During the whole process, the salt is raked up from the bottom with long rakes to the edge of the pan, and placed either in wicker baskets of peeled willow, or heaped upon the boards which are thrown back for the purpose, when in both cases the brine runs back to the pan. The moist salt, either in the same baskets or spread out upon hurdles, is then placed in the drying chamber as long as it loses moisture, when it is packed up for sale. A general view of the nature of the brine, and the mode of procedure in the salt works, does not lead us to expect pure chloride of sodium, and this is confirmed by the analyses. There has been found, for example, in salt from:

	Schönebeck	Sulz.	Ludwigsthall.	Konigsbronn.	Chateau Salins.	Moutier, (Summer salt.) From the brine cisterns.	Moutier, (Summer salt.) From the ropes.
Chloride of sodium . .	93.9	96.88	99.45	95.90	97.82	98.67	97.17
Chloride of magnesium . .	0.3	3.12	—	—	2.12	0.18	0.25
Chloride of calcium . .	—	—	—	0.27	—	—	—
Sulphate of soda . . .	1.0	—	0.05	—	—	0.75	2.00
Sulphate of magnesia . .	—	—	—	—	—	0.40	0.58
Gypsum	0.8	—	0.28	1.10	—	—	—

Of all these salts, chloride of magnesium is that which has the greatest influence upon the quality of the produce, both on account of its deliquescence in the air and its highly saline taste. For, whilst pure chloride of sodium never attracts moisture from the air, it is well known how rapidly ordinary salt becomes wet in damp weather; this is still more evident when the salt has to be removed to a distance, and is proportionately more rapid when it contains a large quantity of chloride of magnesium. On the other hand, such salt is not unfrequently preferred in the kitchen to the purer kinds, as less of it is necessary for salting.

Berthier is the discoverer of a very ingenious method of getting rid of the chloride of magnesium during the soccage; slaked lime is to be added to the brine in the pan, until the whole of the chloride of magnesium is decomposed ($Cl_2\ Mg + Ca\ O = Cl_2\ Ca + Mg\ O$); on being evaporated further, the chloride of calcium formed is decomposed with sulphate of soda into chloride of sodium and gypsum ($Ca\ Cl + NaO, SO_3 = Na\ Cl + CaO, SO_3$). Of course the presence of a quantity of sulphate of soda equivalent to the chloride of magnesium is here essentially necessary.

The requisite quantity of brine for each process of soccage, leaves, when the process is finished, a very impure solution of salt which, however, is not so bad as to be at once rejected. A second, and sometimes even a third charge may be boiled down before the residue —*mother liquor*—is removed, which is either used to produce an inferior kind of salt, or for other purposes. The following table shows the nature of the mother liquor.

Analyst.	In the mother liquor of	Chloride of calcium.	Chloride of magnesium.	Chloride of potassium.	Common salt.	Sulphate of magnesia.	Sulphate of lime.	Bromides and iodides.	Water.
Pfannkuch. .	Rodenburg .	—	18.33	—	5.82	5.44	0.11	trace.	70.30
Berthier . .	Moutier . .	—	4.85	—	20.80	9.50	—	—	64.85
Brandes .	Unna in	9.98	7.89	2.29	7.45	—	0.06	0.100	72.23
Liebig .	Westphalia .	21.78	8.86	1.05	2.21	—	0.01	0.16	65.91

In cases where the brine contains iodides and bromides, these, from their high degree of solubility, will be found in the mother liquor, and, as in Kreuznach, Unna, and Salzhausen, will communicate medicinal properties to it, which are particularly applicable to the cure of scrofulous diseases. The quantity of sulphate of soda can be increased by freezing the liquor, and then obtaining it from this, as from the scale by crystalization. By evaporating the residual liquor, sulphate of potash may be separated, and lastly the chloride of magnesium is converted by the addition of sulphate of soda and heating to 50° (122° F.) into Epsom salts. Both Epsom and Glauber's salt are extensively used in medicine.

[*Salt Springs in the United States.*—The following are, according to the report of Dr. L. C. Beck, the proportions of brine required to produce a bushel of salt at the several salines hitherto explored in the United States, including also one in Canada. The most celebrated localities for the manufacture of salt from brine springs in this country are those on the Conemaugh, in western Pennsylvania, on the Kenhawa in western Virginia, and in Onondaga and Cayuga counties in New York. The salt manufactured in New York State in 1841 was 3,134,317 bushels; in 1826 it had been only 827,508 bushels. Hence it increased nearly 300 per cent. in fifteen years.

Table showing the number of gallons of salt water producing a bushel of salt in different parts of the United States.

Nantucket sea water . .	350	Grand River, Arkansas . .	80
Boon's lick, Missouri . .	450	Illinois River, do. . .	80
Conemaugh, Pennsylvania .	300	Montezuma, N. Y., old wells .	70
Shawneetown, Illinois . .	280	Grand Rapids, Michigan	50 to 60
Jackson, Ohio . . .	213	Muskingum, Ohio . . .	50
Lockhart, Mississippi . .	180	Montezuma, N. Y. (new well) .	50
Shawneetown, 2d saline, . .	123	Onondaga, N. Y. (old wells)	40 to 45
St. Catharine, Upper Canada .	120	Onondaga, N. Y. (new wells, Syracuse,) . . .	30 to 45
Zanesville, Ohio . . .	95		
Kenhawa, Virginia . .	75		

Table showing the composition of various brines from Onondaga and Cayuga Counties, New York, in 1000 parts.

	From the well at Geddes.	From the well at Syracuse.	Old well at Salina.	Well at Liverpool.	New well at Syracuse.	Well at Montezuma.	Old deep well at Montezuma.	New well opened in 1840 at Montezuma.
Carbonic acid,	0.06	0.07	0.09	0.07	8.50	0.08		
Oxide of iron, silica, and trace of carb. of lime,	0.01	0.02	0.04	0.03		0.02		
Carbonate of lime,	0.10	0.14	0.17	0.13		0.18	0.02	
Sulphate of lime,	1.93	5.69	4.72	4.04		5.25	4.31	
Chloride of magnesium,	0.79	0.46	0.51	0.77		1.00	0.30	
Chloride of calcium,	2.03	0.83	1.04	1.72		1.40	1.53	
Chloride of sodium, pure salt,	130.66	132.39	140.02	142.85	173.50	93.35	73.72	
Water and trace of organic matter,	861.39	860.40	853.41	850.39	818.00	898.72	920.12	870.67
Total solid in 1000 grs,	138.55	139.53	146.50	149.54	182.00	101.20	79.88	129.33]

Many of the arts whose province it is to supply the most important demands of society, are subservient to the use which is made of soda, an alkali which thus becomes one of the chief levers of manufacturing industry. The state in which this substance, commonly called *soda*, is supplied by commerce to the arts is essentially that of a *carbonate.* Commercial soda may, therefore, be considered chemically as more or less pure carbonate of soda.

Native soda.—In several places, but not in any great quantity, a mineral mass is met with in nature, which consists chiefly of sesquicarbonate of soda ($2\ NaO + 3\ CO_2 + 3\ aq$); it is left as an incrustation, when the so-called soda lakes dry up in the summer. Thus in Egypt, to the west of the Delta, and in the neighborhood of Fezzan, it occurs in layers half an inch in thickness; and is called by mineralogists *Trona.* The Mexicans call the same substance *Urao* when it occurs in their own country, as for instance in a lake near that city. The following is found to be its composition:

Constituents.	Trona.				Urao.
	From Egypt.			From Fezzan.	Boussingault.
	Laugier.		Klaproth.		
Carbonic acid	22.44	—	32.6	37.0	41.22
Soda				38.0	39.00
Water	14.00	—	31.6	22.5	18.80
Sulphate of soda	18.35	—	20.8	2.5	—
Common salt	38.64	—	15.0	—	—
Foreign matters	6.00	—	—	—	0.98

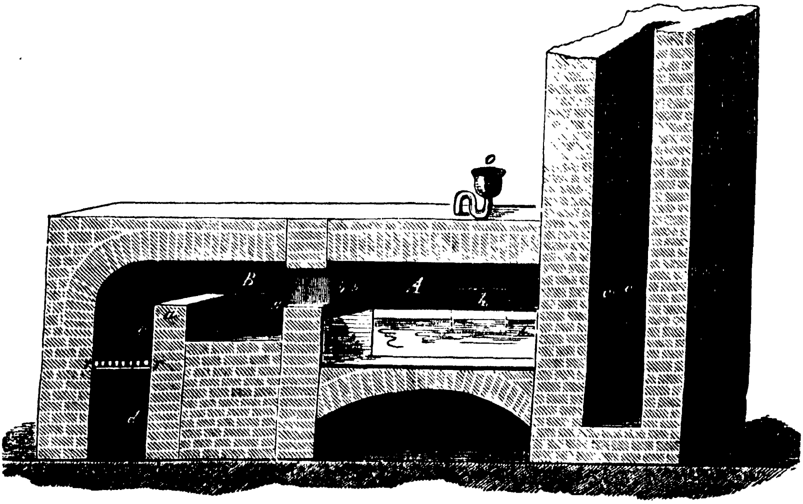
In Hungary, native soda occurs in the department of Bichar near Mariatheresiopel, again in the Lesser Kumania near Shegedin, where there are already five manufactories engaged in its production, and in other localities. The salt, called there *Széksó*, exudes as a snow white crust upon the surface of the ground, and is swept up as a grayish mass mixed with earth at an early hour of the morning before sunrise (when it is said to be most abundant). This soda earth is treated precisely in the same manner as crude soda, and the ash of plants in the potash manufactories, which will be described below; it is lixiviated with water and the lye—which contains besides soda, sulphate of soda, chloride of sodium, and earthy impurities—is evaporated to a saline mass, the coloring extractive matters of which are destroyed by heating to redness. Native soda forms a very small proportion of the enormous quantity consumed in the arts.

The soda, which is required to meet this consumption, is prepared for the greater part by a chemical *transformation of chloride of sodium;*

a much smaller quantity is obtained by the *incineration* of certain *marine plants*.

Artificial Soda from Chloride of Sodium. Historical.—The present mode of carrying on this important manufacture, and now very generally adopted, was the invention of Leblanc, and first carried out on a large scale by him and his partners Dizè and Shée in France. As is well known, this discovery created an era in the history of manufactures; but the manner in which it was made public does honor to the genuine and magnanimous patriotism which animated, in those times of danger, the flower of the French nation. Before the revolution of 1789, no other kind of soda was known in France but that obtained from marine plants, and this for the greater part was imported from abroad, from the coasts of Spain. The wars of the republic with nearly the whole of Europe, in annihilating trade, put a stop to this and other equally important resources for native industry. Amongst others, the importation of potash was stopped. Although in cases of need, soda may be replaced by potash in the manufacture of glass and soap, for the purposes of the bleacher and dyer, &c., yet the prosperity of these branches of manufacture, at a time when the very existence of the republic was at stake, was of as little moment as the fall of a single soldier in a skirmish. All the potash, therefore, that could be obtained in France was immediately applied to the manufacture of saltpetre; for the expulsion of the enemy superseded all minor cares. Necessity is always the mother of great deeds, and the republic mastered the difficulty by an unprecedented development of internal power. Thus the committee of public safety, incited by the proposition of a manufacturer of the name of Carny, in the Year II., called upon all citizens, in a special proclamation, to place in the hands of commissioners within two decades, for the benefit of the re-

Fig. 109.



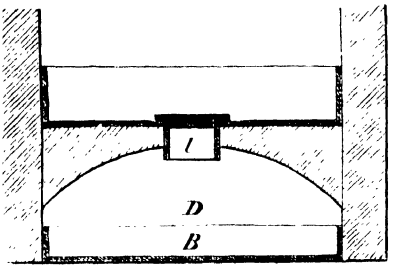
public and without regard to all private ends and speculations, whatever plans and methods of preparing soda might be known to them. The report of the commissioners upon all the numerous plans proposed by disinterested manufacturers, declared the process of Leblanc to be the simplest and best calculated for an extensive scale of manufacture; a decision, the justness of which has been proved by fifty years' experience, no essential improvements having been made in the process. It consists in converting chloride of sodium into sulphate of soda (Glauber's salt), and in the further decomposition of that salt.

Glauber's Salt.—The production of Glauber's salt is sometimes carried on in leaden pans, which, for that purpose, are built into reverberatory furnaces, or rather in furnaces, the soles of which are lined with lead, by heating chloride of sodium with sulphuric acid. Fig. 109 shows the manner in which a furnace of this kind is divided behind the bridge *a* into two separate compartments *B* and *A*. In *A*, the hinder and less heated part, the decomposition is effected, and in the front chamber *B*, which is considerably hotter, all the free acid is expelled, the salt melted, and the process completed. Both compartments are, therefore, in use at the same time, the one engaged in decomposing the fresh charge, the other in melting the previous charge. The flame passes from *B* through five apertures or slits *b*, *b* into *A*, and from thence through three other wider ones *c*, *c* into the chimney. Where several furnaces are worked at once, and on the same spot, one chimney serves for all, which must of course be large in proportion, and the smoke passes into it through subterranean flues. Below the grate *r r*, at *d*, is the ash pit door; above it, at *e*, is the grate door; *g* and *h* are the working apertures. Apertures corresponding to *e*, *g*, and *h*, are made also on the opposite side, so that each compartment of the furnace is accessible from two sides. In order that the contents of the leaden pan *i i* may be easily removed, a part of this is cut away at *h*, which in the mean time is filled up with clay and bricks. Stones which are liable to be too easily acted upon by the acid vapors, must not of course be used in the construction of the furnace.

The charge consists of from 3 to 8 cwts. of culinary salt or pounded rock salt. It is not absolutely necessary to use the most concentrated sulphuric acid, as that obtained direct from the chambers will answer the purpose. A well arranged soda work, therefore, generally includes a number of sulphuric acid chambers, from which the acid is taken at once (at 52° B.) without being subjected to the extra process of concentration. According to theory, about 85 parts of commercial acid, and from 130 to 137 parts of acid from the chamber are required for every 100 parts of salt. But as a slight excess of salt is not injurious, somewhat less acid is generally used, namely, equal quantities of salt and acid. As soon as the furnace is sufficiently heated, the charge of salt is introduced through *h*, and the necessary quantity of sulphuric acid is measured out in a graduated vessel, and poured upon it through the leaden funnel *o*. Violent ebullition immediately ensues from the evolution of hydrochloric acid, which is still further augmented by frequently stirring the mass. At the expiration of about two hours, the evolution of gas ceases, and when the mass has become quiet and sufficiently stiff to solidify, on cooling, it is removed to *B*, that the pan may not be fused, and damaged by the caking of the mass on the application of more heat. In *B* it is calcined, *i.e.* heated to such an extent, that the remainder of the water and acid are completely expelled. As soon as the leaden pan is emptied, a fresh charge of salt is introduced, and the process repeated.

During the operation itself, and still more on clearing out the leaden pan, the workmen are exposed to the injurious effects of the hydrochloric acid vapors. The arrangement shown in Fig. 110, is intended to obviate this evil. Instead of raking the charge of the pan out of the furnace, it is allowed to fall through an aperture *l* in the bottom—which at other times is closed by a leaden door—into the vault *D*. When it has sufficiently cooled, the operation is completed in *B*.

Fig. 110.



By the agency of the water in the sulphuric acid, hydrochloric acid is generated, and sulphate of soda (anhydrous) is produced. For $SO_3, HO + Cl\ Na = SO_3 + NaO + Cl\ H$; sodium, therefore, simply takes the place of hydrogen in the hydrated sulphuric acid, whilst the hydrogen in combination with chlorine is evolved as hydrochloric acid; 100 parts of chloride of sodium thus afford 62 parts of dry hydrochloric acid, and 116 and more parts of sulphate of soda; theoretically there should be 121½ parts.

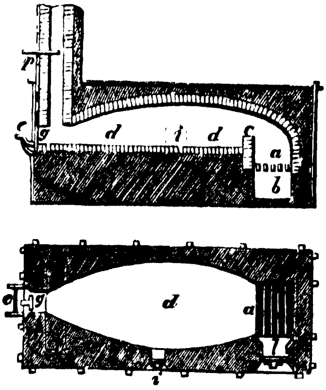
In localities, where there is a sale for hydrochloric acid, and where it can be usefully employed, it is condensed by causing the acid smoke to pass through a series of stone jars containing water (Woulff's apparatus) before escaping by the chimney. It is then better (*i. e.* there is less loss) to use close iron cylinders, like gas retorts, for the decomposition, the pipes of which lead to the condensing vessels. Such advantageous conditions are, however, seldom to be met with, and the hydrochloric acid, instead of being a source of profit, is quite the reverse; and whether it is allowed to escape entirely or is condensed, its removal is always a source of expense.

In condensing with the moisture of the air to aqueous hydrochloric acid, it falls as a cloud and destroys all vegetation in the neighborhood, much to the injury of the inhabitants, giving rise to incessant complaints and compensation for damages. An attempt has been made in England, by heightening the chimneys, to carry the current of gas into the higher regions of the air, where it was anticipated, that the acid would at least fall in such a diluted state as would not be injurious. Thus—between Manchester and Liverpool—the conical chimney of Muspratt rises to a height of 495 feet, being 30½ feet in diameter at the foot, and 11 feet at the top, and containing 1 million of bricks in its structure.*

Others conduct the acid through a channel filled with flints which are constantly kept wetted with water, in order to condense, at least, the greater portion. Others, again, use soft limestones for the same purpose, when carbonic acid, which is harmless, is evolved and chloride of calcium produced. It has further been proposed, to avoid the evolution of hydrochloric acid altogether, by adding sulphuric acid and zinc to a solution of chloride of sodium in water. Hydrogen is evolved and the sulphate of zinc produced is converted into chloride of zinc, and sulphate of soda is obtained at the same time. These products can be separated by crystalization; and from the mother liquor, lime will precipitate hydrate of zinc, which can be used afterwards instead of metallic zinc. Lastly, some have advocated the plan of boiling a solution of chloride of sodium with sulphate of magnesia, and of separating the sulphate of soda from the chloride of magnesium by crystalization; the latter can then be converted into carbonate, and by means of gypsum again into sulphate.†

The combination of the manufacture of bleaching powder with that of soda, as it is carried on in the celebrated works of Tennant at St. Rollox, near Glasgow, is unquestionably the best, although not always practicable. The chloride of sodium is there first employed for the evolution of chlorine, being heated together with sulphuric acid and peroxide of manganese in leaden vessels. Whilst all the hydrochloric acid is used as chlorine in converting lime into bleaching powder, a mixture of sulphate of soda, protosulphate of manganese, and some free sulphuric acid remains, to which as much common salt is added, as is necessary to saturate the free sulphuric acid, and the whole is heated in a reverberatory furnace, Fig. 111. The small quantity of hydrochloric acid which is now evolved, is the only portion that is lost. By heating the solid

Fig. 111.



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* The chimney of Messrs. Tennant's soda works at St. Rollox, Glasgow, is still higher.

† Various other plans have been proposed to supersede that now generally employed, among which we may notice that of Dyer and Hemming's for mining common salt and sesquicarbonate ammonia; Poole's for decomposing common salt by sulphate ammonia; Phillip's for employing green copperas liquors and common salt; Splisbury and Maughams for fluoric and fluosilicic acids and common salt; Longmaid for roasting pyrites and common salt at a low heat in a reverberatory furnace; De Sussex for employing nitric acid; Tilghman for heating common salt and sulphate of lime in a current of steam; and Duclos for melting sulphate of iron and ammonia in a reverberatory furnace. [The method of R. A. Tilghman is described in the Journal of the Franklin Institute, 3d Ser., vol. xiv. p. 242.—Am. Ed.]

melted saline mass to redness in a current of air, the manganese and iron salts are decomposed, and the sulphate of soda can be separated from them by dissolving it out with water; this is then worked as usual in the soda furnace. The same application, but effected in a less convenient manner, is that proposed by Seybell and Maugham, viz., to conduct the hydrochloric acid into a vessel with water and manganese, when chlorine is immediately evolved.

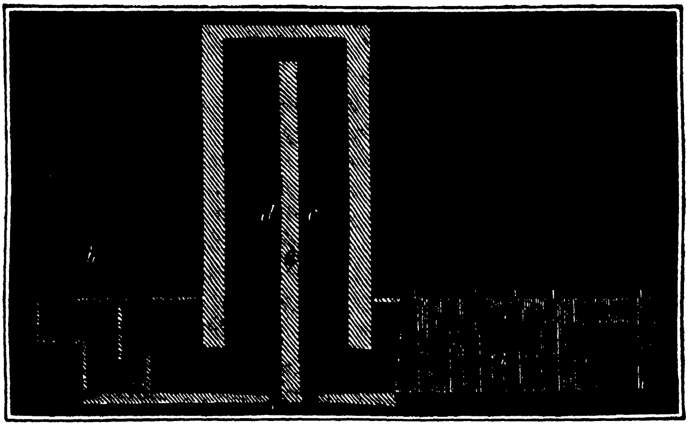
Notwithstanding these propositions, the removal of the hydrochloric acid in an appropriate manner is still one of the most interesting and difficult technical problems; and it is a remarkable fact, that the profits of an establishment should be reduced by the production of so useful a substance.

If, for instance, the proximity of a salt work affords opportunities of producing sal ammoniac from sulphuric acid, ammonia, and common salt, to which Siemens has already called attention, and at the same time sulphate of soda; this of course is an advantage, and the following process can at once be proceeded with.

In the old plan of decomposing common salt, the whole of the muriatic acid was allowed to pass off into the atmosphere. The destruction to the surrounding vegetation, from the effects of the muriatic acid, soon gave rise to repeated demands upon the manufacturers for damages; and in the celebrated cause of the corporation of Liverpool *versus* Muspratt, even led to the defendant removing his works from the town of Liverpool. Various plans have been proposed to remedy this annoyance, and the process which seems most likely to become generally adopted is that of Mr. Bell; but in consequence of other improvements, the application of this process is modified according to circumstances.

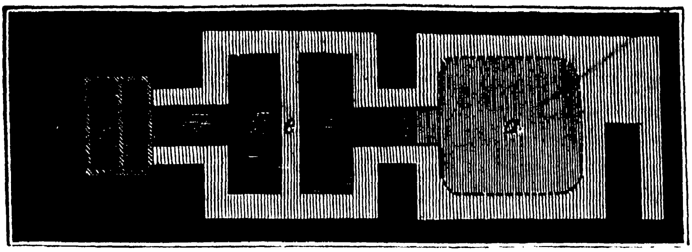
In those cases where the muriatic acid is not applied to the manufacture of bleaching powder, and is consequently not required to be of the same strength, the arrangement adopted is shown in Figs. 112 and 113. *a* is an ordinary reverberatory furnace for decomposing

Fig. 112.



common salt, which is connected by means of a flue *b* entering at the lower end of a tall square tower built of brick or stone, cemented by a mixture of clay and tar. This tower is divided into two compartments *c* and *d* by a partition wall *e*, and the whole filled with small pieces of coke. A large supply of water is kept continually running through several openings of the top of this tower, or *condenser*, as it is technically termed, which streams are still further scattered over the surface of the coke, by impinging upon small rounded pieces of stone or brick. At the lower end of the condenser, a flue *f* leads to a cistern *g* partly filled with water, which is again connected with an inverted cone or funnel *h*, through which a steam jet *i* blows into an underground flue. The drawing only shows the steam escaping into the air as it was first applied. Fig. 112 shows a section of the arrangement, and Fig. 113 a ground plan.

Fig. 113.



The muriatic acid gas, as it escapes from the furnace, comes in contact with the water falling through the coke, which, from its porosity, presents a great surface to the gas in its upward and downward course, and which is thus completely absorbed in its passage, running out at last by openings *k k* at the bottom of the condenser. The traces of liquid muriatic acid, which may be carried away by the mechanical action of the draught, are retained by the water in the cistern *g*. The draught through the furnace and coke condenser is maintained entirely by the action of the little jet of steam blowing through the funnel or cones, and possesses considerably more power for this purpose than the tallest chimney. The steam is so perfectly free from acid vapors, that the face may be fully exposed to it without experiencing the least inconvenience. The use of the underground flue is simply to condense the waste steam, so that, at the open end, little or no aqueous vapor escapes into the atmosphere.

The muriatic acid which runs from the condenser is employed in some cases to generate carbonic acid from limestone, for the manufacture of bicarbonate of soda, or carbonate of magnesia.

A modification of this process, when the object is to obtain strong muriatic acid, consists of the following arrangements. Fig. 114 is the section of a furnace heated from above and below, in which *a* shows the position of a cast iron pan, where the common salt is de-

Fig. 114.

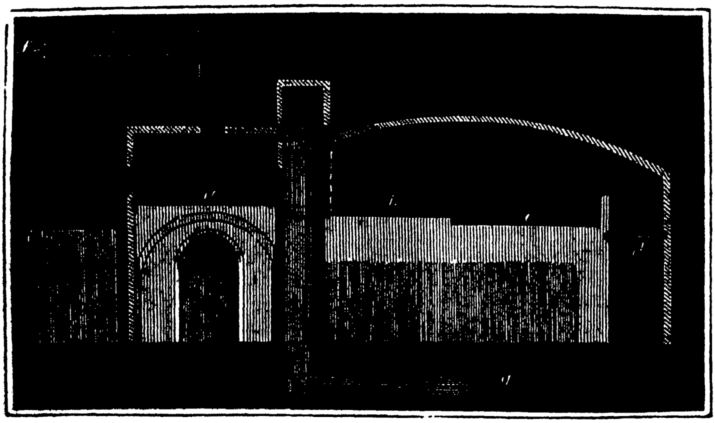
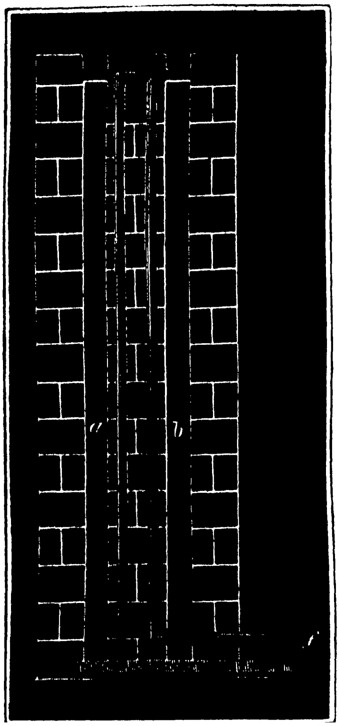


Fig. 115.



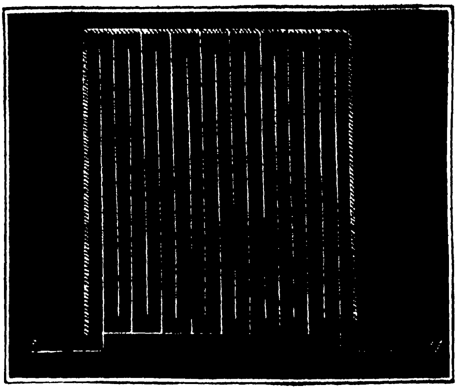
composed by sulphuric acid, previously concentrated as already described up to 1.600 sp. gr., and where the muriatic acid escapes through the flue *f*. As soon as the resulting sulphate is sufficiently dry, it is removed to the other beds of the furnace, *b* and *c*, where all the remaining muriatic acid is entirely driven off by the heat of the fire *d*. These last traces of muriatic acid escapes through the flue *g*.

The muriatic acid which escapes through the flue *f*, is, of course, free from all the gases of the burning fuel, and accompanied by very little steam, in consequence of the strength of the sulphuric acid employed. It passes to a condenser (Fig. 115), in which it traverses the flue *f* inside of the condenser as it were, exposed to the cooling action of the water falling through the coke in the spaces *a b*, and hence, when it enters at the bottom of the coke column it is comparatively cold, and requires much less water for complete condensation. The draught is maintained along with the other arrangements as described in the first instance. The muriatic acid obtained in this way is applicable to the manufacture of bleaching powder.

The spent muriatic acid, so to speak, from the beds *b c*, in Fig.

114, is carried by the flue *g* to another condenser shown in Fig. 116, of a more simple construction, consisting merely of alternate up and down flues of brick, through which the water falls from above. The muriatic acid from the condenser is applicable to the same purposes as that first described. The introduction of the use of the iron pan, and this plan of decomposition which has proved of so much value in alkali works is due to Mr. John Lee, while the employment of such strong sulphuric acid in decomposing common salt is attended with the further advantage of preventing the formation of so much bisulphate as usual.

Fig. 116.



Mr. Longmaid has proposed a plan of manufacturing sulphate of soda without the previous process of producing sulphuric acid. He mixes common salt and ground pyrites together, and exposes them to a slow heat in a reverberatory furnace through which a current of dry atmospheric air is forced. A mutual decomposition ensues: the common salt is converted into sulphate of soda, while the chlorine escapes at first in the form of muriatic acid, and ultimately nearly as pure chlorine. The mixed sulphate of soda and oxide of iron are then balled in the usual way for making carbonate of soda. He proposes to remove the muriatic acid from the chlorine by bringing it in contact with a surface of wood kept moist from the outside, then drying the chlorine and employing it for the production of bleaching powder. This process has only one defect arising from the slowness with which the decomposition of the common salt proceeds; but it presents a plan which, by perseverance in the hands of an able practical manufacturer, would certainly succeed.

Crude Soda.—The object of this process is to convert sulphate of soda by heating it to redness with charcoal and carbonate of lime, into carbonate of soda. Wood charcoal is seldom cheap enough to be used for this purpose; and small coal, or refuse brown coal, which does not leave too much ash, is substituted for it. Any kind of limestone, chalk, &c., in which there is not much alumina, may be used as carbonate of lime. Sometimes deposits of a kind of dusty limestone, tufa from spring water are employed, which then require no pulverization..

According to the original plan, 100 lbs. of sulphate of soda, as much chalk, and 55 lbs. of charcoal should be taken; but the proportion of lime is often increased to 110 or 120. The more intimately the constituents are mixed, the more complete and rapid is the action. For this reason, it is necessary to grind them beforehand to a coarse powder, and to sift and mix them as intimately as possible. The charge, from 2 to 2½ cwts., is heated in a reverberatory furnace, Fig. 111 (p. 265), the sole of which is about 10 feet long, somewhat concave, and of an oval shape; all corners are avoided, that portions of the mass may not collect in them, and escape the action of the fire and the stirring rods. The firing on the grate *a* is supplied through the door *l*, the charge is introduced and constantly raked over in *d*, from the apertures *i* and *g*. For facilitating the use of the long heavy iron stirring rods and rakes, a roller *e* is placed in front of *g* as a support. The register *p* can be entirely dispensed with in this arrangement. Sometimes the furnaces are much larger and calculated for a charge of 20 cwts. Recent experience has, however, shown smaller furnaces, like Fig. 117, with a double-working hearth, to be more advantageous. The hindermost hearth *B* is used simply for heating the mass, and is only separated from the melting hearth *A* by having its sole raised one brick above it. When the mass begins to soften in *B*, it is raked down to *A*, and its place immediately supplied by a fresh quantity.

Fig. 117.

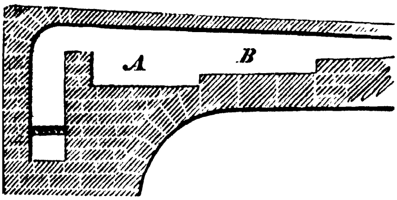
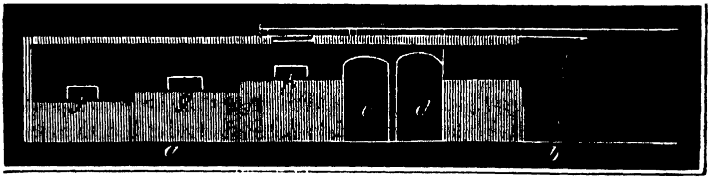


Fig. 118 is a sketch of the present plan of balling furnaces as most

Fig. 118.



economical. There are two furnaces shown, *a* and *b*, with fire places adjoining *d c*. Each furnace has three beds, *f g h*.

Whilst the charge is introduced, the register remains half closed, or the draught would carry up a portion with it. As soon as the whole is introduced, and the mass properly spread over the sole of the furnace, the doors are closed that the heat with the open register, may exert its full power. In a short time, the surface begins to soften and form into roundish balls, and this must be the state of the whole mass before the process can proceed. By cautious stirring (that no dust may fly off) a fresh surface is constantly exposed to hasten the softening, until the whole mass appears to have the consistence of dough. At this period, the actual chemical decomposition begins with a lively evolution of gas. Numerous bubbles of carbonic oxide burst with a blue flame, and rising with the other products of decomposition of the coal, set the mass in motion, which must now be constantly stirred and worked up with the rakes, that all parts may take an equal share in the decomposition. At last the mass of soda completely melts, and from the evolution of gas appears to boil; this, however, gradually ceases, and at length the whole is in a tranquil state of fluidity. The decomposition is thus completed, and it is time to rake out the *crude soda* (or ball soda) as it is now called, into iron wheel-barrows, in which it solidifies.

During the process, the charcoal and the lime do not act simultaneously, but consecutively upon the soda salt, so that really two distinct processes occur one after the other, which could be carried on equally well in two separate furnaces, if the sulphate of soda were first heated to redness with charcoal, and the product then heated with lime. The charcoal is consumed at the expense of the whole of the oxygen in the sulphate of soda ($SO_3\ NaO$) forming carbonic oxide, and sulphuret of sodium alone remains, for $SO_3\ NaO + 4\ C = 4\ CO + S\ Na$.

When this process is completed, the action of the lime begins, and an exchange is effected between its constituents and those of the sulphuret of sodium, so that carbonate of soda and sulphuret of calcium are produced ($NaS + CO_2\ CaO = NaO,\ CO_2 + CaS$). If a portion of the lime has been burnt and become caustic before this decomposition takes place, sulphuret of calcium is formed and a corresponding quantity of caustic soda ($CaO + NaS = CaS + NaO$) which gradually absorbs carbonic acid from the gases in the furnace. The object in view—namely the production of carbonate of soda—would thus be obtained, but in an unsatisfactory manner. For, in endeavoring to separate the soda salt from the difficultly soluble sulphuret of calcium by means of water—which must take place sooner or later—the decomposition under these circumstances is reversed, sulphuret of sodium is again produced and carbonate of lime, and the substances are exactly in the same position as they were immediately after the action of the charcoal. Experience has furnished us a remedy for this evil in using twice as much lime as is absolutely necessary to desulphurise the sulphuret of sodium. This second portion of lime, at the end of the operation, after having lost its carbonic acid, forms with the sulphuret of calcium a peculiar compound which has no further action upon carbonate of soda under water. If, with Dumas, this compound is supposed to consist of 2 eqs. sulphuret of calcium and 1 eq. of lime, then, there must be used in all:

		or	there is actually employed
2 eqs. sulphate of soda	= 1784 —	100	100
8 " charcoal	= 600 —	33.6	55
3 " carbonate of lime	= 1893 —	105.3	100 to 110 or 120,

whence it is evident, that theory leads to the adoption of the same proportions as the circumspect manipulation of manufacturers had already ascertained to be the best. More coal than charcoal is required to produce the same effect, and an excess of charcoal is always desirable.

A single glance at the theoretical explanation of the soda process is sufficient to show of how great importance a proper regulation of the draught, the uniform mixture of the softened mass, and the seizure of the exact moment for its removal from the furnace must be to the success of an operation which mainly depends upon a separation of oxygen. When it is remembered, that a reverberatory furnace is nothing more than a blow-pipe upon a large scale, in which by means of the draught, a flame is made to play upon the substance to be heated, it becomes evident, that, as on the small scale, with a strong draught, an oxidizing (consuming) action must be exerted, so with a lesser draught oxygen must be withdrawn from the heated body, or at least the action can only be slightly oxidizing. On the other hand, the metallic sulphurets (sulphuret of sodium, sulphuret of calcium) have a powerful affinity for oxygen. The draught, therefore, should be so regulated (the register so placed) that no free oxygen should exist in the flame. This, however, is not practicable, as great heat is required; the mass must consequently be kept as short a time as possible in the furnace, and constantly stirred, whilst the draught is regulated in the most favorable manner. Nevertheless a portion of sulphuret of sodium is always converted into soda salts containing some of the acids of sulphur; and sulphate of lime is always formed from sulphuret of calcium, which afterwards gives rise to a second formation of sulphate of soda, becoming converted, in contact with carbonate of soda, into carbonate of lime.

Several new processes have been proposed for converting the sulphate of soda into carbonate, some with the view of saving one or more of the steps subsequent to the balling with coal and limestone, others with the object of recovering the sulphur of the black balls. Amongst these we may notice that of Leighton for admitting steam among the materials when in a melting state; Shanks for passing carbonic acid through the vat liquors to carbonate the soda; Samuels for converting sulphate of soda into sulphuret, by adding sulphuret of barium to a solution of the former; and Clough for neutralizing the caustic soda by means of silica; but as none of them have been carried into practical operations, a reference to the list of specifications, which is annexed, must answer our present purpose.

The "*crude soda*" has the appearance of roundish balls of half vitrified ash, and forms gray, more or less solid masses mixed with particles of coal, consisting of carbonate, sulphate, sulphite, and hyposulphite of soda, caustic soda, sulphuret of sodium, undecomposed chloride of sodium, sulphuret of calcium combined with lime, and lime.

The following analyses have been very recently made of this product.

COMPOSITION OF THE BLACK BALLS FROM THE BALLING FURNACES.

	From Cassel.	From Newcastle.
Sulphate of soda	1.99	3.64
Chloride of sodium	2.54	0.60
Carbonate of soda	23.57	9.89
Hydrate of soda	11.12	25.64
Carbonate of lime	12 90	15.67
Sulphuret of calcium	34.76	35.57
Sulphuret of iron	2.45	1.22
Silicate of magnesia	4.74	0.88
Charcoal	1.59	4.28
Sand	2.02	0.44
Water	2.10	2.17
	99.78	100.00
	Unger.	Richardson.

As the result of experiment it has been found, that 100 parts of sulphate of soda produce 153 to 168 parts of crude soda, in which are contained from 50 to 55 parts (32½ to 33 per cent.) of pure, dry, carbonate of soda, whilst, according to theory, 75 parts ought to be obtained from the same quantity of sulphate of soda.

For many purposes, crude soda is used as it leaves the furnace, and it is consequently an article of commerce. For such purpose a sulphate of soda is employed, which contains from 10 to 12 per cent. of common salt; this remains unchanged in the soda, and communicates to it the property of easily falling to pieces in damp air, thus obviating the necessity for grinding. Sometimes (for instance, to the soap-boilers), a certain quantity of common salt is desirable.

The greater part of the crude soda is converted at once on the spot into pure carbonate of soda—either anhydrous or crystalized. The crystals of this salt are generally a very safe guarantee of its purity, but they contain 10 equivs., or 62.85 per cent. water. *Soda salts* (anhydrous), therefore, as well as crystalized soda are both articles of manufacture.

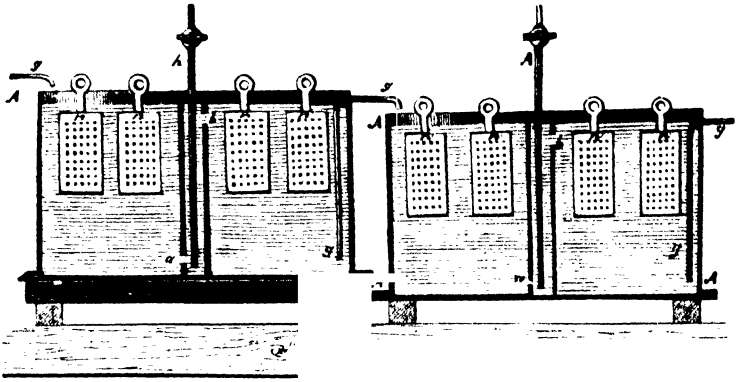
Solution.—As it leaves the furnace, the crude soda is too firm and solid to be easily dissolved out with water. It must, therefore, either be crushed under upright mill-stones and sifted, or loosened and made soluble by hot vapor. With this view the mass is sprinkled with water in a tolerably hot furnace, where, in the atmosphere of vapor, it soon swells up and falls to pieces. In the subsequent treatment with warm water, carbonate of soda and the other soluble salts are taken up, and the compound of lime with sulphuret of calcium remains.

The composition of this tank waste or refuse, after extracting the soda, according to a recent analysis of Unger, is as follows:

Carbonate of lime	19.56
3 Ca S, CaO	32.80
Sulphate of lime	3.69
Hydrosulphate of lime	4.12
Hydrate of lime	4.02
Bisulphuret of calcium	4.67
Sulphuret of calcium	3.25
Hydrate of lime	6.67
Sulphuret of sodium	1.78
Oxide of iron	3.70
Silicate of magnesia	6.91
Charcoal	2.60
Sand	3.09
Water	3.45
	100.31

The whole quantity of water used for the purpose of solution must be evaporated after the separation of the waste with a corresponding consumption of fuel. Although it is of course advantageous on the one hand to use as little water as possible, yet it is equally desirable on the other hand to dissolve out every particle of alkali from the residue. In this, as in all other similar cases, both objects have been attained by one and the same ingenious method. The difficulty is obvious; if too little water is used in the first instance, a portion will remain undissolved; in the opposite case, all the alkali will be dissolved; but, as at first, the whole solution cannot be drawn off, for a considerable quantity is kept back by the spongy residue. It is, therefore, impossible in any case to obtain the whole quantity of soluble matter with one portion of water, a 2d, 3d, and 4th portion will be required, each of which will contain a less quantity in solution, so that altogether there will be a vast excess of water. The contrivance by which this difficulty is overcome, depends upon an uninterrupted continuance of the process, and consists in using the same water which was employed for the first infusion, with fresh portions of crude soda, until the solution has acquired the proper strength for boiling. Just in the same manner, every 2d or subsequent infusion can be increased in strength, so that none but sufficiently concentrated lye is supplied to the evaporating pan. Suppose that a certain quantity of water has taken up 8 per cent. from the first portion of soda, it will take up as much more from the second portion, and leave it containing 16 per cent.; it will be drawn off from the third portion with 24 per cent., and so on. Hot water dissolves more than its own weight, cold water half as much, still colder water at 8° (47° F.) dissolves about 23 per cent. of crystalized carbonate of soda. The arrangement, Fig. 119, shows the manner in which these principles have been practically carried out. Each of the iron lixiviating cisterns *A A*, is divided by a double partition, and the two halves are connected by an aperture *a* at the bottom, and another *b* at the top.

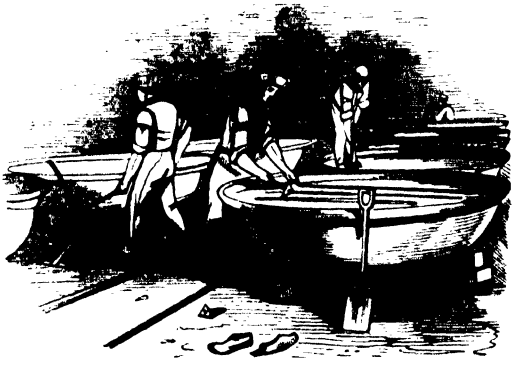
Fig. 119.



In each compartment there are two sheet iron boxes *n n*, pierced with holes in their sides like a sieve; these are filled with crude soda, and suspended just below the surface of the water. The great advantage of this arrangement is easily perceptible. The particles of fluid, as they become saturated and heavy, fall to the bottom, and make room for other particles, which become saturated in the same manner. The solution of the salt is thus much more rapidly effected than in the ordinary method, when the crude material collects at the bottom of the vessel, and such currents cannot occur. For the same reason, (on account of displacement,) the solution of a lump of sugar suspended just below the surface of the water is much more rapid than when it is placed at the bottom of the vessel. In the latter case, the syrup is distinctly seen falling in streaks. A complete apparatus should have 10 or 12 of these boxes placed side by side, and the one raised about 2 inches above the other placed immediately in front of it. In the same manner as the fluid is conducted from the first compartment through the lower aperture *a a* . . into the hollow partition, and from thence through the upper opposite aperture *b b* into the second, so, from the bottom of the latter it enters through the pipes *g g* . . the next lower box at the top. The steam pipes *h h* keep the temperature of the whole at about 40° (104° F.). The fresh water always enters the uppermost cistern first; whilst the lowest only is charged with fresh soda; and whilst the water is traversing the whole series from top to bottom, the same space, but in an opposite direction, is traversed by the cases containing the soda, which from time to time are removed from one cistern to the other. The water is thus gradually converted into a stronger and stronger lye, until, on reaching the lowest cistern, it has attained the proper consistence for boiling. On the contrary, the crude soda is gradually exhausted, and parts with the last portion of its soluble salts to the fresh water in the uppermost cistern.

A lye is, therefore, obtained of pretty uniform strength, in which not only carbonate of soda, but all the soluble salts are contained, and particularly sulphuret of sodium; it is then evaporated in leaden pans quite similar to that represented in Fig. 94. In the mean time, the greater part of the sulphuret of sodium becomes oxidized to hyposulphite of soda (NaS becomes $NaO, S_2 O_2$); the other constituents of the lye remain unchanged, and mixed with the soda in different proportions, according to the nature of the process. If the lye is evaporated at once to dryness, which can be done in iron vessels, all the foreign matters remain mixed with the soda. For this reason, the same method is generally adopted as in the soccage of common salt. When the strength of the lye exceeds a certain amount, small crystals of monohydrated carbonate of soda fall constantly to the bottom ($NaO, CO_2 + aq.$), and these may be collected with scoops, allowed to drain, and are then dried. In this manner nearly all the caustic soda and sulphuret of sodium, as well as the excess of other foreign salts, remain in the mother liquor. If this is evaporated and heated to redness, mixed with saw-dust or coal-dust in a reverberatory furnace, the sulphur of the sulphuret of sodium escapes (probably as sulphuretted hydrogen), and carbonate of soda is produced. The same occurs with the caustic soda, which immediately combines with carbonic acid; the sulphate of soda is reduced at the same time to sulphuret of sodium, and undergoes in this form a similar change. The same purification can be practised upon the salt obtained by evaporating the mother liquor to dryness. By far the purest soda is obtained, when the original crude lye, or the redissolved half-purified salt is evaporated to the point of saturation, and set aside to cool; cold weather is best suited for this purpose. The vessels used for crystalization are made of cast iron, and are generally round; the sketch below shows the manner in which they are arranged in the crystalizing house, Fig. 120. Under these circumstances, the soda separates in large well-formed crystals ($NaO, CO_3 + 10 aq.$), containing a very small amount of sulphate of soda, and when freshly crystalized 62.8 per cent. water of crystalization, which is somewhat diminished in

Fig. 120.



the commercial salt by the efflorescence to which it is subject when exposed to the air. Commercially, soda is met with in three forms, *crude soda*, a designation which is also sometimes applied to the saline mass of inspissated mother liquor; *salts of soda* (soda without water of crystallization); and *crystallized soda.*

The entire loss of all the sulphur, employed as sulphuric acid, and amounting to ⅓ of the pure soda, is, with great justice, made an objection to Leblanc's process. However simple it may appear to employ the means at hand—the hydrochloric acid—for recovering the sulphur from the slate-gray residue, which contains about 15 per cent. in addition to carbon, silica, lime, magnesia, iron, and gypsum, yet it is attended with peculiar difficulties. In the first place, only 2 equivs. of hydrochloric acid are obtained, and there are 3 equivs. of lime to be saturated; even when the observation of Gossage is made use of, according to which moist sulphuret of calcium is easily decomposed by carbonic acid, which can thus be used to assist the action of the hydrochloric acid, yet it would still be difficult to obtain the sulphuretted hydrogen so free from carbonic acid, that it could be burnt in the sulphuric acid chambers (p. 229); and no other use has been found for it.* Darcet and others have employed the residue mixed with sand as a mortar, or for covering the paths in gardens, and have found that it becomes hard in the air, and prevents the growth of grass.

That all the numerous propositions intended to prevent the loss of sulphur, from the beginning, have failed in superseding Leblanc's method, is probably due to the great simplicity of the latter, and to the low price of crude soda. Some of these, however, are of too interesting a nature to be overlooked.

Prückner (afterwards Persoz, and still later Poole) produced sulphate of soda from sulphate of ammonia and chloride of sodium, and converted the sulphate into sulphuret of sodium by heating it to redness with charcoal, which, on the addition of suboxide of copper, produced sulphuret of copper and caustic soda ($NaS + Cu_2O = NaO + Cu_2S$). The solution of the latter was exposed to a stream of carbonic acid, and thus became converted into carbonate of soda. An ingenious method has been devised to make the sulphuret of copper again subservient to the same purpose. By roasting the sulphuret, sulphurous acid and oxide of copper are obtained. The former is carried through ammonia, and the sulphite of ammonia exposed to the air until it has become converted into sulphate of ammonia; the oxide of copper mixed with charcoal powder, and exposed to a very slight red heat, is converted into suboxide, and then again used with the sulphate of ammonia as at first. If the oxide were used, too much hyposulphate of soda would be formed.

Dyar and Hemming decompose chloride of sodium by means of carbonate of ammonia, in order to produce soda without the use of

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* The real difficulties are the risk of the workmen, and the rapid destruction of the gasometers.

sulphur (sulphuric acid). When after the interchange of the acids in both salts, the carbonate of soda has been separated, the sal-ammoniac in the residual liquid is reconverted into carbonate of ammonia by carbonate of lime. The advantage here gained, is the production of soda free from sulphur; the difficulty, however, consists in avoiding a loss of ammonia. To economize the sulphuric acid, the residue from the decomposition of iron pyrites, or the lye from disintegrated cockscomb pyrites has been employed (Phillips) for the conversion of chloride of sodium into sulphate of soda. Lastly, Blanc and Blazille have advocated the formation of a soluble silicate of soda, by fusing together chloride of sodium and silica, and converting this into carbonate, by a current of carbonic acid, with the separation of silica; in a similar manner, only with the additional aid of fluoric acid, Maugham produces silicate of soda, and decomposes it by means of carbonate of lime. Anthon's experiments, in which chloride of sodium is mixed with charcoal, silica or metallic iron, and exposed at a red heat to aqueous vapour, lead to no result. In localities where potash (carbonate of potash) is at a moderate price, the production of saltpetre may be combined with that of soda, by decomposing Chili saltpetre (nitrate of soda), and carbonate of potash, into soda and ordinary saltpetre.

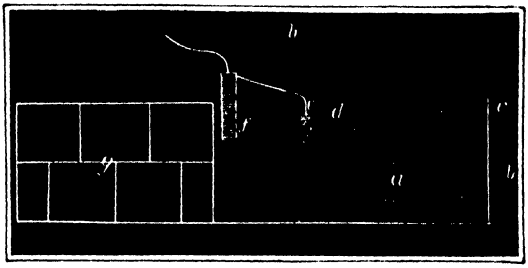
Before closing the account of the production of soda from common salt, we think it desirable to notice cursorily one of the chief outlets for the muriatic acid which is produced in such immense quantities in the soda works, and which it is now in some countries, and ought to be in all, made compulsory upon manufacturers to condense. The account of the manufacture of bleaching powder has been reserved for a future chapter of the work, where it will be more fitly introduced. We think it nevertheless essential to a complete description of the alkali works that a slight sketch of the manufacture of bleaching powder should here follow.

Bleaching powder or chloride of lime is a compound of very extensive consumption in the arts, being used in bleach works, and by calico printers in a great variety of processes for removing color from their goods. The production of this substance is dependent upon the property which hydrate of lime possesses, in common with the hydrates of the alkalies, of absorbing gaseous chlorine with avidity, and when placed in the most favorable conditions to the extent of about 40 per cent. Chloride of lime was first prepared by Mr. Tennant of Glasgow in the year 1798, and applied by him to the bleaching of cotton cloth. The process requires a chamber in which the hydrate of lime (dry or *anhydrous* lime absorbs no chlorine) is spread out in a layer of about three or four inches in thickness, and chlorine gas generated from another apparatus is caused to fall or pour down upon it from the top of the chamber; in about forty-eight hours the lime has absorbed the full quantity of chlorine to convert it into bleaching powder.

The chlorine gas is generated by heating together peroxide of manganese and hydrochloric acid. The oxygen of the peroxide, uniting with the hydrogen of the acid, forms water, and the half of the chlorine is evolved in the free state, whilst the other half remains in combination with the manganese ($2\,HCl + Mn\,O_2 = 2\,HO + Mn\,Cl + Cl$).

Fig. 121 is a sketch of the most approved form of apparatus for employing the strong muriatic acid of the process described above (p. 267-8) in the manufacture of bleaching powder; *a* is a flat stone still, with a flag stone lining, thus leaving an intermediate space *b*; *c* is the acid pipe; *d* the exit pipe of the chlorine gas which is washed in water in the little vessel *e*, from any muriatic acid, &c., and finally passes into the ordinary chlorine chamber *g* through a small coke column *f*, where it comes in contact with a thin stream of oil of vitriol to remove all traces of aqueous vapor. The manganese and muriatic acid in the still are heated by steam from the pipe *h* which occupies the space *b*; and a recent patented improvement by Mr. Pattison for introducing steam into the interior of the still to assist in working off the last portions of chlorine, seem to make this whole arrangement most complete and economical.

Fig. 121.



Chloride of lime is a white powder with a peculiar smell, not of chlorine, but of hypochlorous acid; exposed to the air it gradually absorbs carbonic acid and evolves chlorine; it is only partially soluble in water, leaving a large residue of hydrate of lime. The addition of an acid to chloride of lime causes a much more rapid evolution of chlorine, and the acid combines with the lime. It was at first supposed that chloride of lime was a simple combination of lime with chlorine ($Ca\,O + Cl$) until the discovery of hypochlorous acid by M. Balard rendered it probable that the bleaching substance in chloride of lime was hypochlorite of lime. This view has again been rendered doubtful by the researches of Millon, who is led to suppose that the bleaching substance is a combination similar to the peroxides of the metals, in which calcium is united with oxygen and chlorine, the chlorine being substituted for the oxygen of the peroxide. Gay-Lussac and others have also investigated the nature of this compound, but its constitution is still doubtful. Its application to manufactures will be treated in a future chapter.

The manganese employed in the process for bleaching powder is rendered comparatively useless after being once united with chlorine, and until recently, when the chloride of manganese has been employed for the purification of illuminating gas (see appendix), it was treated only as a waste product, the chief expense in the manufacture being occasioned by the supply of fresh peroxide of manganese from the mines. A patent was taken out in 1844 by Messrs. de Sussex and Arrott for recovering the waste manganese, and rendering it again subservient to the production of chlorine. The plans proposed by the patentees have reference to the chloride and sulphate of manganese, both of which are waste products. The chloride is either heated very strongly in fire clay retorts until the whole of the chlorine is driven off in the form of hydrochloric acid, and as free chlorine, leaving the manganese in the state of oxide, or is exposed on the hearth of a reverberatory furnace to the flame of hydrogen gas mixed with the ordinary flame from a coal fire, when the chlorine is expelled as hydrochloric acid, and the deutoxide of manganese is left; or lastly the chloride is mixed with carbonate of lime, and exposed to the compound hydrogen flame, when by mutual decomposition, chloride of calcium and protoxide of manganese remain; these can then be separated by water. The sulphate of manganese is mixed with charcoal, coke or saw-dust, and exposed to a strong heat in retorts of fire clay or iron, when sulphuret of manganese mixed with some protoxide of the metal is produced; this is then mixed with an additional quantity of carbonaceous matter, and subjected to the joint action of the heat and atmospheric oxygen in an open retort, and the whole is thus converted into protoxide. The lower oxides of the metal obtained by any of the foregoing processes, are either fused with about three times their weight of caustic or carbonated alkali, and a manganate of the alkali formed, which may be decomposed by the action of the air, or by carbonic acid passed through it into peroxide of the metal and carbonated alkali. Chlorine may also be passed over the moist deutoxide with the view of converting it into peroxide, or, lastly, the lower oxides may be exposed to nitrous gas generated by some other process of manufacture, as in the preparation of oxalic acid, nitrate of lead, &c., giving rise to the production of the peroxide. It is possible that the use of manganese will be superseded in the production of chlorine by a process for which a patent has been granted to Mr. Charles Dunlop of Messrs. Tennant and Co., Glasgow. The plan proposed consists in mixing common salt with nitrate of soda, and submitting the mixture to the action of sulphuric acid; chlorine and nitrous gas are evolved, and are caused to traverse a vessel containing strong sulphuric acid, by which the nitrous gas is readily absorbed, and the chlorine passes off. A current of atmospheric air is now passed through the nitrous sulphuric acid, until the nitrous is converted into nitric acid; these mixed acids are then made to act upon common salt without any addition of nitrate of soda, and the same gaseous products are obtained as before.

The muriatic acid which is produced by the system of condensation applied to the reverberatory furnace in decomposing common salt, instead of running to waste, is likewise employed in the following manner.

Bicarbonate of Soda.—A large cistern formed of stone laid in clay, and well bedded as shown in *E E E*, Fig. 122, is filled with chalk, and the muriatic acid as it flows from the condensers, is admitted by the pipe *A*. It thus enters the cistern at the bottom, rises up through the chalk, disengaging carbonic acid in its passage, and the solution of chloride of calcium escapes at the point *C* through another pipe, similar to that by which it entered. The escaping liquid flows off through the pipe *D*. The carbonic acid gas makes its exit through the opening *B*, whence it is conducted to the large air-tight cistern containing the crystalized carbonate of soda. The carbonic acid cannot escape by any other opening, as the whole cistern is filled with liquid up to the level of *C*, while this pipe and *D* are kept full of the liquid chloride of calcium. The pipe *A* and *C* are made of stone and fitted into the sides of the cistern, Fig. 123. The only precaution is to fill the cistern every morning with chalk.

Fig. 122.

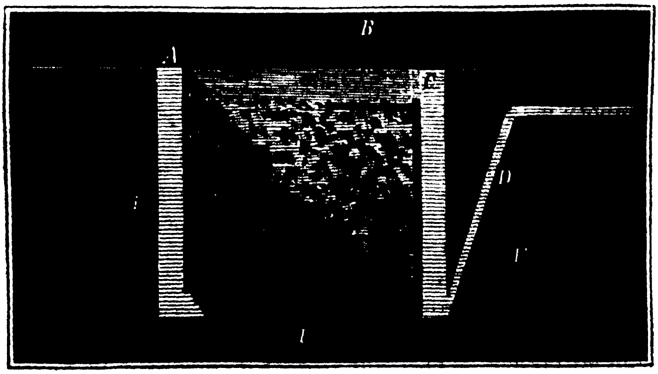
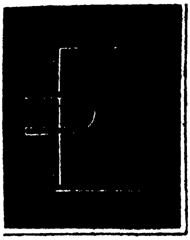
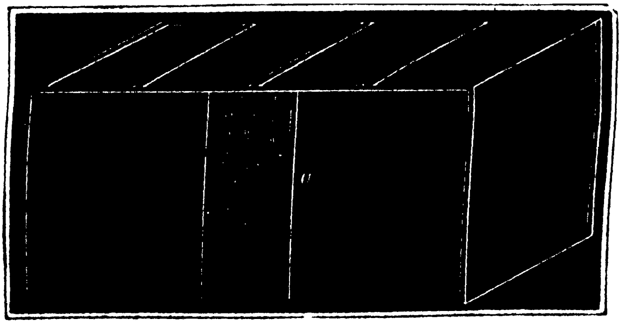


Fig. 123.



The carbonic acid is conveyed to a large air-tight cistern with a man-hole door in the side, and a small pipe at the bottom of the cis-

Fig. 124.



tern to allow the water of crystalization to flow off as the absorption of the carbonic acid proceeds. Large masses of crystalized soda are piled one upon another in the cistern, Fig. 124, where *a* shows the door with the masses of soda crystals. The door is then closed, and the gas admitted. Considerable heat is evolved, and at the end of ten days or a fortnight, the whole is converted into bicarbonate of soda, which is, however, very damp. The soda is now removed to stoves fitted with wooden shelving, and dried by air gently heated in iron pipes. When perfectly dry to the touch, it is ground between stones in a similar manner to flour, taking care that the motion of the stones is so slow as to prevent the evolution of any great heat.

Soda from Marine Plants.—It is one of the specific properties of those plants, which are found growing on the sea shore, or in the sea itself, to imbibe and assimilate the mineral ingredients of sea water (p. 246). Thus, for instance, they assimilate the soda of the chloride of sodium, when any function of vegetable life, for instance the saturation of an organic acid, requires the presence of a base. Hence, without reference to the plants exclusively inhabiting the ocean, as the fucoids, we can understand why the vegetation of the sea shore, namely, certain species of *Salsola*, *Triglochis*, *Salicornia*, *Atriplex*, *Statice*, *Batis*, *Mesembryanthemum*, *Chenopodium*, *Reaumeria*, &c., should be so firmly attached to that locality, which they only exchange for the neighborhood of salt springs. On burning these plants, the compounds of soda with the organic acids remain in the ash as carbonate of soda mixed with other salts. Besides carbonate of soda, the ash contains in the form of soluble salts, sulphate and hyposulphite of soda, sulphuret, iodide, bromide and chloride of sodium, ferrocyanide of sodium, and the corresponding combinations of potassium ; besides these, there is an insoluble portion consisting of carbonate and phosphate of lime, sulphuret of calcium, magnesia, alumina, silica, sulphuret of iron, and particles of charcoal. In general the ash of sea plants, compared with that of those growing on the shore, is not rich in carbonate of soda, but contains a large quantity of the salts of potash ; this general fact is, however, not without exceptions, for Guibourt's analysis of the ash of *Salsola tragus* showed it to contain 29.04 per cent. carbonate of potash, 17.89 chloride of potassium, 4.93 sulphate of potash, 40.26 carbonate of lime, and 7.88 phosphate of lime and oxide of iron.

The following table contains the results of analyses by Schweitzer, Forchhammer, Gödechens, and James.

Composition of the Ashes of Sea-Weeds, after deducting Carbon and Carbonic Acid.

Constituents.	Laminaria saccharina. North Seas.	Fucus serratus. North Sea.	Laminaria latifolia.	Furcellaria fastiginta.	Chondrus crispus.	Iridaea cellulis.	Polysyphonia elongata.	Delesseria sanguinea.	Fucus digitatus. Clyde.	Fucus nodosus. Clyde.	Fucus serratus. Clyde.	Fucus vesiculosus. Clyde.	Fucus vesiculosus. Mersey.	Fucus vesiculosus. North Sea.	Fucus vesiculosus. Denmark.	Fucus vesiculosus. Greenland.
Potash	24.77	16.02	16.91	21.36	18.00	23.42	21.23	13.72	22.40	10.07	4.51	15.23	—	17.68	5.03	17.86
Soda	1.84	6.01	—	24.77	19.47	16.06	5.06	21.34	8.29	15.80	21.15	11.16	15.10	5.78	7.78	21 43
Lime	6.50	7.05	8.28	6 02	7.11	10.23	2.92	2.30	8.79	10.98	11.09	8.15	16.77	4.71	21.65	3.31
Magnesia	8.13	7.59	6.80	11.04	11.80	—	20.56	5.94	7.44	10.93	11.66	7.16	15.19	6.89	10.96	7.44
Chloride of sodium . .	33.72	38.72	26.92	—	—	1.66	13.85	—	28.39	20.16	18.76	25.10	9.89	35.38	3.53	25.93
Chloride of potassium .	—	—	10.18	—	—	—	—	—	—	—	—	—	—	—	—	—
Iodide of sodium . .	4.70	.27	—	—	—	—	—	—	3.62	.54	1.33	.37	—	.13	—	—
Phosphate of lime . .	8.41	4.95	12.80	3.96	.76	23.23	2.99	3.90	5.63	3.34	9.67	2.99	—	5.44	9.67	10.09
Phosphate of iron . .	.75	.64	—	—	—	—	—	—	—	—	—					
Oxide of iron . . .	—	—	—	—	—	—	—	—	.62	.29	.34	.33	4.42	—	—	—
Oxide of manganese . .	—	—	—	.22	—	—	—	—	—	—	—	—	—	—	—	—
Sulphuric acid . . .	10.60	18.35	12.63	32.63	42.86	25.19	28.60	40.42	13.26	26.69	21.06	28.16	30.94	23.71	26.34	13.94
Silica	.58	.40	.69	—	—	—	2.83	12.38	1.56	1.20	.43	1.35	7.69	.28	11.04	—
Sum,	100.00	100.00	95.21	100.00	100.00	99.79	98.04	100.00	100.00	100.00	100.00	100.00	100.00	100.00	96.00	100.00
Per centage of Ash in weed dried at 100° C. (112° F.)	9.78	25.83	13.62	18.92	20.61	9.86	17.10	13.17	20.40	16.19	15.63	16.39	13.22	20.56	—	16.22

Preparation of the Ash.—The sea-weed is collected at low water and allowed to dry in the sun, the plants on the shore are mowed down and dried in the same manner. When they have become perfectly dry, they are burnt to ashes, not however upon level ground, where the wind would blow away the ashes, but in pits, 3 feet deep and 4 feet square, into which the dry fresh weed is thrown as soon as the previous portion is consumed. When the operation has been continued for several days, the ash in the pits becomes so hot, that it cakes together into a semi-vitrified mass; it is then broken up and fit for use.

Barilla.—In Spain, *Salsola soda* is cultivated annually on the sea coast, and the plants are burnt to produce one of the most valuable kinds of ash. Formerly it was very much esteemed in commerce under the name of *barilla;* it forms solid slag-like lumps of a dark ash gray color, and contains from 25 to 30 per cent. of pure carbonate of soda. In France, which is the chief market for this produce, three varieties are distinguished; *barilla* itself or *soude douce*, an inferior kind, *soude mêlangée*, and a third still less prized, *soude bourde*, all of which are brought from Alicante; that obtained from Carthagena is of medium quality.

COMPOSITION OF BARILLA OR VAREC.

Constituents.	Alicante.	Cherbourg.	Cherbourg.	Unknown.	Unknown.	Spain.	Villette.	Granville.
Sulphate of potash .	—	22.19	42.54	18.80	22.00	15.85	20.35	13.50
Chloride of potassium	—	16.00	19.64	—	—	10.55	19.53	15.60
Chloride of sodium .	65.00	45.78	25.38	73.20	68 00	68.35	54.11	65.68
Carbonate of soda .	2.00	9.53	3.71	6.00	6.00	traces	3.76	.22
Sulphate of lime .	—	—	—	—	—	1.10	—	—
Insoluble matter .	3.00	1.50	.73	—	—	—	—	—
Iodine compounds	—	traces	traces	traces	traces	—	traces	traces
Sulphate of soda .	30.00	—	—	—	—	—	—	—
Water . .	—	5.00	8.00	2.00	4.00	4.00	1.25	5.00
Sum,	*100.00	*100.00	*100.00	*100.00	*100.00	†99.85	100.00	100.00

Salicor.—In the same manner *Salicornia annua* (belonging to the family of the *Atripliceæ*), is cultivated on the French coasts of the Mediterranean (near Narbonne), where, after collecting the seed, the plant is burnt to ashes, which is then termed *Salicor*, and contains about 14 or 15 per cent. of carbonate of soda.

Blanquette.—A kind of soda containing from 3 to 8 per cent. is known in commerce by the name of *Blanquette*, which is obtained by incinerating all the plants growing on the shores between Frotignan and Aiguemorte; in the south of France, these are *Salicornia europæa, Salsola tragus*, and *kali*, *Atriplex portulacaïdes* and *Statice limonium*. In former times, the addition of chloride of sodium to this ash, which already contained it in large quantity, was a fraudulent practice of frequent occurrence.

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* Analysis, by Girardin.

† Analysis, by T. Richardson.

Varec, Kelp.—Lastly, the ash sold under the name of *Varec* or *Kelp*, which is obtained from sea-weed on the shores of the North Sea—the former also in Normandy, the latter in Scotland, Ireland, and the Orkneys—can hardly be classed amongst the varieties of soda; kelp containing only 2 per cent., and varec no carbonate of soda at all, but consisting of one half chloride of sodium, and the other half of about equal parts chloride of potassium and sulphate of potash.* Kelp is of similar composition, and distinguished by containing metallic iodides. In France, varec was used by the soap boilers as a good substitute for chloride of sodium, upon which a high duty was levied. In Scotland, kelp is a source of potash salts and iodine. When the lye obtained from this ash is evaporated, the soda and *potash* salts separate one after the other; the latter are used in the alum works, whilst the mother liquor distilled with sulphuric acid and manganese yields *iodine*. Dickie found iodine only in those plants which were in actual contact with the sea, or to which sea water was carried by the wind; such were *Lichen confinis*, *Statice armeria*, and *Grimmia maritima;* on the contrary, no trace of iodine could be discovered in *Ramalia scopulorum* and *Salsola kali*, which grow more inland. The fucoidal plants are doubtless the principal sources of the iodine in the ash. Soda is also produced on the coasts of the Caspian, as well as on the Egyptian and Syrian coasts of the Mediterranean and in Sicily (*Rochetta*).

POTASHES.

That which is ordinarily called soda, is a carbonate of the alkali and crude potash, or *potash* is also a carbonate of potash, and is a substance of no less importance in the arts than soda. Potashes are never obtained by a chemical decomposition of any other potash salt, or as a product ready formed in nature, but always from the ashes of plants. It, therefore, becomes necessary at the outset, to become well acquainted with the nature of these ashes, which have also been much more thoroughly studied, than was the case with those of marine plants. For this reason, the following facts were merely generally noticed on a former occasion (page 282).

The Ash.—The science whose object it is to investigate life and its phenomena, teaches us that the vital principle in vegetables, requires, as food for plants, certain earthy and alkaline constituents of the soil, which, appear more properly to belong to the mineral kingdom, and indeed compose its mass, quite as imperatively, only in smaller quantity, as the carbon, hydrogen, and nitrogen, which are supplied to plants by the air and from other sources. These constituents: potash, soda, lime, magnesia, oxide of iron, phosphoric and sulphuric acids are in fact originally contained in the rocks, which, by the destructive influence of the atmosphere, the changes of temperature, &c., have become disintegrated, and their constituents being released from intimate chemical combination, have formed with the

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* Vide table, p. 284.

remains of decayed vegetation what is called the *soil.* From this source, therefore, plants have to look for this indispensable part of their food. In what manner the mineral constituents are disposed of by the vital agency of plants, what part they play in the vegetable organism, is for the present veiled in mystery; we only know, and that is here of the greatest importance, that a very considerable portion of the saline bases are in combination with vegetable acids in the plants. Thus potash in the vine is combined with tartaric acid, in wood sorrel with oxalic acid, lime in other plants is found combined with malic acid, &c.

When vegetable substances, wood, &c., are destroyed by fire, all the mineral constituents taken from the soil naturally remain in a fixed state, after the volatilization of the combustible matters, formed from the carbon, hydrogen, &c. This residue is called *the ash,* whatever substances it may consist of. All the vegetable acids, which were combined in the plants with mineral bases, are also burnt and leave *carbonates* in their stead in the ash, inasmuch as the bases are of that class which do not lose their carbonic acid by heat, as is the case with the earths. The mode of combination in which the constituents are found in the ash, gives, however, a very inadequate and confused idea of their actual state in the living plant, as the temperature of incineration gives rise to violent decompositions, and new combinations.[*] Up to this time, the following bases have been found in the ash: *potash, soda, lime, magnesia, oxide of iron,* and *manganese;* the acids are: *carbonic, sulphuric, phosphoric,* and these are accompanied by *chlorine;*[†] the absence of alumina has always been observed, and is explained by the insolubility of the compounds of alumina contained in the soil, which are thus prevented from entering by the roots of plants.[‡]

The extraordinary differences in the quality and quantity of ash obtained under different circumstances, arise from various causes.

Although differences of this kind in different species of plants would not, perhaps, be thought singular, yet it is a remarkable fact, that the ashes of two specimens belonging to one and the same class are seldom perfectly alike in composition, and are often considerably at variance. The researches which have been made upon this subject leave no doubt that plants, in the absence of the one constituent of the soil, can take up some other, which to them is of equal value, as regards its chemical action, and that the bases replace each other and act conjointly with reference to the functions of the plants. Now as the action of a base is dependent upon the amount of oxygen which

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[*] An extremely interesting paper upon this subject, by Professor H. Rose, appeared in the Chemical Gazette for April, 1847, in which the fallacious method pursued in all former analyses of ash is pointed out, and a plan more conformable with the desired object advanced.

[†] Copper has also been found in the ash of clover grown in the neighborhood of Mansfeldt.

[‡] Alumina has recently been found in the ash of several plants, by Prince Salm-Horstmar, and its occurrence accounted for by the fact that those plants, in the ash of which it was found, excrete an acid which dissolves the alumina in the soil. See Chemical Gazette for August, 1847.

it contains, and is, indeed, measured by that quantity, the bases of such ashes—independent of that portion, which is in combination with the mineral acids—must together contain one and the same quantity of oxygen, which, indeed appears proved by the very close approximations obtained by experiment. In the ash of a fir, Saussure found 3.6 carbonate potash, 46.34 carbonate of lime, and 6.77 carbonate of magnesia. In the ash of the same tree, but from a different locality, 7.36 carbonate of potash, 51.19 carbonate of lime, and no magnesia. In both cases, the oxygen of the acid in these bases is 9.0. The ash of a tobacco plant from the neighborhood of Debreczin in Hungary contained, in combination with carbonic acid, 43.91 potash, 3.40 soda, 41.79 lime, and 10.9 magnesia; that of another kind of tobacco, from the same neighborhood, 42.03 potash, 46.97 lime, and 11.00 magnesia, without any soda. The total amount of oxygen in the former case is 24.27, in the latter 24.57 (Will and Fresenius).

But even in the same specimen, as might have been anticipated, the nature of the ash varies with the part of the plant from which it was obtained; different vital functions being performed by different organs, these have to transform and assimilate other kinds of food, and in variable quantity, and even this again is not uniform throughout the different periods of development and changes of season. Thus Saussure found in the leaves of the oak, gathered on the 10th May, 5.3, on the 27th Sept. 5.5 per cent. of ash; in the wood he found 0.2; in the bark 6.0; in the wood of the branches 0.4; in the bark of the same 6.0; in the inner bark 7.3 per cent. of ash. So in the wood of the white beech 0.6; in the sap wood 0.7; in the bark 0.7 per cent. of ash. Again, in the leaves of the poplar, gathered on the 26th May, 6.6; on the 12th Sept. 9.3; in the wood of the stem 0.8; in its bark 7.2 per cent. of ash.

The extent of variation in the nature of the ash obtained from different parts of the same tree, will be evident from the following examples.*

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* Rammelsberg has published some very curious results upon the power of selection exerted by different organs of the same plant (see Chemical Gazette, October 1, 1847). He found potash, but not a trace of soda in the seed of rape and peas, whilst the straw yielded both the alkalies, but by far the larger portion was soda. The soil upon which the plants were grown contained both alkalies.

The following table exhibits the point in question better than that in the text, and also some other curious relations. The analyses were conducted upon the plan recommended by Professor Rose, (see p. 286, note.)

	seed.	straw.	seed.	straw.
Potash	25.18	8.13	43.09	8.20
Soda	—	19.82	—	12.50
Lime	12.91	20.05	4.77	30.53
Magnesia . .	11.39	2.56	8.06	6.93
Peroxide of iron	0.62			
Phosphoric acid	45.95	4.76	40.56	9.21
Sulphuric acid .	0.53	7.60	0.44	7.01
Carbonic acid .	2.20	16.31	0.79	17.36
Muriatic acid .	0.11	19.93	1.96	7.15
Silicic acid .	1.11	0.84	0.33	0.62

Hertwig.

	Fir wood.	Fir bark.	Needles (leaves) of fir.
Carbonate of soda .	7.42	2.95	29.09
" potash	11.30		
Chloride of sodium .	trace	—	
Sulphate of potash .	—	—	
Carbonate of lime .	50.94	64.8	15.41
" magnesia .	5.60	0.93	3.89
Phosphate of lime .	3.43	5.03	38.36
" magnesia .	2.90	4.18	
Protoxide of manganese . .	trace	—	
Basic phosphate of iron . .	1.04	1.04	
" " of alumina	1.75	2.24	
Silica . . .	13.37	17.28	12.36

Will and Fresenius.

	Rye.	
	grain.	straw.
Potash . . .	32.72	17.19
Soda	4.44	—
Lime	2.91	9.06
Magnesia . . .	10.12	2.41
Oxide of iron . .	0.82	1.36
Phosphoric acid . .	47.22	3.84
Chloride of sodium .	trace	0.56
" of potassium .	0.41	0.25
Sulphuric acid . .	1.46	0.82
Silica	0.17	64.50

Lastly, it is worthy of remark, that the influence of an extraordinary soil is sometimes evinced by the composition of the ash. Amongst others, Böttinger found in the ash of the wood of a fir tree, which certainly was sickly, and growing upon a doleritic soil (in the neighborhood of a manganese mine), 15 per cent. of protoxide of manganese, whilst in healthy wood of the same tree only 2.7 per cent. was obtained.*

In general, as will be seen from what has been stated, the herbaceous plants yield much more ash than shrubs, and these again more than trees. The trunk (wood) in these, contains little ash, the branches and twigs considerably more; but the bark and leaves afford the largest quantity. Saussure found in the peeled branches of oak 29 times as much ash as in the wood, in the bark 30 times, in the inner bark 36 times, in the sap wood twice, and in the leaves 36 times as much (p. 287); so in the white beech, the sap wood contained 1.1 times, the bark 22 times as much as the wood. According to Hertwig, the quantity of ash from the bark of beech is 19 times that from the wood; the bark of the fir produces (according to the same observer) 5.4 times, the needles (leaves) 5.8 times as much ash as the wood. These relations will be still more clearly seen in the following table, which contains all the determinations that are of peculiar interest for the preparation of potashes.†

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* In like manner Saussure obtained from flowering vetches on arable land 12 per cent., from the same plant grown in distilled water, only 4 per cent. of ash.

[† Prof. E. Emmons, from about 150 analyses of the ashes of American woods, has deduced the following conclusions.

"1. That the proportion of ash in the limbs and branches is greater than in the inside wood, and greater also in the outside than inside wood, though exceptions occur to the latter inference.

"2. In the bark of the trunk the inorganic matter acquires the maximum proportion.

"3. The alkalies acquire their maximum proportion in the fruits and envelopes.

"4. The phosphates acquire their maximum proportion in the outside wood, fruits, and envelopes.

"5. Lime is found in its maximum proportion in the bark.

"6. The phosphates and alkalies are found in their minimum proportion in the bark of the trunk."—AM. ED.]

Quantity of Ash in 100 parts: Trees.

Species of tree.	Part burnt for ash.	Karsten.	Berthier.	Mollerat.		Saussure.	Winkler.	Hertwig.	Will and Fresenius.
Oak . .	Wood	young 0.15 old 0.11	3.30	1.40	1.97	0.2	—	—	—
	Branches	—	—	—	—	0.4	—	—	—
	Bark	—	6.00	—	—	6.0	—	—	—
	Leaves	—	—	—	—	5.5	—	—	—
	(Charcoal)	—	2.50	—	—	—	0.75	—	—
		—	—	—	—	—	—	—	—
Red beech .	Wood	young 0.37 old 0.40	—	0.612	0.58	—	—	0.38	—
	Bark	—	—	—	—	—	—	6.62	—
	(Charcoal)	—	3.00	—	—	—	1.25	—	—
Hornbeam	Wood	young 0.32 old 0.35	—	1.14	1.12	0.6	—	—	—
	Sap-wood	—	—	—	—	0.7	—	—	—
	Bark	—	—	—	—	13.4	—	—	—
	(Charcoal)	—	2.65	—	—	—	—	—	—
Alder . .	Wood	young 0.35 old 0.40	—	1.39	—	—	—	—	—
Birch . .	Wood	young 0.25 old 0.30	1.00	1.07	—	—	—	—	—
	Charcoal	—	—	—	—	—	0.80	—	—
Scotch fir (P. picea)	Wood	0.15	—	1.68	—	—	—	—	—
	Seeds	—	—	—	—	—	—	—	4.47
	(Charcoal)	—	—	—	—	—	1.11	—	—
Fir (P. abies) .	Wood	young 0.22 old 0.25	—	—	—	—	—	—	—
	Bark	—	—	—	—	—	—	1.78	—
	Needles	—	—	—	—	2.90	—	2.31	—
	(Charcoal)	—	1.24	—	—	—	1.44	—	—
Pine (P. sylvatica)	Wood	young 0.12 old 0.15	0.83	1.80	—	1.19	—	—	—
	Needles	—	—	—	—	2.60	—	6.25	—
	Seeds	—	—	—	—	—	—	—	4.98
	(Charcoal)	—	—	—	—	Branches 1.50	1.38	—	—
Lime . .	Wood	0.40	5.00	1.45	—	—	—	—	—
	(Charcoal)	—	—	—	—	—	3.55	—	—
Poplar . .	Wood	—	—	1.306	1.24	0.80	—	—	—
Elm . .	Wood	—	—	2·28	—	—	—	—	—
Ash . .	Wood	—	—	2.30	—	—	—	—	—

Ash in 100 parts; Shrubs.

Elder	1.64	Berthier.	Wild rose . .	0.71	Mollerat
"	1.39	Mollerat.	Heath . .	1.41	"
Hazel . . .	0.50	Saussure.	Green-weed, or Whin . .	1.62	"
Wortleberry . .	2.60		Heckle . .	1.66	"
" . . .	0.68	Mollerat.	Blackberry . .	0.76	"
Elder . . .	1.16	"	Broom . .	1.48	"
Barberry . .	0.71	"	Sumach . .	1.71	"
Juniper . .	1.84	"			

Ash in 100 parts: Herbs.

Potato straw .	15.00	Berthier.	Maize straw (corn stalks)	12.20	Saussure.
" leaves .	1.15	Mollerat.	Cane, stem .	1.70	Karsten
Pease halm .	5.05	Hertwig.	Fern . . .	2.75	"
" " . .	11.30	Boussingault.	" . . .	2.90	Mollerat
" " . .	8.10	Saussure.	" . . .	5.00	Pertuis.
Oat straw . .	5.10	Boussingault.	Plantain leaves .	9.22	Abbene.
Nettle . . .	10.67	Pertuis.	" branches	2.30	"
Thistle . . .	4.03	"	Acacia . .	2.46	"
Rushes . . .	4.33	"	Vine . . .	4.66	"
Wheat straw .	4.40	Berthier.	Grape stalk . .	8.89	"
" " . .	7.00	Boussingault.	Vine pith . .	7.29	Blengini.
" " . .	4.30	Saussure.	Ditto from another place .	3.57	
Rye straw . .	0.30	Karsten.			
Rye straw .	3.60	Boussingault.			

Constituents of the Ash.—The constituents that are found in the ash have already been noticed in a general way. The bases are united with the acids in such a manner, that the whole appears to be a mixture of alkaline, earthy and metallic salts, a mode of combination, which as it exists in the ash, is more probably referable to the heat employed in incineration, than to the vital agency of the plant. If the ash is treated with water, an important separation results; all the sulphates, chlorides (some silicate), and the carbonates of the alkalies in particular are dissolved—the really valuable portion, therefore, of the alkaline constituents—whilst the carbonates, phosphates and silicates of the earths remain insoluble. In examining ashes, therefore, it must never be omitted to ascertain the relation of the soluble to the insoluble portion, *i. e.* the value of the ash to the manufacturer of potash. The best amongst the older determinations, are those of Berthier; of the more recent, those of Fresenius, Hertwig, Böttinger, and others.

According to Berthier.*

	Constituents of 100 parts of ash.	White beech wood.	White beech charcoal.	Red beech wood.	Oak wood.	Oak charcoal.	Oak bark.
	Carbonic acid . . .		4.43	3.65	2.88	4.39	1.45
Soluble in water.	Sulphuric acid . .		1.30	1.19	0.97	0.90	0.37
	Muriatic acid . . .		0.83	0.85	0.01	0.62	0.04
	Silicic acid . . .		0.18	0.16	0.02	0.15	0.05
	Potash		9.12	10.45	8.11	9.43	4.33
	Soda		2.14				
	Together . . .	19.22	18.00	16.30	12.00	15.5	6.25

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* In the following tables, the entire quantity of the soluble constituents added to that of the insoluble, amounts in each case to 100; but as there is invariably a loss in separating by analysis the different substances composing the ash, the addition of the numbers against each constituent does not always make up that sum; the deficiency, therefore, exhibits the amount of loss. In some cases, however, the deficiency arises from the whole of the constituents not having been estimated.

Insoluble in water.	Carbonic acid	26.92	24.43	27.53	34.99	26.91	37.22
	Phosphoric acid	8.11	7.22	4.77	0.71	6·27	—
	Silicic acid	4.05	3.20	4.85	3.36	1.52	1.03
	Lime	31.31	35.75	35.66	48.41	39.95	47.78
	Magnesia	6.33	5.70	5.86	0.53	7.15	0.75
	Oxide of iron	1.30	0.08	1.25	—	0.09	—
	Oxide of manganese	2.76	5.70	3.77	—	2.60	6.98
	Together	80.78	82.08	83.70	88.0	84.5	93.75

	Constituents of 100 parts of ash.	Lime wood.	Birch wood.	Alder wood.	Fir wood.	Fir charcoal.	Pine wood.
Soluble in water.	Carbonic acid	2.96	2.72	—	7.76	7.34	2.89
	Sulphuric acid	0.81	0.37	1.24	0.80	3.75	1.67
	Muriatic acid	0.19	0.03	0.06	0.08	—	0.92
	Silicic acid	0.17	0.16	—	0.26	1.09	0.18
	Potash	6.55	12.72	—	16.80	15.32	4.41
	Soda					22.55	3.53
	Together	10.8	16.0	18.8	25.7	50.0	13.6
Insoluble in water.	Carbonic acid	35.75	26.04	25.17	17.17	10.75	32.77
	Phosphoric acid	2.51	3.61	6.25	3.14	0.90	0.91
	Silicic acid	1.80	4.62	4.06	5.97	6.50	4.19
	Lime	46.53	43.85	40.76	29.72	13.60	38.51
	Magnesia	1.97	2.52	2.03	3.28	4.35	9.56
	Oxide of iron	0.09	0.42	2.92	10.53	11.15	0.09
	" manganese	0.54	2.94	—	4.48	2.75	0.36
	Together	89.2	84.0	81 2	74.3	50.0	86.4

According to Berthier.

	Constituents of 100 parts of ash.	Mulberry tree.	Nut tree wood.	Elder wood.	Wheat straw.	Potatoe straw.	Fern.
Soluble in water.	Carbonic acid	5.82	3.11	7.71	trace	0.26	4.35
	Sulphuric acid	2.09	0.78	2.06	0.20	0.97	1.62
	Muriatic acid	1.01	0.08	0 13	1.31	0.50	3.19
	Silicic acid	—	0.08	0.06	3.53	—	—
	Potash	13.16	11.27	21.54	5.05	2.47	19.84
	Soda	2.91					
	Together	25.0	15.4	31.5	10.1	4.2	29.0
Insoluble in water.	Carbonic acid	31.75	32.33	22.06	—		17.96
	Phosphoric acid	1.36	4.19	5.83	1.08		5.68
	Silicic acid	2.19	3.67	2.25	73.36	36.4	15.48
	Lime	34.85	37.06	34.57	5.72		30.39
	Magnesia	3.48	3.84	1.76	—		0.50
	Oxide of iron	0.38	3.50	0.08	2.42		0.50
	" manganese	0.98	—	1.26	7.25 Potash.		0.50
	Together	75.0	84.6	68.5	89.9	95.8	71.10

According to Hertwig.

	Constituents of 100 parts of ash.	Beach wood.	Beech bark.	Pine needles.	Bean straw.	Pea straw.	Potatoe straw.
Soluble in water.	Carbonate of potash	11.72		10.72	13.32	4.16	Sulphate of soda 4.69
	" of soda	12.37			16.06	8.27	
	Chloride of sodium	trace			0.28	4.63	
	Sulphate of potash	3.49		1.95	3.24	10 75	Chloride of sodium 2.28
	Silicate of potash	—		3.90	—	—	
	Together . .	27.77	3.02	12.70	32.91	27.82	6.97
	Carbon. of lime	49.54	64.76	63.32	39.50	47.81	48.68
Insoluble in water.	Magnesia	7.74	16.90	1.86	1.92	4.05	3.76
	Phosp. of lime	3.32	2.71	6.35	6.43	5.15	5.73
	" Magnesia	2.92	0.66		6.66	4.37	
	Basic " of iron	0.76	0.46	0.88	3.49	0.90	1.30
	" " alumina	1.51	0.84	0.71		1.20	2.75
	" " mangan.	1.59	—	—	—	—	—
	Silica . . .	2.46	9.04	10.31	7.97	7.81	29.81
	Together . .	72.23	96.98	86.30	65.97	72.18	93.03

FRESENIUS.

	Rye straw.	
	Silicate of potash .	6.88
	Sulphate of potash .	1.75
	Chloride of potassium	0.25
	" sodium .	0.56
	Silicate of lime . .	4.19
	Magnesia . . .	0.76
	Phosphate of lime .	2.50
	" magnesia	1.28
	" iron .	1.57
	" manganese	trace
		19.47
Insoluble in water.	Silicate of potash .	9 21
	" lime . .	3.43
	" magnesia .	1.16
	Phosphate of iron .	1 63
	" manganese	trace
	Carbon . . .	0.94
		80.26

BÖTTINGER.

	Red beech wood.	Pine wood.* (P. sylvestris.)
Chlorine . . .	0.133	0.39
Silicic acid . .	1.459	3.03
Sulphuric acid . .	1.351	1.94
Phosphoric acid .	3.065	5.20
Oxide of iron . .	0.803	
Lime . . .	63.244	31.67
Magnesia . . .	11.270	19.71
Potash . . .	15.794	2.77
Soda . . .	2.877	16.61
Protoxide of manganese	—	18.13

After the deduction of the carbonic acid.

In one single instance only, in the seeds of barley from French Switzerland, has fluorine been found as a constituent of the ash.

What kinds of Plants are Employed.—It is self-evident that all the constituents of the ash must be valuable as manure, in proportion as they are indispensable to vegetation, or inasmuch as they contain everything which arable land requires for the retention and increase of its fertility. In agriculture, where a greater quantity of the mineral constituents are taken from the soil in the crops and produce, than

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* From a sickly trunk, p. 289.

can be replaced by the soil from its own mass (by constant disintegration), it becomes necessary to return, as far as possible, the substances in question (in the form of manure). The whole profit, for example, that could be derived by extracting potash from the ashes of weeds grown upon arable land, would, in other words, be so much deducted from the fruitfulness of the soil. It is a different case with forest culture, which, in removing the wood from the soil, does not impoverish it beyond what nature, without the aid of man, is always able to replace.

There are, therefore, no great objections to the extraction of potashes from the ashes of fire wood, whilst the ashes of other plants can only be used for that purpose, when the other interests of husbandry are not materially injured by it.* In some thinly populated countries, as in the north of Europe, or in the United States, wood is in such abundance and so cheap, that it can be burnt solely for the sake of the ash. In the same manner straw and weeds can be consumed in Russia, where manure is of very little value. In other countries, on the contrary, the production of ashes is only secondary to the production of heat in stoves, &c. Besides these sources, yeast and the lees of wine are used in the wine districts, in the north of France (at Valenciennes), the residue from the brandy distilleries; and lastly, in Java, the stems and leaves of the indigo plant, after the separation of the coloring matter, are used as excellent materials for the production of potashes.

Production of Ashes from the Yeast or Lees of Wine.—The yeast, which is collected into one common vessel, after the wine has been fermented and drawn off, is allowed to settle down completely, in order to separate it from the remainder of the wine. A thick mud remains, which is brought, about ⅓ of a cwt. at a time, into bags and pressed. The cakes should be bent in a curved manner after leaving the press, that they may dry readily and completely in the sun; they are considered dry when they have become brittle and pulverizable.

The combustion of these cakes of yeast is performed upon a kind of plastered thrashing floor, which is surrounded by a square of loose brick work, to keep the ashes together. At first this wall is low, but it is heightened as the heap of ash increases. A bundle of twigs is first ignited in the middle, and a few cakes are placed around it, to which others are added as soon as the former are at a full red heat; and this operation is kept up until the stock is exhausted. The great point is to regulate the fire in such a manner that the whole shall be completely burnt, without creating such a powerful flame as would carry off particles of the ash or volatilize too much alkali. The incineration of 1000 cakes of yeast, which together weigh 60 cwts.,

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* Thus Hermbstädt's plan of planting wormwood for the production of potash cannot be strictly followed, although this plant will grow upon very poor soil. According to Hermbstädt's own experiments, one Magdeburg acre (= 18000 sq. feet) affords in a summer three crops or 20,000 lbs. of the dry plant, which produce 2364 lbs. of ash, and from it 936.6 lbs. of potashes, which is equivalent to 11.8 per cent of ash, and 4.7 per cent. of potashes.

affords on an average 10 cwts. of ash of excellent quality. The lees of wine do not produce quite so good an article.

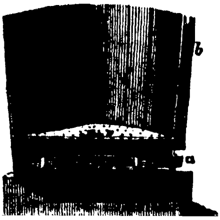
The name *woad ash* (Waidasche) given originally to this substance in commerce, as well as to the better sorts of ashes, or to all those which were intended to pass as such, arose from the best kinds of potashes being selected by dyers of blue color to supply the *woad* tubs.

In the North.—From the north, from Sweden, for example, a crude kind of ash prepared in a peculiar manner was formerly brought into commerce under the name of *Ochras* or *Okras.* For the preparation of this ash, old decayed trees were selected. The wood, split up into billets, was burnt to ash on the spot, in a low situation protected from the wind, and with as little fire as possible; the ash, having been separated from charcoal, half burnt wood and stones, was collected together in a shed. When a sufficient quantity had been brought together, it was submitted to a kind of crude calcination. This operation commenced by the workman transforming the whole mass by the gradual addition of water and constant agitation with rakes, into a dough, or stiff mortar, which was then arranged in alternate layers with pinewood, so as to form a sort of pile. Upon a series of billets arranged on the ground, a layer of this dough was deposited, then another series of billets in a cross direction, another layer of the ash and so on. After igniting this pile, which was several feet high, and in which the fire was urged to its greatest intensity, the ash became red hot and fused; when this state had become general throughout, the pile was destroyed and the fused mass stirred about with poles, to which it attached itself for the greater part on cooling. It had the appearance of slag, and was of a bluish color.

The production of Potash.—At present no crude ash is brought into the market, like that we have here been describing, but only the potash itself. This is obtained by extracting with water all the *soluble portion* of the ash (containing all the carbonate of potash and soda), *evaporating* the lye and *heating* the residue to *redness.*

Lixiviation.—The process of lixiviation is similar in principle to that practised with crude soda, but is carried out in a still cruder manner. The tubs used for this purpose, are generally merely tar barrels sawed in half, a number of these are furnished with two cross beams upon which rests a false (sieve like) bottom covered with straw, and below this is a plug *a*; these are called the *ash tubs*, Fig. 125. In order to facilitate the descent of the lye into the space between the two bottoms, it is as well to introduce a tube *b* at the beginning for the escape of the air. The ash cisterns are arranged in a double row one above the other; the hindermost upon a scaffolding, and the front set upon wooden stands. Parallel with these and in great part sunk in the earth is a third foremost row of empty cisterns, "the *wells.*"

Fig. 125.



Before charging the ash cisterns, it is necessary to sift the ash from coal and charred wood (which are thrown upon the fire) and to moisten it thoroughly, that the water may pass through it of uniform strength.

When all the cisterns in both rows are charged with moist ash, which is firmly pressed down upon the straw, that no interstices may be left, the lixiviation begins, and the first cistern in the uppermost row is supplied with a quantity of fresh water. In taking up the soluble portion from the ash, this becomes converted into a strong lye, on leaving *a*, and being in a fit state for boiling, is immediately brought into the pan for evaporation. In the mean time a second portion of water is poured upon the ash in the first cistern, which is by no means exhausted; a second much weaker lye is produced, which is allowed to run into the first ash cistern of the second row, whence it also issues in a fit state of saturation for boiling. The third portion of water is still too weak on leaving the first and second cisterns, and is only fit for boiling after having passed through a third cistern (the second of the upper row), thus every fresh portion of water comes at last in contact with a fresh portion of ash. Whilst the furthermost ash cisterns are at work, those first used can be emptied and refilled.

In this manner some of the cisterns are always ready charged for bringing up the lye to the proper state of saturation, (it should contain from 20 to 25 per cent. of salt,) and as water is poured upon the ash as long as anything is dissolved (which is estimated by the hydrometer), no portion of the soluble matter, no potash is lost. By treating the ash with cold water, nearly all the sulphate of potash would remain behind; but partly in order to increase the weight of the potash, partly because the potash in that salt is made available in many of its applications, it is thought preferable to use hot water, or at least towards the end of the operation.

The simple and appropriate process just described, which is that practised at Blansko, in Moravia, is not so generally followed as it might be. In the Odenwald and Hinterland (Grand Duchy of Hesse), the imperfect method of solution gives rise, amongst other inconveniences, to a great waste of fuel. In the latter district, the lye with which the pan is supplied is so weak, that the fire must be kept up for 60 hours, in order to obtain by evaporation from 70 to 100 lbs. of crude potash.

Evaporation.—The cast iron evaporating vessels should be flat, and in the shape of pans, that a large surface may be in contact with the fire, and at the same time expose a large evaporating surface. More space is thus afforded to the workman for breaking up and removing the mass of salt, while the bottom can be supported in several places. The same arrangement for applying heat as that employed with the salt pans (p. 256) is the most appropriate, and the flame in escaping is advantageously used for warming a feeder, whence the evaporating pan receives its supply.

The evaporation goes on quickly at first, and the evaporated water is constantly replaced by lye of the proper strength, until the contents of the pan become thick and syrupy, and a hot portion of the lye quickly solidifies to a crystaline mass on cooling. No further addition is then made, and the whole is evaporated to dryness at a moderate heat. In this manner a saline mass is left containing about 6 per cent. of water, and firmly attached to the bottom. The color is derived from empyreumatic substances, which give a yellowish-brown appearance to the lye. The *crude potash*, or the flux (Fluss), has now to be broken away from the pan by means of chisels or axes, and the evaporation is then commenced anew. To avoid this operation, the lye may be evaporated to dryness with constant stirring, which prevents the salt from adhering to the sides or bottom of the pan, but is by no means a less laborious operation, and affords a salt containing at least twice as much water; the pans, however, are less subject to damage.

In Russia two kinds of potash are at present manufactured; namely that from *wood ashes*, more particularly in the districts beyond the Wolga, in the government of Nischnei-Novogorod and Kasan; and that from the ash of *straw*, and the *vegetation of the Steppes*, which is brought from the south, and is only about 10 per cent. less rich than the former. The production of ash constitutes one of the fiscal duties imposed by the landlords upon the peasantry in those countries; the method of preparation is consequently carried on upon a large scale on the estates; but in a crude and somewhat different manner. The ash (obtained from fire-hearths, and by burning the weeds), is three times extracted, and the lye is evaporated in flat copper pans heated by a straw fire, not to dryness, but in the first instance, only to the point of crystalization, when it is drawn off into wooden cisterns. Impure carbonate of potash deposits in brown crystals, which, after being drained are calcined in a muffle furnace (see below). The mother liquor is returned to the wells. In these countries, the whole value of the straw and brush wood, which is used as fuel, consists in the ash which it produces.

The residue, left after lixiviation, is employed in the glass-houses for the production of green bottle glass, and is also valuable as a manure, on account of the phosphates which it contains. When it has been exposed for some time to the air, the carbonic acid decomposes the silicate of potash, and on lixiviating it a second time, some more carbonate of potash is obtained, but in much less quantity.*

The value of the soluble salt from the ash (the potashes) is much increased, and the salt is rendered more appropriate for many of its uses, when, as is here and there practised, the difficultly soluble sulphate of potash is separated by evaporation and cooling from the lye which has been saturated with the soluble part of the ash, and when two products, this salt namely, and a better kind of potash, are brought separately into the market: by the plan adopted at present,

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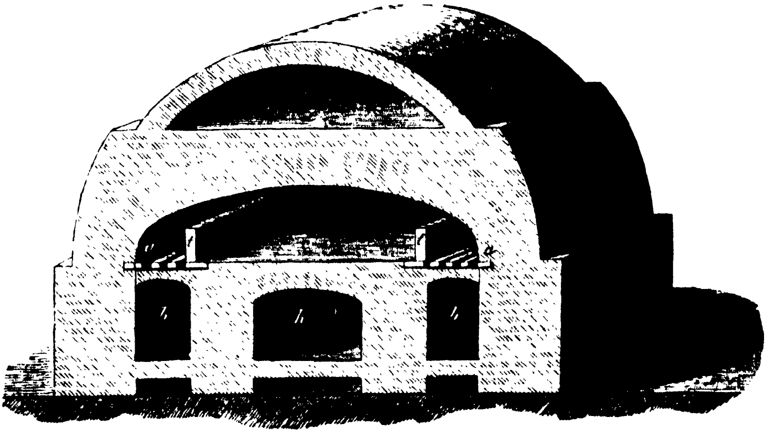
* According to an old observation, ash which has long been kept and stored up, produces more potash. A trial has also been made to increase the amount of potash by what was termed "*Germing*" (Keimen), which consists in spreading out the sifted and moistened ash upon a level stone floor, where it remains exposed for several months, and is frequently wetted and turned over. Both practices are explained upon the same principle.

the sulphate of potash which many consumers of potashes do not use at all, is separated by each of them during purification; it is thus collected in small quantities in different places, and its value is lost to the alum manufacturer and others.

Calcination.—Crude potash, as has already been observed, contains water and empyreumatic substances, which must be destroyed by a red heat, by "*calcination.*" The calcining furnace for potash, Fig. 126, differs from an ordinary reverberatory furnace in having a double firing (with the grates *a*,*a*, and the ash-pit *b* and *b*), which is separated by two narrow iron plates (fire bridges) *t*,*t*, from the working or *calcining hearth*, the latter being from 3 to 4 feet wide. The space *h* is left open, that the sole *c* may be kept more dry, and to economize stone. The arch *e* is also not necessary, and may be used for any other purpose. The air, which feeds the fire, has access through the ash-pit *b*, and the grate *a*, to the fuel, and produces a flame which plays above the fire bridges *t*,*t*, over the calcining hearth. That the flame may be sufficiently long and lively, dry wood in small billets must be used. Before introducing the charge, the furnace should be heated and thoroughly warmed until it is perfectly dry, and no more moisture is deposited in and about it. For this reason it is advisable not to allow the furnace to cool between two consecutive operations, as the warming is a source of much expense. As soon as the furnace has nearly attained a red heat, about 3 or 4 cwts. of the crude potash is broken up and spread carefully over the calcining hearth. The mass now assumes a different appearance, depending upon the greater or lesser quantity of water of crystalization which it contains, and this is evolved with more or less frothing; when too much is present, the operation is impeded, inasmuch as the heat can then only be raised very gradually. By constant agitation, the water is driven off in as uniform a manner as possible. After the lapse of about an hour all the water has been expelled, and the heat must

Fig. 126.



then be increased, that the whole mass may become red hot, and that the air in passing through the furnace may consume the combustible and coloring matters. At this period, the potash takes fire, and burns with a flame of slight intensity, becoming black by the carbonization of the combustible matter; it, however, soon becomes clearer and clearer, until, at length, a sample appears quite white, and free from carbon. An incrustation generally attaches itself to the sole of the furnace. To remove this, the flame must be allowed to play upon it, when it softens and is easily loosened. The white calcined ash is then removed and allowed to cool; but must be packed in close casks before it has had time to absorb moisture from the air. Crude potash loses about 15 or 20 per cent. of its weight in the calcining furnace.

When caution is not employed in managing the heat, and the mass fuses before the combustible matters are destroyed, they become surrounded by the fluid salt, and are decomposed, merely leaving their charcoal intermingled with the potash, which then cannot consequently be burnt white. Fortunately, carbonate of potash is difficult of fusion, and this evil can only occur when the ash contains a large proportion of chlorides, which fuse at an incipient red heat.

Calcined potash is a hard, light, porous and granular saline mass, the white color of which merges into pearl gray, or becomes yellowish or bluish. Single pieces often exhibit blue and red spots on the fractured surface. The red color is caused by oxide of iron, the gray by intermingled particles of carbon, and the blue by the action of the alkali upon oxide of manganese, giving rise to a minute quantity of manganate of potash.

Constituents of Calcined Potashes.—Commercial potashes are never completely soluble in water; sometimes a considerable residue is left, at others only a few light flocks remain; this partly arises from the imperfect filtration of the lye through the straw in the ash cisterns, but chiefly from the calcination, in which operation a small quantity of crude ash from the fire is mechanically carried over by the flame, and deposited upon the potashes. The following substances are those which have as yet been observed in potashes:

In *the soluble portion:* neutral carbonate of potash, sulphate of potash, chloride of potassium, silicate of potash—these are always present: there are sometimes found in addition, neutral carbonate of soda, phosphate of potash, sulphuret of potassium, manganate of potash, bicarbonate of potash, caustic potash, and organic matter.*

In *the insoluble portion* there is always silicic acid, and sometimes, silicate and phosphate of lime, carbonate of lime, phosphate and carbonate of magnesia, oxide of iron, protoxide of manganese, alumina, and lastly, sand and carbon.

The caustic potash is due probably to the addition of the slaked

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* The observation made by Preusz, that iodine is present in the potashes from the Moselle, requires further confirmation.

lime, and is only found in American potashes. The sulphuret of potassium, on the contrary, is produced by the action of the organic matters, which combine with a portion of the oxygen of the sulphate of potash. The traces of bicarbonate of potash, which have been met with here and there, can only be accounted for by supposing neutral carbonate of potash to absorb carbonic acid from the air on being kept exposed for a length of time. The presence of the other substances is explained by reference to the analyses of ash (p. 290). It must also be stated, that potash manufacturers are in the habit of mixing chloride of potassium—which is obtained from the under lye in soap-boiling—sand, &c., with their goods, much to the deterioration of their quality.

Hermann found in a complete analysis of the potashes from Kasan, the following ingredients:

In the soluble portion.		In the insoluble portion.	
Carbonic acid	27.790		
Potash	47.455	Lime	0.054
Soda	2.730	Alumina	0.012
Sulphate of potash	17.062	Manganic acid	0.013
Chloride of potassium	3.965	Silica	0.132
Chromide of potassium	trace		
Phosphate of potash	0.443		0.211
Silicic acid	0.344	Soluble portion	99.789
	99.789		100.000

In European commerce, the various kinds of potashes are classified, either according to the locality whence they are imported, or according to the route by which they arrive; thus we have, American, Russian, Turkey, German, Moselle, Illyrian, Saxon, Bohemian, Dantzig, Heidelberg potashes; they are seldom distinguished by their color or appearance, as is the case with pearl-ash.

For certain purposes, more particularly pharmaceutical, "*purified potash*" is prepared *sal tartari*, which consists of potashes separated from all insoluble matter, and from everything but alkali in combination with carbonic acid. Commercial potashes are then either treated with an equal weight of cold water, the lye strained and evaporated to dryness—an operation which it is often necessary to repeat—or the potashes are dissolved in 2 parts of boiling water, and the concentrated filtered lye set aside to cool, that the sulphate of potash may separate. The decanted lye is evaporated again; when white carbonate of potash crystalizes this is then drained and dried. In the former process, the purified potash contains nearly all the chloride of potassium, and much silicate of potash; in the latter but little of either of these substances remains.

ESTIMATION OF THE VALUE OF SODA AND POTASHES.

(ALKALIMETRY.)

The value of these two substances in the arts is dependent upon the extent of their chemical action; this action is solely exerted by that portion of alkali which is loosely combined, and can easily be set free to serve any purpose for which it may be required in manufactures. With the exception of a few instances, which have either already been noticed, or will be mentioned in the sequel, this is entirely confined to that portion of alkali which is in combination with carbonic acid. The value of soda is, therefore, proportional to the quantity of *soda* contained in the carbonate; and that of any kind of potashes, to the amount of alkali, *potash*, in the corresponding salt.

A complete chemical analysis would be the surest means of ascertaining the amount of soda or potash, in either of the crude substances; but the tediousness of the operation, the great practice required in manipulation, and the cost of apparatus, render any such method nearly impracticable to the manufacturer. An essential service has, therefore, been rendered by chemistry to the arts, in pointing out a mode of ascertaining, with sufficient exactitude, the amount of soda or potash in the crude salt, which can be carried out in an off-hand manner, without material cost, and which does not require any great amount of practice or dexterity in its execution.

Principles of Alkalimetry.—As the action of any of the stronger acids, for instance, sulphuric acid, is only extended to those salts, or can at least be restricted to those, upon which the practical use of soda and potash depend, (to the carbonates of the alkalies, therefore,) the common alkalimetrical methods are founded upon the decomposition of these salts by an acid of this kind. For this purpose sulphuric acid has always been selected as the most energetic and least expensive, as an acid that can be everywhere procured, which is not volatile at common temperatures, and can, consequently, be weighed or measured without fear of loss. In fact, carbonic acid is completely expelled from its compounds by sulphuric acid. The law of definite proportions will, of course, be applicable here as in every other decomposition or combination. In accordance with this law, 1 equiv. of hydrated sulphuric acid (SO_3, HO) = 613.64 is required to unite with 1 equiv. of potash (KaO) = 589.9 contained in 1 equiv. of carbonate of potash (KaO, CO_2) = 864,9, in order to convert it into sulphate of potash, and the same quantity will unite with 1 equiv. soda (NaO) = 390.9 from 1 equiv. of carbonate of soda (NaO, CO_2) = 665.8 in forming it into sulphate of soda; in each case 1 equiv. of carbonic acid will be liberated (CO_2) = 275.0; or,

100 parts of potash require for neutralization 104.2 of hydrated sulphuric acid
100 " " soda " " " 156·9 " " " "
100 " " carbonate of potash " " 70.95 " " " "
100 " " carbonate of soda " " 92.15 " " " " lastly,
1 part of liberated carbonic acid corresponds with 3.145 of carbonate of potash.
1 " " " " " " 2.420 " " soda.

By the older methods, the measure applied, to ascertain the value of potash or soda, was the quantity of sulphuric acid which is required to expel the whole of the carbonic acid; the idea was first broached by Richter, afterwards put into practice by the French chemist, Decroizilles, in 1806, and has since been rendered much more applicable by the improvements of Gay-Lussac.*

The more recent method of Will and Fresenius makes the quantity of carbonic acid that is expelled by sulphuric acid, the measure of alkalinity.

Gay-Lussac's Method.—The peculiarity of Gay Lussac's method, and of those of his predecessors, is, that all weighing operations are converted as much as possible into measurements; and it will also be easily perceived, that the certainty of this test depends chiefly upon the accuracy with which the amount of hydrated sulphuric acid is ascertained in the dilute acid (*test acid*) used for saturation. Gay-Lussac attains this by carefully weighing 100 grammes of pure sulphuric acid of sp. gr. 1.8427 at 15° (59° F.) and 962.09 grammes of water,† which on being mixed and allowed to cool (to 15° = 59° F.), exactly occupy the space of 1000 grammes of distilled water, or 1000 C. C. = 1 litre. In making the test-acid, the measure, which is divided from the bottom upwards into half C. C., is filled to the uppermost line, to the 0, therefore, with test-acid. As this acid contains 100 grammes of hydrated sulphuric acid in 1000 divisions of the measure, the $\frac{100}{2}$ C. C. of the glass will contain exactly 5 grammes of acid, which, according to the law above, will require an equivalent, namely 4.807 of pure anhydrous potash for saturation. This quantity 4.807 is, therefore, weighed from the mass to be examined; if it were pure potash, the whole of the 100 divisions of the test-acid would of course be just sufficient; if it only contained one-half its weight of pure potash, then 50 parts or divisions would be required; if only ¼th, then 25 divisions; in short, there would be just as much per cent. of pure potash contained in the specimen, as is indicated by the number of volumes of test-acid required for saturation.

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* On the authority of Mr. Griffin, of London, who has paid a great deal of attention to the alkalimetry, and whose promised work upon that subject is anxiously looked for, we may state that a very accurate method of estimating the value of potashes was published by Dr. Lewis, nearly a quarter of a century before the publication of Richter's experiments, and consequently at a much earlier period than those of Decroizilles, as the result of that gentleman's investigation of the first potashes introduced into England from the *colony* of New York. The pamphlet is entitled "Experiments and Observations on American potashes, with an easy method of determining their respective qualities. By W. Lewis, M. D., F. R. S., London, 1767."

† That the practical man may be spared these weighings, two glass flasks are always sold with Gay Lussac's apparatus, the one of which when filled up to a certain mark, in the narrow neck, contains at 15° C. exactly 54.268 C. C. (= 100 grammes) of such sulphuric acid; the other, filled in like manner to a certain mark, contains 1000 C. C. If the contents of the first are poured into the second, and it is then filled up to 1000 C. C. with distilled water, we obtain the necessary quantity of acid of the proper strength; for safety, it is better to add the acid gradually to a portion of the water, and not the water to the acid; the whole is then filled up to 1000 C. C.

In testing for soda, an equivalent to 5 grammes of acid must also be weighed, which is 3.187 grammes.

Small quantities, like 3 or 4 grammes, cannot be weighed with great accuracy upon a common balance; Gay-Lussac, therefore, recommends that 10 times as much should be weighed, therefore, 48.07 potash, or 31.87 soda, and dissolved in so much water that the whole shall occupy 500 C. C. When by means of a pipette, $\frac{1}{5}$th of this is taken as the test-quantity, the quantity thus measured will be a closer approximation to 4.807 grammes. A glass, graduated into 500 C. C. and a pipette with a mark showing 50 C. C. must be procured for this purpose.*

The volume of test-acid employed will also indicate the per centage, without further calculation, when the acid is so apportioned that the measure shall contain 104.2 hydrated sulphuric acid for potash, or 159.9 for soda, and each experiment is made with 100 parts of potash or soda.

Pure sulphuric acid, such as is requisite for Gay-Lussac's method of testing, is not always to be procured, but Otto has shown, that common English sulphuric acid may be substituted, when its power of saturation has been previously determined. This is then ascertained by a previous experiment, and for a large quantity of acid, which can afterwards be used for a great number of tests. A preliminary experiment of this kind is made by testing the acid diluted with about 12 parts of water by means of an alkali, or what is the same thing, by means of a carbonated alkali of known purity; dry carbonate of soda, which has been prepared by heating the bicarbonate to redness, is best adapted for this purpose. If a quantity is taken equivalent to 100 parts of pure potash, 112.8 parts, therefore, the same result is obtained as if carbonate of potash had been used, which latter substance is much more difficult to obtain pure and in a dry state. All that is now necessary, is to bring the ordinary sulphuric acid diluted with about 12 parts of water into a test glass, and to ascertain (observing the precautions to be mentioned below) how many volumes (degrees) are required to complete the decomposition of 112.8 parts of carbonate of soda. The number of volumes employed will contain exactly 402.02 parts of hydrated sulphuric acid, and if mixed with water so as to occupy 100 volumes, we shall have a test-acid quite similar to that of Gay-Lussac, *i. e.* every volume employed to saturate a substance containing 100 parts of potashes, will indicate the presence of $\frac{1}{100}$th of potash. The same quantity of acid (104.02 parts of hydrate) is just sufficient to decompose 66.3 parts of soda, and each volume will, therefore, indicate $\frac{1}{100}$th of soda, when the test is made with 66.3 parts of the substance containing the soda.

The measures, which are ½ an inch in width, and graduated into 100 equal parts, are either made, like Fig. 127, with a side tube,

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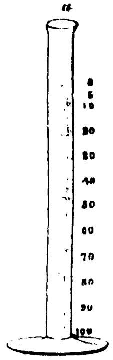
* It need scarcely be noticed that any other measure or system of weights may be used instead of the French, in precisely the same manner.

which is convenient, but very brittle, or consist of a simple tube with a foot Fig. 128, in which, for the convenience of pouring, the graduation is begun a few inches from the top.

The method of conducting the operation requires some special notice. The first thing to be observed is the very unequal nature of the sample to be tested (particularly in potashes), the determination of the mean quantity of potash in which is the object of the test. It is best to take pieces from different parts of the mass, pound them together, and weigh out the test-quantity from this mixture. If this should contain so large a proportion of insoluble matter as to affect the volume of the solution, of which the tenth part has to be measured, then, the only plan is to filter and wash thoroughly in the first instance, a precaution which must always be adopted with wood ashes. In this case, it is advisable, on account of the small quantity of alkali, to double the weight of the test-quantity, and afterwards to halve the result.

Fig. 127.

Fig. 128.

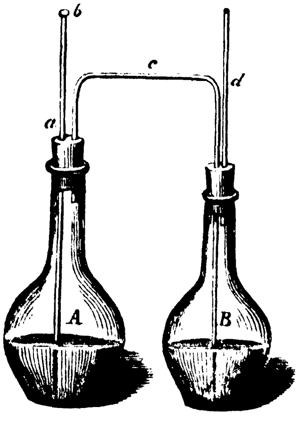


On the addition of sulphuric acid the carbonic acid is not immediately evolved, but forms, with the undecomposed portion of alkali, a bicarbonate, until the decomposition has extended to more than the half, and the fluid has become saturated with carbonic acid, which then escapes with violent effervescence; towards the end, however, this effervescence becomes so indistinct, that it is impossible to know whether the operation is finished or not. Yet the correctness of the experiment depends entirely upon the accurate determination of the point of saturation. Consequently it is necessary to employ a blue vegetable coloring matter, tincture of litmus, which remains unchanged in the beginning; but when $\frac{11}{20}$ of the saturation has been effected, or at that period when the decomposition of the bicarbonate commences, and carbonic acid is set free, becomes of a wine red color, and, at length, when the saturation is completed, is colored more intensely red by a very slight excess of sulphuric acid. Until the wine red color appears, the test acid may be freely added, but then it must be done more cautiously and towards the end, when the evolution of carbonic acid has nearly ceased, by two drops at a time ($\frac{1}{4}$ volume) until no more gas escapes. At this period the free carbonic acid in the fluid renders it difficult to judge with accuracy of the color. In order, therefore, to ascertain whether the reddening is attributable to it, or to free sulphuric acid, after each addition, a streak upon blue litmus paper is made with a glass rod moistened in the test liquid. As soon as an excess of sulphuric acid has been employed, the paper remains red after having been dried, which is not the case if the reddening has been occasioned by carbonic acid. This excess of acid, *i. e.* as many $\frac{1}{4}$th volumes as there are lasting red streaks, must now be deducted from the whole quantity used. As the action of the acid upon litmus paper is somewhat lessened by the presence of the sulphate of potash produced, an extra ¼ volume is deducted in addition.

The action of sulphuric acid upon sulphuret of sodium, sulphite, and hyposulphite of soda, which are frequently present in artificial soda, as well as upon sulphuret of potassium, is quite the same as upon the carbonates of the alkalies; these, however, do not at all increase the value of soda. A test of this kind, therefore, shows a higher value for soda than it actually possesses; an error which (according to Gay-Lussac) may be avoided, by previously heating such a test specimen to redness with chlorate of potash. By this means, the substances named become converted into sulphates at the expense of the oxygen of the chlorate of potash, which (chlorate) itself remains as chloride, whilst the carbonated alkali is not acted upon; the hyposulphite (S_2O_2) however, produces 2 eq. of sulphuric acid, the one of which decomposes an equivalent proportion of carbonate, which is consequently somewhat under estimated. The opposite action which the silicates and phosphates exert upon the test acid, and consequently upon the test itself, is unavoidable. For these reasons the test for soda, by means of the alkalimeter, cannot entirely be relied upon.

Method of Will and Fresenius.—The possibility of ascertaining the quantity of alkali by determining the amount of carbonic acid, depends upon the fact, that only neutral carbonates are present in potashes and soda, so that each single equivalent of carbonic acid expelled, corresponds exactly to 2.145 of pure potash, and to 3.145 of carbonate, or to 1.421 equivalents of pure soda, and to 2.421 of carbonate of soda. For the sake of simplicity, the carbonic acid is estimated by the loss of weight, which a previously weighed apparatus containing the test portion and the acid, experiences, when this acid is expelled. It is necessary in this method, that nothing but carbonic acid should escape during the operation; now although no loss is to be anticipated from the other substances, yet this volatile acid cannot pass off from an aqueous solution, without being charged with aqueous vapor. The ingenious manner in which this evil is obviated by the apparatus of Will and Fresenius, and the manner in which the necessary temperature is generated in the fluid without the application of external heat, will be seen by observing its construction, Fig. 129. *A* is a larger flask of about 2 oz. capacity, in which the decomposition is effected. *B* a somewhat smaller flask containing English sulphuric acid. Both are supplied with doubly pierced corks for the reception of the three tubes *a*, *c*, and *d*. The tube *a* is confined to the flask *A*, being im-

Fig. 129.



mersed below the level of the fluid; in the same manner *d* is only connected with the flask *B*, and only extends just below the cork. Lastly the tube *c* enters the neck of *A* on the one side, but does not extend further, and by a double bend is brought into connection with *B*, which it enters, dipping into the sulphuric acid. The mouth of *a* is closed by wax during the experiment, so that no orifice is left to the whole apparatus, but the mouth of the tube *d*.

For weighing the test portion, and the whole apparatus, an ordinary apothecary's scale is used. It is one of the great advantages of this method, that the experiment may be made upon a much larger scale than is possible in ordinary analysis. By this means, this cheap balance, when made to turn with the ⅛th of a grain, affords quite as much accuracy, as those which are made for scientific purposes, and are at least 20 times as costly; particularly, when such inaccuracies, as may arise from the unequal length of the arms are obviated, by placing the weight upon the *same scale-pan* as the substance or apparatus to be weighed, it having been previously exactly balanced by a counterpoise (double weighing).

As a test-portion, several grammes of potash or soda previously thoroughly dried over a flame in a small metallic or porcelain vessel, are weighed and introduced by means of a card into the flask *A*, which is then filled with water to about ⅓d; the apparatus is then closed by the wax stopper, and brought into equilibrium on the balance by a counterpoise. The decomposition is now induced by sucking out a small quantity of air with the mouth from the tube *d*. The air is thus drawn not only from *B* but also from *A*, both flasks being connected by the tube *c*; bubbles of air are, therefore, seen passing from *A* through the sulphuric acid. On stopping the suction, acid passes from *B* into *A* through the tube *c*. The carbonic acid which is now evolved in *A* with effervescence and a rise in temperature, can only escape by the tube *c* into the flask *B*, whence it must pass through the remainder of the sulphuric acid, and the tube *d* into the air. This sulphuric acid condenses with great energy all the aqueous vapor, and retains everything that the current of gas might possibly carry mechanically with it. When this operation has been repeated several times, the decomposition is completed. There is still, however, a portion of carbonic acid remaining in the apparatus, which was previously filled with air, and some still clings to the saline solution, which by this time has become cold. Both must be removed before the apparatus is reweighed.* For this purpose by suction, as in the beginning at *d*, so much sulphuric acid is caused to pass over at once as will give rise to a considerable elevation of temperature in *A*, by which means the carbonic acid in solution is evolved, and with it that portion still clinging to the other parts of the apparatus. For by removing the wax stopper *b*, the mouth of *a* is

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[* Prof. W. B. Rogers has proved that even sulphuric acid absorbs of carbonic acid nearly its own volume, which would render necessary the heating of the vessel *B* before drawing air through it to complete the operation.—AM. ED.]

opened, and air may then be drawn through the apparatus from *d*, until all the carbonic acid is expelled. Here too, all the moisture which is removed by the current of air in *A*, will remain in the sulphuric acid in *B*. When the whole apparatus has cooled, it is placed upon the scale, and the amount of carbonic acid is ascertained by the weights which must be added to re-establish the equilibrium.

It has been stated above that 3.145 grammes of dry carbonate of potash contain exactly 1 gramme of carbonic acid; the calculation of the per centage of this salt from the result, is very much simplified if 3.145 grammes of potashes are always taken as the test-quantity, as every centigramme of carbonic acid which has been evolved, will then indicate 1 per cent. of carbonate of potash; if, however, $2 \times 3.145 = 6.29$ grammes are taken, as has been recommended, then 1 per cent. will be indicated by 2 centigrammes. In the same manner $2 \times 2.42 = 4.84$ grammes of soda must be used.

The presence of any salts which are decomposed by the sulphuric acid, but the acids of which are not volatile, have of course no effect whatever upon the result. This, however, is not the case with the sulphurets of the metals,* nor with the sulphites and hyposulphites, the first of which evolve sulphuretted hydrogen, the second sulphurous acid, and the last hyposulphurous acid, which is immediately decomposed into sulphur and sulphurous acid. Sulphuretted hydrogen or sulphurous acid may, therefore, be evolved, which, calculated as carbonic acid, would erroneously augment the amount of potash (or soda). This, however, is easily obviated by the addition of some yellow (neutral) chromate of potash, which converts both the volatile acids into sulphuric acid and water, and remains in combination with both, together with sulphur, as sulphate of chromium.

If there are carbonates of the earths in the insoluble portion of the potashes, the solution must be filtered and the residue well washed, and this must always be done in testing ashes and crude soda.

An error of an opposite kind, which rectifies itself in Gay-Lussac's process, may arise from the presence of caustic potash or soda. As these evolve no carbonic acid, they will not influence the result obtained by this process, although both in potashes and soda, they are quite as valuable as the carbonated alkali. To ensure the estimation of these, the test-portion should be previously mixed in a moist state with carbonate of ammonia, and dried at a very high temperature, by which means all the caustic alkali becomes carbonated. If the

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* H. Rose has lately shown, that the sulphuret of sodium and caustic soda in crude soda have one and the same origin. They are both caused by the decomposition of sulphuret of calcium in water. A portion of this metallic sulphuret is decomposed with the elements of water into hydrate of lime and sulphuretted hydrogen, which latter unites with another portion of undecomposed sulphuret, to form the hydrosulphuret of sulphuret of calcium. Both products of decomposition are present, when the crude soda is dissolved out by water, and re-act upon the carbonate of soda in such a manner, that the hydrosulphuret of sulphuret of calcium, and the hydrate of lime, are both converted into carbonate of lime, whilst hydrosulphuret of sulphuret of sodium, and a portion of hydrate of soda are produced. In contact with the air, the former (by oxidation) is converted into one or other of the higher sulphurets, which is then found in the mother liquor.

sulphuret of an alkaline metal is present, as is the case to a considerable extent in crude soda, the mass is moistened with caustic ammonia instead of with water. The amount of caustic alkali can be ascertained by the apparatus, Fig. 129, although not with very great accuracy, but it cannot be determined at all by Gay-Lussac's method. Two experiments are required for this purpose, the one made in the ordinary manner, the other after the test portion has been treated with carbonate of ammonia. The difference in the amount of carbonic acid obtained in each experiment will then show the quantity of caustic alkali contained in the specimen. Strictly speaking, the alkalimetric tests are not analyses for potash or soda, but merely accurate measurements of the amount of action, which ashes, potashes or soda will produce with an acid. For when both alkalies occur conjointly, which is the case in potashes, and judging from the ash analyses cited, there is more frequently soda present than was previously supposed, this is not indicated by either method quantitatively, or indeed at all. Although for most applications the knowledge of its general action is sufficient, yet in many instances it is quite as desirable to know the exact amount of potash, for instance, in potashes.

It must not be overlooked, that the mere amount of alkali, however this may have been ascertained, does not indicate the actual value of the potashes or soda, because both, but more particularly the former, take up moisture when exposed for any time to the air. It is consequently very necessary to determine the amount of loss which a weighed quantity experiences on drying, as well as its alkalimetric value.

The measurement of the acids upon Gay-Lussac's principle certainly affords the advantage of very small quantities of acid being contained in a comparatively large space, which can, therefore, be read off on a long scale: but the accuracy which arises from this is very much modified by the foreign salts with volatile acids, for, if no loss is to be occasioned by them, the practical man must be possessed of the means of preventing their action, which presupposes a good knowledge of practical chemistry. Much practice is also required in distinguishing the varieties of tint in the litmus paper, and in judging of the point of saturation. The same applies to the preparation of the test-acid, and everything depends upon the degree of accuracy with which that is prepared.

It is, therefore, highly probable that the more recent method of Will and Fresenius will be found more easy of execution by those unaccustomed to chemical manipulation.

Value of Soda-ash and Potashes.—The following tables show the results of some alkalimetrical researches upon different kinds of soda and potashes given by Will and Fresenius.

VARIETIES OF SODA.

	Per cent. carbonate of soda.	Per cent. water.	Caustic soda.	Sulphuret of sodium.	Sulphite of soda.	Hyposulphite of soda.
Yellow calcined, Belgian . . .	83.5	24	little	none	much	much
White	42.8	4	none	—	—	—
Dieusé soda, very white* . .	78.9	4	2.14	—	—	—
Cassel soda, white	84.5	undetermined.	3.0 to 5.2	—	some	some
English soda	76.8		2.7—4.7	little	—	much
White calcined, from Büchner and Wilkins in Darmstadt . . .	91.6		—	—	little	—
Soda from Debreczin . . .	89.2	15.6	—	—	—	—
White calcined, from Wesenfeld and Co., in Barmen	99.9	8	—	—	—	—

None of the varieties examined, contained carbonates of the earths in the insoluble residue.

VARIETIES OF POTASHES.

	per cent.			per cent.	
	Dry carbonate of potash.	Water.		Dry carbonate of potash.	Water.
Bohemian potashes . .	94.6	10	Saxon potashes . .	61.2	9.3
Illyrian I. " . .	95.9	7.6	Heidelberg, potash of Fries	68.0	1
Illyrian II. " . .	93.8	14			

By means of Gay-Lussac's alkalimeter, the quantity of *pure potash* was estimated in the following varieties.

	degrees.		degrees.
American potashes, 1st variety,	54 — 58	Kasan potashes . . .	54 — 55
" " 2d "	48 — 52	Polish " . . .	55 — 60
" " 3d "	25 — 42	Riga . " . . .	30 — 50
New York " 1st "	55 — 60	Tuscany potashes, 1st variety,	50 — 55
" " 2d "	25 — 45	" " 2d "	55 — 60
" " 3d "	25 — 40	" " 3d "	50 — 55

Acidimeter.—It is obvious, that by reversing the process, the alkalimeter may be used for testing the acids which are employed in commerce, or in fact will serve the purpose of an *acidimeter.*

The old established mode of ascertaining the value of sulphuric acid, hydrochloric acid, &c., by the specific gravity, or what is the same thing, by the degrees of an hydrometer (generally Beaumé's) will hardly be superseded, on account of its simplicity. In the case of concentrated acids this is much less likely, as the indications of the

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* This variety, much prized in commerce, contains, according to another analysis of Penot, 53 per cent. dry carbonate of soda, and 22 per cent. caustic soda.

hydrometer are sufficiently accurate. With diluted acids, on the contrary, like vinegar, &c., the differences in the specific gravity corresponding to the differences of strength are so small, that the indications of the hydrometer become very indistinct. The indications of this instrument are rendered still more fallacious by the presence of extractive matters, salts, alcohol, &c., which either increase or diminish the specific gravity.

In such cases the apparatus of Will and Fresenius is more applicable. The strength of an acid is thus determined by the weight of carbonic acid, which a weighed quantity of it is enabled to evolve. For this purpose bicarbonate of soda dried in the air is used, because, of all similar salts, this contains the most carbonic acid. It is not necessary that it should be perfectly dry or free from extraneous salts, provided amongst these, there be no neutral carbonate, for example, of soda; and should it contain this, it can easily be separated by washing with cold water. When the acid to be heated has been weighed, diluted with water, and introduced into the flask *A*, Fig. 129, a glass tube in the shape of a thimble, short and closed at the end is filled with bicarbonate of soda (in excess), and this is hung by a silken thread between the cork and neck of the flask, in such a manner that the salt and acid do not at once come into contact. Ordinary concentrated sulphuric acid is placed in *B*. In this state the apparatus is placed in the scale with a counterpoise, and by a quick removal and re-insertion of the cork, the little tube is dropped into the acid. The decomposition is accelerated by agitation. When the operation is finished, the carbonic acid still remaining in the fluid must be removed; but this cannot be done by causing concentrated acid to flow over from *B*. The flask *A* is, therefore, placed for a few minutes into hot water, and air is drawn through the apparatus until all the carbonic acid is removed; it is then dried and weighed when cool.

Every equivalent of carbonic acid that has been expelled, indicates an equivalent of hydrated or anhydrous acid in the specimen tested.

BORAX.

The salt which is sold and consumed under this name,* is the biborate of soda ($NaO, 2\ BO_3$), which, with 5 or 10 atoms of water of crystalization, forms the two kinds of crystalized borax of commerce. That which contains 5 atoms of water ($NaO, 2\ BO_3 + 5\ aq.$), is called octahedral borax, on account of the octahedral form of the crystals, and is the rarer of the two; it contains, in its pure state, 30 per cent. water. This salt has only lately been distinguished by Payen, from the well-known variety with 10 atoms of water ($NaO, 2\ BO_3 + 10\ aq.$), which crystalizes in prisms. The water, in the former, amounts to 30.9; in the latter to 47.2 per cent.

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* Borax is derived from the Arabian word baurach; Agricola calls Borax Chrysocolla, gold cement, on account of the use to which it is applied in soldering gold.

Both varieties, when exposed to the action of heat, part with all their water, and expand into a vesicular mass, before melting to a clear glass, which possesses the important property of dissolving most of the metallic oxides with the assumption of characteristic colors; it also adheres to the bright surface of metals, protecting them when covered with it, even at a red heat, from the oxidizing action of the air. It is this property which renders borax so valuable as a flux, as glass, and above all, as a means of facilitating the soldering and welding of metals. Borax is also used in medicine.

The borax of commerce is derived from two different sources. Whilst, in former times, the mineral as it occurs in nature, after being purified, was the only known borax; this has now been almost completely superseded by artificial borax, prepared from volcanic boracic acid and soda; a branch of manufacture which has been mainly dependent upon the vast extension of the soda trade.

Artificial Borax.—Occurrence of Boracic Acid.—This manufacture, which French industry has cultivated with such signal success, is carried on upon so large a scale in France, that nearly the whole amount of boracic acid is there consumed, which the north of Italy can supply. The occurrence of this acid in the grand duchy of Tuscany, which abounds in volcanic products, is as peculiar, interesting and important, as the method of procuring it. The boracic acid, in those volcanic districts, which extend over 35 to 40 miles, is brought from the interior of the earth by numerous jets of vapor, which are there called *suffioni*. These suffioni are announced from a great distance by the ascent of thick columns of vapor, which often rise to a considerable height. The entire surface of the volcanic district, consisting of chalk and marl, is subject to constant shocks, caused by subterranean agencies; columns of boiling water are frequently projected into the air, which is strongly impregnated, at the same time, with sulphurous vapor,* and the whole presents a scene of vast desolation. In some parts, the apertures whence the vapors issue, are freely exposed; in others, they are covered by standing water, which, by the constant agitation of the soil, and of the vapor, become converted into small muddy lakes (Lagoons).

It is well known, that boracic acid forms an exception to the general rule observed by those bodies which are fixed when melted in the fire, and to which class it belongs. It volatilizes, namely, in such quantity with the aqueous vapor from a boiling solution, as to render its quantitative estimation very inaccurate under such circumstances. The presence of boracic acid in the suffioni is evidently accounted for in this manner. It is, nevertheless, remarkable, that by simple condensation of the current of gas and vapor, no boracic acid can be obtained, a fact, which can only be explained by the extremely minute quantity held in solution. This quantity, however, is considerably increased when a lake covers the aperture of the suffioni. It would appear, from the observations of Payen and Bowring, whom we have to thank

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* Sulphuretted hydrogen, according to M. Larderel.

for the best accounts upon this subject, that the boracic acid is brought up, by the water of the lakes which occasionally enters the mouths of the suffioni, for the acid, being probably deposited before the vapor reaches the surface, requires the aid of more water to dissolve it. The real source of the boracic acid in the suffioni is totally unknown, and all that can be stated upon the subject is the theoretical opinion of Dumas. This philosopher has endeavored to explain the phenomena, by the assumption of a very deep bed of sulphuret of boron, with which the water of the lakes comes into contact. In this case, boracic acid and sulphuretted hydrogen would be produced with a great evolution of heat, and these would be accompanied by the products of decomposition of the other constituents of the water, which really is the case, as far as hydrochloric acid and ammonia are concerned. The remaining phenomena are then easily explained by the contact of the products of decomposition with deposits of limestone and clay. At a certain distance above the scene of decomposition, the boracic acid may be deposited, and according as the water of the lagoons does, or does not reach it, it will be taken up, and pass off in the vapor, or will be left unvolatilized.

Payen found that these suffioni contained, at a temperature between 97° and 100° (174°—212° F.), much solid matter carried up mechanically, besides permanent gases and aqueous vapor. The mixture of permanent gases consisted, in 100 parts, of 75.3 carbonic acid, 34.81 nitrogen, 6.57 oxygen, 1.32 sulphuretted hydrogen, whence it is evident that atmospheric air must have access, and take part in the decomposition.

In the condensable portion were found clay, sulphate of lime, ammonia, sulphate of alumina, protosulphate of iron, muriatic acid, and organic matter, having the smell of marine fish, with little or no boracic acid. Sulphur is deposited in all parts where there are crevices and pores in the soil.

Method of obtaining Boracic Acid.—In this district there are nine manufactories at distances of 1 to 1½ miles from each other; these are: Larderello, Monte Cerboli, San Frederigo, Castel Nuovo, Sasso, Monte Rotundo, Lustignano, Serrazano and Lago, all situated at the foot of a moderate eminence, from whence jets of vapor arise in different directions.* The process is founded upon the observation already mentioned, that the acid is volatilized with the vapor of water.

The Lagoons.—The arrangement consists of a series of basins in connection with each other (artificial lagoons), constructed of rough brickwork, in a circular form, and lined with clay, round the mouths of one or more of the larger suffioni. The diameter of these basins varies from 16 or 20 feet in the smaller, to 60 or 80 feet in the larger,

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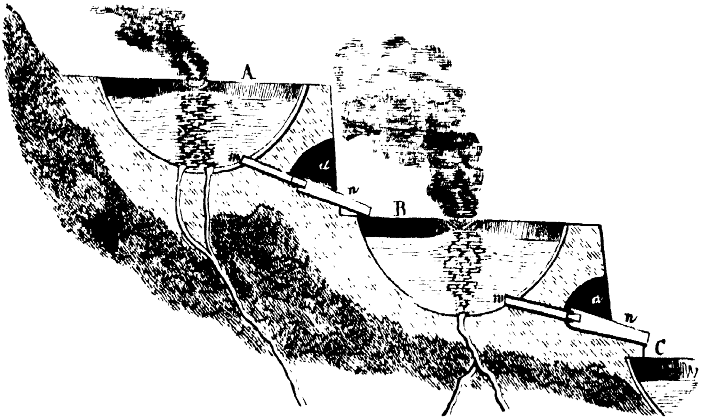
* In an account of the production of boracic acid in Tuscany, read before the French Academy in 1846, by M. Larderel, the localities of these works are differently given, and are said to amount now to the number of ten. They are Monte Cerboli (Larderello), Castel Nuovo, Sasso, Monte Rotundo, San Frederigo, Lago, Sant Ippolito, Lustignano, Acquaviva, Serrazano; the first three are situated in the district of Pomerance, the others in that of Massa Maritima.

and they are from 6 to 10 feet deep.* Fig. 130 represents the manner in which they are arranged in terraces on the side of the hill.

Fig. 130.



On the lower side of each basin is an arch *a a*, by means of which the plugs of the tubes *m* are accessible, and by opening these, the water from the higher, flows into the lower lagoon, through the channel *n*.

These artificial basins, of which there are 6 or 8, serve to saturate with boracic acid the water of neighboring springs or brooks, with which the uppermost, *A*, is supplied, until it is sufficiently impregnated to pay for the expense of working.

When the fresh water arrives at the lagoon *A*, it is partially imbibed, the vapor being at first condensed; but as soon as it has attained the temperature of the vapor it is again evolved, and the whole of the lagoon is kept in constant agitation by the current of gas at a temperature of from 93° to 95° C. (199° to 203° F.) At the expiration of 24 hours, during which time it has been kept in this state, the plug is removed, and the water allowed to flow into basin *B*, where the same operation is repeated. The fluid becomes charged
with some more boracic [illegible] ocess is [illegible] bstances, the quantity of
which is [illegible] the acid is volatilized [illegible] in those which suc-
with the aqueous var The arrangement consists of a series of basins in
titative estimation each other (artificial lagoons), constructed of rough
presence [illegible] in a circular form, and lined with clay, round the mouths
th one or more of the larger suffioni. The diameter of these basins
varies from 16 or 20 feet in the smaller, to 60 or 80 feet in the larger,

Clarification.—From the last lagoon, the solution is received in a large clarifying vessel, "*Vasque*," composed of brick work, 24 feet square, and 4 feet deep, in which, during one night, the greater part of the mud is deposited, and from which the surface liquid is drawn off into a reservoir of the same dimensions for the supply of the evaporating pans.

Evaporation.—The vessels for evaporation are leaden pans similar to those used in the preparation of sulphuric acid, and described at p. 238; they are 12 feet square, and 14 inches deep. Seven of these pans, placed side by side, form one connected whole, and have together a capacity of nearly 3000 cubic feet. The single pans are situated in the manner of terraces one above the other upon a wooden scaffolding, in such a manner that the first four form the upper range, the following two the second, and the lowest pan the last. No fire is employed, but the heat requisite for evaporation is obtained from one or more of the jets of steam, enclosed in pipes, and conducted between the foundation and the bottoms of the pans. Thus, not only the highly valuable crude material itself, but at the same time heat for concentrating it, is in these districts, supplied by nature; and indeed, if it were not for these remarkably favorable circumstances, the production of boracic acid would be almost an impossibility, in a country where fuel is so very scarce.[*]

When the 4 upper pans have been filled with fluid from the reservoirs, and this has remained in them during 24 hours, the half of it will have been evaporated, and the pair of pans below, will just be large enough to hold the remaining half. This, therefore, is drawn off, and the upper pans are supplied with a fresh portion from the clarifier. At the expiration of another 24 hours, the half is again evaporated, and the fluid is reduced to $\frac{1}{4}$th of its original volume; it now consists of a much stronger solution of boracic acid, and may be brought into the lowest vessels where the evaporation is completed.[†] The process, as here described, undergoes no interruption; the lye from each pair

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[*] The presence of boracic acid in the vapors of the suffioni of Tuscany, was clearly shown by Franz Höfer, Apothecary to the Court at Florence, in the year 1778, who mentions, in a pamphlet, "Upon the sedative salts found in Tuscany," that this acid affords, with soda, a kind of borax exceeding the ordinary borax in purity. Neither this, nor Mascagni's more recent hints prevailed in rousing the indolence of the inhabitants of those districts to more than a few unsuccessful undertakings. Their bad speculations overstocked the market, and brought ruin upon themselves. The improvements of Ciaschi at the beginning of the present century, who introduced the consecutive saturation in the lagoons, and those of Larderello, his successor, in 1817, at that time the proprietor of all the lagoons, who carried out the idea of using steam heat instead of expensive fuel, first raised this valuable branch of industry to its full pitch. In the year 1818, the same district of Monte Cerboli, which now produces a yearly income of £4000, would have been let to any body for a rent of £6 10s. per annum.

[†] Until 1827 wood was used for heating the evaporating pans; since that time the above described method has been introduced, and has effected a saving, according to M. Larderel, of about 10,000,000 francs.

The evaporation lasts altogether 62 hours. At present, there are 400 evaporating pans in operation, each of 10 feet surface, besides which there are several others, with diaphragms arranged in rows, 300 feet in length, in which the water constantly evaporating, flows slowly through the different divisions until it becomes sufficiently concentrated. More than 1200 lbs. of water are thus evaporated daily.

of pans is only removed to make room for a fresh charge of weaker solution. During evaporation much sulphate of lime is deposited in the pans, which must be removed from time to time by rakes. In the same manner as the fluid becomes richer by the addition of boracic acid in the lagoons, so it is still further enriched in the pans, by the evaporation of the water, until at length the same fluid in which it was hardly possible to discern the presence of boracic acid, has become converted in the lowest pans into a solution, which, when mixed with the mother liquor of a former crystalization, has a specific gravity of 1.07 to 1.08.

Fig. 131.

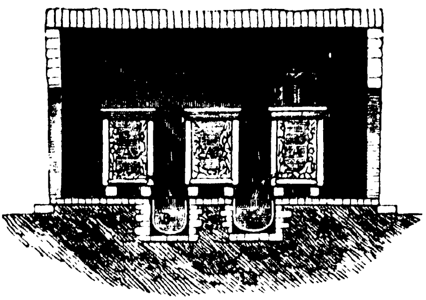
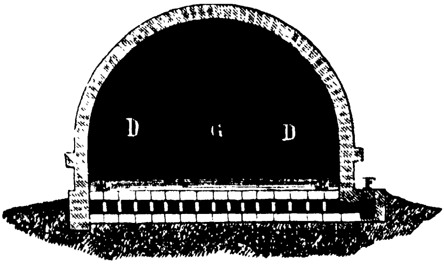


Fig. 132.



Crystalization. — The mixture of fresh, saturated solution and mother liquor is now taken from the pans, and is brought into the vessels *AAA*, Fig. 131. These are round wooden tubs, lined with lead; they are 4 feet high, 31 inches in diameter, and have a capacity of about 8 cubic feet. They are so arranged, as will be seen by the drawing, that the mother liquor may be easily withdrawn, and returned to the lowest pans. The small lamellar crystals are placed in baskets *C* to drain, and whilst still moist, are spread out in a layer 1½ inch in thickness on the floor *EE* of the drying chamber *D*, Fig. 132. The floor of this chamber is double, and a jet of steam entering at *F* is made to circulate below the one floor, in the space left between it and the other. The chamber is accessible by the door *G*. The dry acid is conveyed in the first instance to Leghorn, and from thence, by sea, to its destination.

Constituents of the Crude Acid.—Wittstein gives as the correct analysis of commercial boracic acid in 100 parts:

			86.324
Crystalized boracic acid .	76.494	Sulphate of magnesia .	2.632
Sulphuric acid combined		" " lime . . .	1.018
with boracic acid . .	1.322	" " soda . . .	0.917
Sulphate of ammonia .	8.508	" " perox. iron .	0.365
	86.324		91.256

	91.256		92.243
Sulphate of alumina	0.320	Silica	1.200
" " potash	0.369	Water of crystalization in the salts	6.557
" " manganese	trace	Organic matter containing nitrogen	trace
Chloride of ammonium	0.298		
	92.243		100.000

Hence, it appears, that upon the whole, although the best is retained for the manufacture of borax in Leghorn, a very impure product is obtained. This would not be the case to such an extent, if the mother liquor, instead of being returned into the pan, were evaporated again, and after the separation of the boracic acid were used, for instance, for the manufacture of alum. The experience of the French manufacturers likewise tends to prove, that the impurities in the acid from Tuscany increase from year to year, so that the quantity of foreign matters, which, at first, was only from 8 to 10 per cent., has gradually increased to 18, 23 (as in the analysis), and even to 25 per cent.; a fact which is probably to be accounted for by the increasing disintegration of the earthy strata by the action of the currents of steam.

Each set of 14 pans, therefore, produces by the process described, after 3 times 24 hours' evaporation, 180 lbs. of crystalized acid, which presupposes the removal of 36,000 lbs. of water. From the statements made at p. 78 and p. 79, it appears, that to evaporate 4.7 lbs. of water, 1 lb. of ordinary firewood is required. In Tuscany, the yearly produce is now 15,000 cwts. of acid (Payen), the water evaporated must, therefore, amount at least to 1.6 millions of cwts., which, under ordinary circumstances, would require 21,000 stacks of wood (1 stack = 100 cubic feet, containing about $\frac{7}{10}$ths of solid wood). According to Bowring, the yearly produce since 1836 has been nearly 3 millions of pounds, therefore, double the former average.*

Saturation of the Boracic Acid.—To saturate 100 parts of commercial boracic acid, 120 parts of crystalized soda, or an equivalent quantity of salts of soda have been found requisite. Vats lined with lead *A*, Fig. 133, are used for this purpose, precisely similar to those employed in the manufacture of stearic acid (p. 122). The steam for heating enters the vat by a pipe *c* from the boiler *C*; the tube

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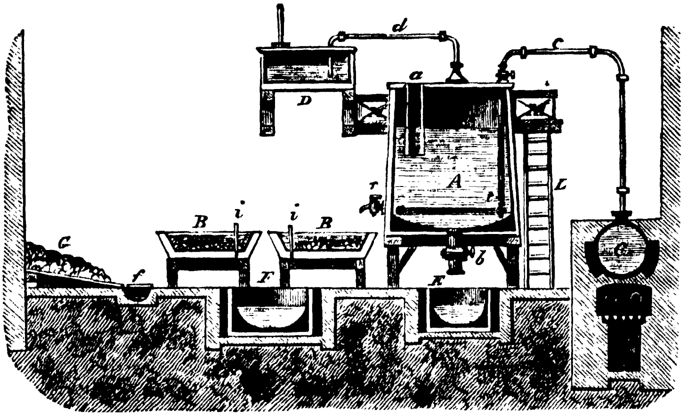
* M. Larderel states the production of boracic acid to have increased in the following proportions:

	Pounds, Tuscan weight.
1818—1828	1,[illegible]00,000
1829—1838	14,000,000
1839	2,152,000
1840	2,525,752
1841	2,547,804
1842	2,655,139
1843	2,655,202
1844	2,655,200
1845	2,655,000
1846	3,000,000

The produce may be still further increased, if required:

extends to the bottom of the vat, and terminates in a horizontal circular bend *t*, which is pierced with holes for the escape of the vapor.

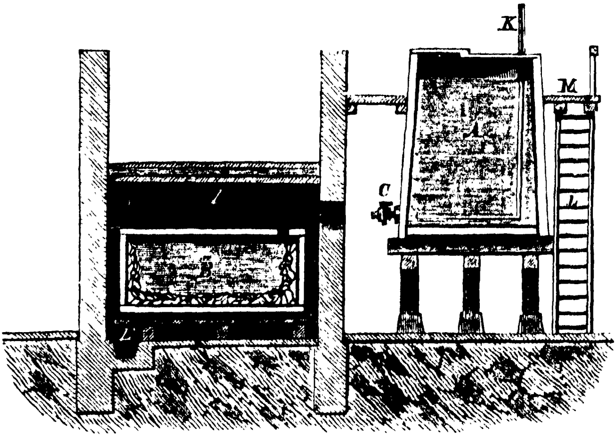
Fig. 133.



Two cocks, one at the side *r*, and another *b*, at the lowest part of the arched bottom, serve to empty the vessel; the aperture *a* with its tube is for the introduction of the charge, the whole is closed with a cover to prevent any loss of heat. Ladders *L*, and platforms *M*, are attached to the apparatus, for the convenience of ascending to the upper parts. In the beginning, nothing but the mother liquor from the last crystalization is placed in the vat, to which the soda and water are added in sufficient quantity to produce about 200 lbs. including that from the condensation of the vapor. When the soda is dissolved, and the temperature of the fluid has risen to 100° C. (212° F.), the boracic acid in coarse powder is introduced, and to prevent loss from effervescence, in quantities of 10 lbs. at a time. In this operation, the boracic acid is not only neutralized, but a considerable loss of soda is occasioned by the sulphates and chlorides, which are mixed with it. Thus, sulphate of soda and some common salt are produced, also carbonate of lime, carbonate of magnesia, hydrated oxide of iron, and principally carbonate of ammonia. In an open vessel, the latter would volatilize with the aqueous vapor; to prevent the loss of this valuable secondary product, the apparatus is so constructed, that the gases and vapors shall pass through a tube *d* in the lid, to a neighboring condenser *D*, and be evolved through sulphuric acid. The carbonic acid is thus set free, and all the ammonia remains as sulphate of ammonia. When all the acid has been added, the solution must indicate 21° Beaumé (1.166 sp. gr.), and its temperature must be raised to the boiling point, to 105° C. (221° F.); the steam is then shut off, the aperture *a* is closed, and the solution allowed to remain at rest for 12 hours. As soon as the lye has become sufficiently clear, it is drawn off by the cock *r*, into the shallow crystalizing vessels *BB*, which are lined with lead; the deposit falls through *b* into *E*, where it is washed and then thrown away. When the crystalization is finished in the vessels *B B*, the leaden plugs *ii* are removed, and the mother liquor collects in the common reservoir *F*. It has already been stated, that this is returned to the vat *A*, for the next saturating process with boracic acid; but at last the foreign salts accumulate to such an extent, that they must be separated in some other manner. The borax is allowed to crystalize at a temperature of 33° C. (92° F.), when all the other salts remain dissolved, and then by a subsequent evaporation, the sulphates of soda and magnesia are obtained.*

Crystalization.—The crystals are detached from the vessels *B B*, by means of chisels and hammers, and placed upon an inclined board *g*, where the remainder of the mother liquor collects in the channel *f*. This first crop is much too impure, and also in other respects unfit for the market, it must consequently be recrystalized, which operation is performed in the apparatus, Fig. 134.

Fig. 134.



The small crystals from the waste are often redissolved with the crude borax, both being placed in a large vat *A*, which only differs from that represented in Fig. 133, by having larger dimensions and no cock at the bottom. The vat must be heated in the same manner by steam, and lined with lead, and be sufficiently large to contain at least 180 cwts. of borax. The crude borax and the waste are placed in an iron wire-basket, which hangs by a chain passing over a pulley just below the surface of the water. The object and advantage of this mode of solution has already been noticed at page 275; all stir-

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* This process is somewhat differently described by M. Koehnke. (see Chem. Gaz., vol. iii. 131.) A solution of caustic soda is prepared, amounting to about 170 lbs. of 1.090 to 1.095 sp. gr., to this 40 lbs. of good Tuscan boracic acid is added, and the whole is boiled until the lye is reduced to 120 or 125 lbs., or indicates 1.175 to 1.180 sp. gr. Upon this the liquid is poured boiling hot into a wooden tub, which is well surrounded with woollen cloths and straw, and carefully covered to retain the heat as long as possible, so that a good and regular crystalization may be effected.

ring is thus dispensed with. It is necessary to add about 4 per cent. more carbonate of soda to the crude borax, and steam is then allowed to enter, until the solution indicates 21° Beaumé. When this point has been attained, the whole solution is drawn off by the cock *C* into the crystalizing vessel *B*.*

As large crystals alone are saleable, and these can only be procured with difficulty, and by avoiding all agitation and rapid cooling, the arrangement of these growing cisterns is somewhat more complicated. They are constructed of stout boards lined internally with lead, covered with a closely fitting lid, which is also lined with lead, and are situated in an external box, with which they are not in contact. The space between the two vessels is filled with small coal *H*, and the lid is covered with a triple layer of coarse woolen stuff, that the cooling process may be retarded as much as possible. The vessels must not be placed near each other, as the shaking occasioned by removing the salt from the one, would disturb the growth of the crystals in the other. The crystalization continues from 25 to 30 hours, according to the temperature of the atmosphere, and is finished when the thermometer in the interior stands at 25° or 30° C. (77° to 86° F.) The mother liquor is then drawn off with wide syphons as rapidly as possible. When all that can be removed by the syphons is separated, that which remains amongst the angles of the crystals is taken up by sponges, that no small crystals may deposit upon the large ones, and the whole is immediately covered, and left at rest for several hours. This is necessary to avoid cracks and crevices in the crystals, which would be occasioned by the action of the cold air. The workman must not enter the vessel to remove the crystals, until the temperature of the interior has sunk to that of the surrounding air. The hewn cake of salt is then placed upon a table to be broken up into single crystals and picked over. The crystals which are sufficiently firm, and not too small, are then thrown into baskets with wide meshes, that the grains and dust may fall through, before they are packed.

In this process, common borax with 60 per cent. of water is always obtained from a lye of 1.166 density. If octahedral borax, with 30 per cent. of water is required, the lye must have a density of 30° B. (= 1.256 sp. gr.), and be evaporated at a temperature of 100° (212° F.), before it is introduced into the crystalizing vessels. Octahedral borax begins to form at a temperature of 79° C. (174° F.), and ceases at 56° (133° F.) At this temperature, the mother liquor must be rapidly removed, or the crystals will become covered with a coating of ordinary borax. The crystals attach themselves so firmly to each other, that in removing them, hard, sonorous plates of any size may be obtained.

A remarkable prejudice of the buyers, who call the octahedral variety melted borax, and think that they are buying the ordinary

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* The floor *F* below this is smooth and inclined, and made of glazed stones, from whence all that is spilt, flows into the channel *E*.

kind when the plates present the projecting points and angles of the crystals, obliges the manufacturer to remove with a hatchet this true indication of their purity, before sending the salt to the market.

In both cases, whether the one or other variety of crystals have been grown, the mother liquor deposits, in the wide basins to which it has been removed, an abundant crop of prismatic borax, which, after being drained, is used for enamel coatings. This mass of small grained crystals, not having the stamp of purity upon it, is seldom to be met with in retail. The small size and want of firmness in the crystals of artificial borax, were in the first instance so prejudicial to its introduction, that it was necessary to imitate the exact outward appearance of Dutch borax (native purified, from Amsterdam), its brown color, the mode of packing it, the rubbed appearance of the crystals caused by land carriage, &c., with the greatest minuteness, in order to render it saleable.

Sautter has patented a process for obtaining borax without the intervention of water. 38 parts of pure dry boracic acid are thoroughly mixed with 45 parts of crystalized carbonate of soda, in powder. This mixture is placed in a room, heated to from 90° to 115° F., upon wooden planks, in layers of about an inch in thickness; this temperature is found sufficient to enable the boracic acid to expel the carbonic acid and the excess of water from the carbonate of soda, and perfect borax or borate of soda results.

Native Borax (*Tinkal*).—Native borax has been found in several localities, for instance, at Halberstadt, in Siebenbürgen, in the mines of Viquintizoa and Escapa in Peru, in Ceylon, in Tartary, China, but more particularly in India and Thibet, from whence the greater part of that used in the arts was obtained. According to Turner, the lakes which furnish the Indian borax are situated a few days' journey from Tezhoo-Lomboo; and the borax is found in great blocks on the shores and bottom of the stagnant salt lakes, whilst more towards the middle, common salt is predominant. On the contrary, Blanc and Pater Rovato state, that these lakes of Thibet are situated amongst the mountains of that country, the most celebrated of them, called Necbal, being located in the Canton of Sumbul. The water is said to be distributed in sluices, until, by evaporation, it deposits salt, after which it is allowed to flow off. The crude native borax is called by the Indians, tinkal. It is impure, and has the form of distinct six-sided crystals, more or less flattened, and some lines in length; these are sometimes colorless, sometimes yellowish or green, and always covered with an earthy incrustation, which is fatty to the touch, and smells of soap.

This latter property is derived from a substance resembling soap, composed of soda and a fatty body surrounding the crystals. The fat can be separated by acids, and then assumes the appearance of a dark brown rancid oil, soluble in ether.

From a vêry ancient period, borax has been purified in the sea-port towns, "*refined*," and more particularly in Venice, (whence the appellation, Venetian borax, which is equivalent to purified borax;) at a later period, the process was introduced into the Dutch towns, for instance, at Amsterdam. The process has always been kept secret, yet nevertheless two different methods of purification have become known.

In one of these, the impurities are separated by lime, the tinkal being softened in a small quantity of cold water, and stirred about with a gradual addition of about 1 per cent. of slaked lime. The turbid lime water is alternately poured off, and when the impurities have settled down on standing, the clear liquid is again poured upon the crystals, and this process is repeated several times. In this manner, the greater part of the soapy compound is removed, and what still remains is separated by dissolving the crystals in hot water, and adding about 2 per cent. of chloride of calcium. Chloride of sodium is produced, and an insoluble lime soap, which is removed by straining, and the clear liquid is then evaporated to the consistence of 21° B.

The other process consists in placing the powdered tinkal in a tub with holes pierced in the bottom, and washing it with a solution of caustic soda of 1.034 sp. gr. as long as this passes through colored. The lye makes the soapy matter much more soluble. After draining, the crystals are dissolved in water, 12 per cent. of soda is added, which precipitates the foreign matters and earths; these must be strained off, and the lye evaporated to the consistence of 20° B.

In both cases, the crystalization is effected in wooden vessels lined with lead, and having the form of short inverted cones. This shape is preferable, because the deposit which may form, collects in the lower narrow part, and does not interfere with the crystalization. The use of lime facilitates the clarification, but may occasion a loss by the formation of insoluble borate of lime, for which reason the use of it cannot be very strongly recommended. Commercial borax, compared with that obtained from tinkal, notwithstanding its greater purity, has one particular fault, that the crystals, when heated, split in the direction of their natural cleavage, fall to pieces and fly off from the part required to be soldered, by which means a loss is occasioned, and the work retarded. The very great precautions used in the crystalization, lessen this evil; but it is more effectually remedied by the addition of a small quantity of tinkal before recrystalization.

SALTPETRE, OR NITRE.

What is Saltpetre?—The term saltpetre, in an extended sense, comprises all the more common salts of nitric acid, which find any application in the arts; they are distinguished from each other by the addition of the name of the base, as: silver-saltpetre (lunar caustic), potash-saltpetre, and soda-saltpetre (cubic nitre). In a more limited sense, the nitrate of potash only, is called saltpetre, which, together with nitrate of soda, is of more importance than all the others, in consequence of the large quantities that are consumed, and the peculiar uses to which it is applied. The use of these two varieties of nitre for different purposes, is dependent upon the property they possess of parting with oxygen at a red heat, or of purveying oxygen to other substances, which have a tendency to combine with it. Other substances, therefore, such as charcoal, may be burnt or consumed, by means of saltpetre, in the same manner as by the oxygen of the air, and the action is generally much more energetic. Saltpetre, chemically speaking, is one of the most powerful oxidizing agents. The oxygen is always derived from the nitric acid, and in such a manner that nitrogen is simultaneously liberated. Nitrate of potash heated alone, affords in the first instance nearly pure oxygen gas and nitrate of potash; on being still further heated, it is completely decomposed, nitrogen mixed with oxygen is evolved, and pure potash remains. An indirect use is made of saltpetre for many purposes, where its nitric acid is the active agent; the separation of this acid from saltpetre is also one of the most important processes connected with this salt.

On the coasts of South America bordering on the Pacific Ocean, about 42 miles from the harbor of Yquique, and about as far from Conception, on the boundary between Peru and Chili, in the district of Atacama, very extensive deposits of nitrate of soda (NaO, NO_5) have been recently found, in an otherwise barren country, covered with a slight layer of clay.* These layers, 2 or 3 feet in thickness, extend 150 English miles, and afford immense quantities of the salt, which is brought into commerce under the name of *Chili-saltpetre* or cubic nitre. In the pits, the deposits consisting of dry, hard, nearly pure salt, are seen almost immediately below the surface. The commercial salt is a brownish mass always moist, and has a dirty appearance, consisting of rounded crystaline grains, and containing, according to

	Hoffstetter.	Lecanu.	Wittstein.
Nitrate of soda	94.29	96.70	99.63
" " potash . . .	0.43	—	—
" " magnesia	0.86	—	—
" " lime	—	trace	trace
Chloride of sodium . . .	1.99	1.30	0.37
Sulphate of potash . . .	0.24	trace	—
Water	1.99	2.00	—
Insoluble matter . . .	0.20	—	—
	100.00	100.00	100.00

and also small quantities of iodide of sodium, and iodate of soda, according to Lembert. The salt is, therefore, very pure, although the quantity of impurity is not always the same. In a moist atmosphere, Chili-saltpetre attracts water, and becomes completely fluid, a property which distinguishes it from ordinary (potash) saltpetre, and renders it quite inapplicable to some of the purposes for which

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* The mines are at the villages of Quantajava and St. Rosa. The layers of saltpetre follow the margin of a basin or former lake, and have evidently been left by the evaporation of its waters. The soil of the whole neighborhood is covered with chloride of sodium.

the latter is employed, for instance, to the manufacture of gunpowder. It is, however, better adapted for the production of aqua fortis (nitric acid), and as a source of nitric acid in the manufacture of sulphuric acid, both on account of its cheapness and because it contains 10 per cent. more nitric acid. Nitrate of soda requires at 0° (32° F.) 1.25 parts, at 18.5° (65° F.) 1.14 parts, and at 47° (116.3° F.) 0.77 parts of water for solution, in which it dissolves with a great production of cold.

Ordinary Saltpetre.—Ordinary saltpetre, nitrate of potash (KO, NO_5), sometimes called prismatic saltpetre, also contains no water in the crystalized state. The presence of this salt in the sap of the sunflower, of common borage, of the celandine, of tobacco, and other plants, as well as in small quantity in spring water, has not as yet been employed for any practical purpose.

Occurrence of Native Saltpetre—Ready formed or native saltpetre has been frequently met with in the soil, and in several places it is extracted; it is never found, however, in distinct layers, like the cubic nitre in Peru, but disseminated throughout the soil, and occasionally as an incrustation upon the surface.

In the chalk formation on the banks of the Seine, near Roche-Guyon and Mousseau, for instance, there are several caves, which are used as stables and for other purposes. In the front part of these caves, which look towards the south, but not in the hindermost internal parts, saltpetre is found in the surface rock; the matter containing the saltpetre is collected several times during the year, and is spontaneously reproduced; it is extracted in the usual manner.

According to Lavoisier, the saltpetre is accompanied by chloride of sodium and chloride of calcium. He found in specimens taken from the cavern of Fouquières 3⅛, from that collected near the church of Mousseau 5⅜, and from another locality only 1¼ per cent. of nitrate of potash, after having treated the aqueous extract of the saline mixture with potashes. The saltpetre caverns in the island of Ceylon, which were carefully examined by Davy, are extremely interesting. These consist of natural caves in a limestone rock, containing magnesia and feldspar, which have been gradually enlarged by the removal of the nitrified stone. Some of these, like that of Boulatwellegode are the resort of innumerable bats, whose excrement collects in them. In others, there are none of these animals, as is the case in the cave of Memoora, which is situated in a hill about 300 feet high, and thickly wooded; it is 100 feet broad, 80 feet high, and extends to the depth of 200 feet. The thickness of the roof is, therefore, not very considerable, and the floor is composed of the naked rock without any covering of earth. Davy found here sixteen workmen employed, each of whom furnished ½ cwt. of saltpetre yearly to the government. The fact, that during the six dry months of every year for the last fifty years, this work has been going on, proves that the produce on the whole cannot be inconsiderable. Davy found, on examining a specimen of the rock from Memoora cave, in 100 parts:

2.4 nitrate of potash
0.7 " " magnesia
0.2 sulphate of magnesia
26.5 carbonate of lime
9.4 water, and
60.8 of residue, insoluble in weak nitric acid, and consisting of feldspar, quartz, mica and talc. The potash is, no doubt, derived from the disintegrated feldspar, and was always found accompanying the nitrates of the earths, whether these consisted of magnesia or lime. The mode of producing saltpetre from these caves is simple and cheap, but somewhat crude. The workmen loosen the stone from the inner surface by means of iron tools, and mix the pounded mass with about an equal portion of wood-ashes. When water is poured upon the mixture, the nitrates of the earths part with their acid to the potash in the ashes, the earths are precipitated, as carbonates of lime and magnesia. The clear decanted lye, which contains the nitre produced by the ashes, as well as that naturally present in the rock, is first exposed in pits and evaporated to a considerable extent by the heat of the sun alone; it is then further evaporated in pans to the point of crystalization. That which crystalizes on cooling, is crude saltpetre, which is immediately sent off.

Similar caves are known on the coasts of the Adriatic, in Italy, (Pulo di Mofetta,) in some parts of the United States, (Tennessee, Kentucky, on the Missouri and Crooked river,) in Africa and in Teneriffe.

The occurrence of native nitrates in South America, in some districts of India, Arabia, Egypt, Persia, Spain and Hungary is somewhat different. In India, Bengal, and the neighborhood of Patna, are the sources of the largest portion of the saltpetre supplied to the European market from Houghly, which is previously boiled at Chiopera. In Hungary the country about Semeny, Debreczin, and Nagy-Kallo is celebrated for its saltpetre pits, and supplies the different saltpetre works in the Counties of Bihar, Szaboltsch, and Szathmar (belonging to the Freiherrn von Vaj), as well as those of Parndorf and Zorndorf in the County Wieselberg, Norod and Bürüs in the County Schaumeg, Szelnitz in Liptau County, Neusohl in the Gespannschaft of Sohl, and Oedenberg and Raboth, in the County Oedenberg. These salts are found widely disseminated in those districts, but never extend to any great depth below the surface, never lower than where the air can easily penetrate. The infiltration of rain and dew naturally dissolves the salts, so that the soil is never moistened by pure water, but by a weak solution of nitre. When this solution is evaporated by the action of the sun and air, its place is immediately occupied by a fresh solution from below, which rises in consequence of the porous nature of the soil, in obedience to the law of capillary attraction, and is vaporized in the same manner. Thus all the saltpetre is gradually brought to the surface from the lower layers, and remains after the evaporation of the water in hot weather, as an incrustation of considerable thickness, sometimes in the form of solid crystals, at others as bundles of fine threads. It is collected in the form of a saline mass mixed with earth. Davy found in Bengalese saltpetre earth, from the district Tirhoot:

8.3	nitrate of potash
3.7	" " lime
0.8	sulphate of lime
0.2	chloride of sodium
35.0	carbonate of lime with traces of magnesia
12.0	water in which was some organic matter, and
40.0	matter insoluble in nitric acid
100.0	

The process to which this earth is subjected, is the same in principle as that practised with the rock of the caverns, only the addition of ashes is frequently omitted, from a scarcity of that substance, and indeed, it is here not so essential, as the earth itself is richer in nitrate of potash. Nitrate of lime then remains in the mother liquor, and is lost. The Hungarians treat the earth in precisely the same manner, after it has been loosened with the plough and collected. This country (Hungary) as has been remarked, is particularly abundant in saltpetre, which occurs mostly in boggy places, for example, in the old bed of the Theisz, on the left shore of the river which is exposed to inundation; in the neighborhood of certain salt water bogs, and in other places. 100 square fathoms Hessian produce yearly 4⅓ cwts. of impure saltpetre, the produce being collected at six different times.

The soil in some parts of Spain is also incrusted with saltpetre, in New Castile, Arragon, Catalonia, La Mancha, Granada, &c., the produce of those districts being worked, according to Proust, at Saragossa, Alcazar de San Juan, Tremblaque, &c.

Formation of Saltpetre in the Temperate Zones.—From the preceding facts and observations, it appears that the localities which naturally afford saltpetre, without the intervention of man or animals, are nearly entirely confined to the tropics. For whilst the soil of those countries, without any extraneous assistance, produces abundance for home consumption, and partly supplies the foreign market, potash saltpetre, which is the most valuable, occurs only in a very few spots in the temperate zones, where its formation has not been assisted by the addition of ready formed nitrates, and the produce of these parts is as nothing compared with the vast consumption of the salt. Nevertheless a kind of artificial nitrification is always going on here upon a large scale, under certain other conditions, which are only found collectively combined in the neighborhood of inhabited places. The first amongst these, is the necessity for the presence of nitrogenized matter, either of vegetable origin, or consisting of the refuse of animal bodies or fluids, urine, excrement, blood, &c. &c., which in the presence of powerful bases, for example, potash, lime, magnesia, decay and rot, and gradually give rise to nitrates of the bases. Nitrate of potash, however, is found in small proportion as compared with the nitrates of the earths, potash being contained in all soils to a much smaller extent than the earths.

All the observations and experiments which have been made, tend to show, that in the formation of saltpetre, the following conditions must always be fulfilled, namely:

The presence of the above-mentioned *bases*, lime, magnesia, potash, and these must be in a loose porous state, so as to be easily permeable—as they are contained, for instance, in marl, chalk, mortar, &c., but not in the form of marble, dolomite, feldspar, &c.

The presence of moisture in such quantity that the matters engaged in the formation of saltpetre may be uniformly penetrated, but not inundated by it.

A temperature of 15° (59° F.), *or* 20° (68° F.); for a temperature of 0° (32° F.) is sufficient to put a stop to the process entirely. Lastly,

The unimpeded access of air.

These conditions are universally necessary; but the colder regions require in addition—

The presence of decaying vegetable or animal matters, containing nitrogen.

The action of *light* appears rather to accelerate the process, than to be absolutely necessary.

It is of little consequence, as will easily be conceived, to the formation of saltpetre, whether these conditions are of accidental occurrence, or whether they are expressly created for the purpose. In fact, the crude material for the production of saltpetre is as easily obtained in the temperate zones by artificial means, as by collecting the substances in which it has naturally been formed. The localities in which saltpetre earth is artificially produced, are called saltpetre plantations; the earth, on the contrary, which is collected together from different places, is called *swept saltpetre.* (*Kehrsalpetre, Gayerde, Gaysalpetre.*)

A few examples will indicate the manner in which advantage is taken of the different localities.

Saltpetre from Walls.—In densely populated towns, with narrow streets, where the excrements of beasts of burden, the refuse from slaughter-houses, and from trades of a like nature, where the water from the houses, the refuse of markets and other similar matters mix with the fluid in the drains, and are in a constant state of putrefaction, it may be seen, how the coating of mortar at the base of the external walls is gradually eaten away, and becomes covered with a floccular, white crystaline efflorescence, a phenomenon the appearance of which is a source of alarm on account of the injury which ensues to the buildings, and which is called *saltpetre rot.*

The same phenomenon is not unfrequent in other parts of the walls which are not directly exposed to the mud of the streets, but to the infiltration of fluids, for instance, from the drains of privies, or to the urine of cattle in stables. It is, however, very necessary, before collecting any such efflorescence, to ascertain, either by the taste, or better by lixiviation and evaporation, the nature of the salt, for the observations of Kuhlman have proved, that these often arise from the sulphates and carbonates of the alkalies contained in the limestone, and do not consist of nitrates.

Production of Saltpetre in Switzerland.—The earth below the flooring of stables, or in the neighborhood of dung heaps, in the cellars of dwelling houses, where the remains of vegetable or other organic matters have been left to decompose, is a material which can be used for the production of saltpetre. Thus, in Switzerland, for instance, in Appenzell, the position of the stalls on the declivities of the mountains, when not too dry, and having a more northerly aspect, is made subservient to the production of saltpetre. When the building has its entrance towards the mountain, and the opposite side is supported by beams or a raised foundation, the floor of the stall is necessarily hollow. A pit is then dug 2 or 3 feet below the floor, and of the same dimensions, and this is filled with a sandy porous earth, which retains all the urine that falls through. In two or three years this earth has become sufficiently impregnated with saltpetre for lixiviation, and the same operation can then be repeated every year, for the saltpetre boilers affirm, that the earth which has already served for one saturation, when again brought into the pit is better fitted than fresh earth for a renewal of the process.

At Longpont.—The foregoing plan may be regarded as a crude saltpetre plantation, as is also that at Longpont in France, where the stone quarry, which orignated with the erection of the Abbey Church in that town, is employed for the same purpose. The quarry is sufficiently exposed to the air, and is always very damp. Earth and dung are alternately arranged in layers 4 inches thick, one above the other, and the whole heap is then covered with earth. Moisture being always present in sufficient quantity, it is not necessary to water it, but the liquid manure from the stables and houses is conveyed to it, and materially increases the amount of nitrogenized matter. At the expiration of the second year, the heap has rotted away to a uniform mass of earth, and must then be advanced nearer to the mouth of the quarry (more exposed to the air), where it is occasionally turned over, and in the course of two more years is in a fit state for lixiviating. From the dung of 25 cows, asses, and mules, about 10 or 12 cwts. of saltpetre are thus obtained.

Thouvenel's method.—A proposition depending upon the same principles was made seventy years ago by Thouvenel, and recommended by experienced men as quite compatible with the system of French agriculture. The proposal was, to connect the production of saltpetre with the sheepfolds, and use a portion of the manure from the sheep for that purpose. Whether agriculture does not suffer as much from the diminution in the quantity of manure, as is gained by the production of saltpetre, still requires a positive and direct answer. The earth in the stalls and sheep-cots is in the first place loosened to about a foot below the surface, and the animals are plentifully supplied with straw. Whilst the dung of the sheep gradually forms manure with the straw, the porous earth absorbs the fluid excrement without mixing with the former. After some months, therefore, when it has become necessary, the straw manure may be removed, and the earth below it turned over, and covered with a layer of fresh earth, which increases its power of absorption. This operation is repeated several times during the year, and the earth then becomes sufficiently impregnated with the excrementitious substances to fit it for the production of saltpetre. The operation is then conducted in an airy shed, where the earth is heaped up 3 feet high into a kind of wall or dam, turned over once a month, and watered at intervals with liquid manure. At the end of two years it is fit for extracting.

In Sweden.—In Sweden saltpetre is one of the revenue taxes, and is consequently prepared by the peasants on the estates themselves in wooden sheds or huts, the floors of which are covered with clay or boards. A mixture of loose earth, refuse of all kinds, both animal and vegetable, with lime, marl, or exhausted ashes is made up into a heap, and watered from time to time with the urine of animals, partly to keep the mass damp, and partly to increase the quantity of saltpetre, for no animal fluid is so rich in nitrogen, as urine. During the summer the heap is turned over weekly, and in the winter every month, care being taken to keep the whole as loose as possible, either by the insertion of twigs, or by piercing holes through it. It is also believed that saltpetre is more readily formed when the light is excluded; the whole operation requires two or three years.

Saltpetre Plantations.—The preparation of the so-called saltpetre earth, and the actual production of saltpetre upon a large scale, form two distinct operations in the *saltpetre plantations*, as is also the case in Thouvenel's method. Earth impregnated with putrid nitrogenized matter is either collected from cattle stalls or slaughter-houses in the neighborhood, or heaps in which putrefaction can go on are erected for the purpose of producing this earth. There are three classes of substances which can be used for this purpose; the substance must either consist of vegetable matter, as weeds (belonging chiefly to the families of the *Solanaceæ*, *Euphorbiaceæ*, or *Fungi*, which are those containing the largest quantity of nitrogen), pea, bean, and Indian corn-straw, sunflower, &c.; or it is solid animal refuse, as the dung of birds and quadrupeds, the mud from stagnants ponds, mud from the streets, flesh, cuttings from the tanners, &c.; or lastly, fluids containing nitrogen, as urine, liquid from cesspools, water in which bloody flesh or cheese has been washed, &c. The vegetable substances are first spread out upon a layer of earth, upon these the other solid matters are laid to a height of some feet, and the whole is covered with a second layer of earth. The fluids are used for watering the heap, which must always be moistened throughout, but never wet. To allow the fluid to penetrate, holes are bored from above towards the middle. After a time, the separate fragments lose all form, and rot into a uniform mass, which is then mixed up with the earth below. It is certain, that during the putrefaction which goes on in such a heap, a very large portion of the nitrogen escapes, as ammonia, which must be considered as so much loss of saltpetre, for ammonia in all probability is the starting point for the whole production of saltpetre.

The earth thus prepared must be intimately mixed with old mortar, marl, loose limestone, or lime ashes (the requisite bases), and exposed to the action of the air in a constantly moist state. Hence arises the necessity of giving the whole a great extent of surface, and forming it into heaps, as it must not be allowed to occupy too much space. When the height of the heap is more than a fathom, the upper part dries too rapidly, and the erection of the heap becomes too laborious; according to circumstances, therefore, the shape of the heap varies. When no roof protects the heap from the access of rain, the nature and inclination of the ground must admit of the water which runs off, being collected into a cistern or pit. The ground should, therefore, be a layer of clay, and the heaps should be opposed to the prevailing wind, and secured by their position from inundation. Experience has also shown that a degree of moisture corresponding with that of ordinary garden mould is most advantageous. The heap is generally made in the shape of a flattened pyramid, from 6 to 7 feet in thickness, and about a fathom high; a passage being left open at every 15 feet; a space must also be left between the heaps for the passage of the barrows used in building and removing them. The inclined surface of the pyramidal heaps is generally arched, but in such a manner, that the arch is not so wide as the heap is broad. The spaces on each side are traversed by gutters, where the fluid used for moistening the heaps, which is kept in reservoirs, collects, so that it runs off and permeates the sides of the heap, just where evaporation is most rapid, and the formation of saltpetre greatest.

When the process has attained a certain point, a white mouldy appearance is perceived on the surface of the heap, consisting of nitrates of the earths. The earth is considered fit or ripe for lixiviation, when 1000 cubic inches will produce about 5 ounces of saltpetre, a state which it generally requires three years to attain. For every 10 cwts. yearly produce, 120 cubic fathoms at least of earth must be laid out in heaps, of which ⅓ becomes ripe each year. Although no accurate method is known of ascertaining the quantity contained in the earth, except that of dissolving out a few cubic feet, the workmen are, nevertheless, enabled to judge of its fitness by the amount of cooling taste produced by the earth on the tongue. This method must obviously be subject to grave errors, and the saltpetre must be much too unequally distributed over the whole heap to admit of its quantity being ascertained by a single handful. When the fitness of the earth has been proved by one or the other method, it is of importance, in order to save time and labor, that the bulk of earth, in which the saltpetre has been produced, and which has to be lixiviated, should be reduced as much as possible, and this can only be done, by accumulating the nitrates in one part of the earth. The application of the same principle, which was explained with reference to the efflorescence of saltpetre on the soil in Bengal, affords a convenient means of doing this. The following is the method practised.

When the earth is nearly ripe, no more liquid manure is poured upon the heap, as time would not be allowed for the nitrogenous matters to be converted into saltpetre, and these would only contaminate that which has already been formed. Thus no compensation is made for the fluid, which, leaving its saltpetre behind, evaporates from the surface above, but the liquid present in the heap is constantly drawn up by capillary attraction, and evaporates in the same way as before. In this manner, the saltpetre is accumulated to a certain extent in the outermost layers, and is scraped off to a depth of 2 or 3 inches several times in the year. The earth thus collected cannot be used immediately, and is, therefore, best preserved under a shed, frequently turned over and sprinkled with water (not with manure), by which the amount of saltpetre is somewhat increased. At last, so little remains of the whole heap, and what does remain, contains so little saltpetre that it is not worth collecting, and the heap must be renewed. For this latter purpose, not only fresh earth is employed, but also that which has been lixiviated, until it is exhausted and useless. It is also affirmed, that earth still containing a little saltpetre, acts more powerfully in inciting the formation of fresh saltpetre than such as has been entirely deprived of that salt. In some places, the heap is simply reconstructed with its former dimensions upon and around the old residual portion, whilst in other parts it is considered better to mix this residue with the fresh earth, and reconstruct the heap with the mixture.

The method adopted in Prussia with the saltpetre-earth is somewhat different from that above described; but in certain respects it is better adapted to the object in view; the heaps are there constructed with perpendicular sides, and called, consequently, very appropriately, "*walls*." The side opposed to the wind is simple and flat, the opposite side forms a series of steps down to the bottom, which give greater firmness to the whole. On each ledge or step is a gutter which carries back the excess of liquid poured upon it to a cistern. In this arrangement, the watering takes place at the back, whilst the evaporation proceeds chiefly on the side opposed to the wind, so that the saltpetre is drawn by degrees towards the latter part, whence it is also gradually removed. Just as much lixiviated and fresh earth is added to the ledges behind, as ripe earth is removed from the front, so that the wall, retaining its form and thickness, is gradually being altered in position, but is always preserved at the same distance from the neighboring walls. Thus, the production of saltpetre is never checked by the entire removal of the heaps, and this is a great advantage, as it is much more difficult to set the process going, than to keep it constantly in action.

The large importation of Indian saltpetre, however, has latterly nearly put a stop to the expensive and troublesome culture of the plantations.

Theory of the Process of Nitrification.—When a collective view is taken of the different methods of procuring saltpetre, it becomes evident that not one of them can actually be called an artificial production of the salt. Whatever bears this name in practice, as for cultivation of the "plantations," is merely the combination and fulfilment of certain conditions which have been found by experience to be absolutely necessary to that spontaneous process of a chemical nature which terminates in the production of the nitrates. The work of those engaged in the plantations has no immediate influence upon this process, and only tends to ward off the obstructions which oppose it, and preserve the conditions which have already been enumerated.

These conditions have been ascertained, and established by numerous observations. Glauber, and at a subsequent period, Stahl (1698) occupied themselves with this subject; Lavoisier, in the year 1777, published his theory of the process in a pamphlet devoted to the subject; and lastly, since the year 1775, when the French government offered a prize for the best treatise "upon the principles upon which the production of saltpetre is based, and the best method of putting them in practice," and the accepted and otherwise remarkable documents, amongst the sixty-six that were sent in, were made known by the commissioners of the academy, and enriched with explanations and remarks in a compendious treatise of their own; the knowledge thus gained, has been very much increased and augmented in more recent times by the important investigations of Kuhlmann. Notwithstanding the large amount of accurate information thus collected upon the principles concerned in the production of saltpetre, yet the researches mentioned, and amongst the more recent, those of Gay-Lussac and Liebig, although they have thrown much light upon the probable nature of the process, have failed in establishing the views advocated, as actual positive facts.

The whole explanation of the process hinges upon the source of the elements of the nitric acid, and more particularly upon the source of the nitrogen.

With reference, in the first place, to the supposition, that the two principal constituents of the atmosphere (nitrogen and oxygen) are the sources of these elements in saltpetre, it must be stated that this, of all others, is least confirmed by observation. It is, indeed, known that lightning in passing through the air, induces the elements to unite and form nitric acid, the presence of which can often be demonstrated in rain and spring water, but this action is so very limited, and of such rare occurrence, that its adoption as an explanation of the formation of saltpetre is inadmissible, and so much the more so, as the phenomenon from its very nature is inapplicable to every case. Saltpetre, for instance, can be formed under circumstances which render it quite impossible that the nitric acid existing in the air can have access to the mixture of lime, &c. The opinion (formerly expressed by Longchamp) is quite as untenable, which ascribes the union of the free oxygen and nitrogen in the atmosphere, to an action exerted by the porous mineral constituents of the soil, similar to that of platina-sponge. Fontanelle found no trace of a nitrate in washed or unwashed limestone sand, or in washed or unwashed granite powder, which he exposed, ½ a cwt. at a time, to the atmosphere during three years, protected from the rain, and moistened with distilled water. On the contrary, earth mixed with lime rubbish, when exposed under similar circumstances, yielded 4 per cent., with ⅒th sheeps-dung 5½ per cent., with ⅒th horse-dung 5 per cent., with ⅒th cow-dung 4½ per cent., with animal manure 6 per cent., and with animal manure, and ⅕th lime rubbish at the same time, 8 per cent. The same results were obtained with chalk, which produced no saltpetre by itself, but was observed to do so when in contact with nitrogenous matter.

The nitrogen in the nitric acid is, therefore, not derived from the atmosphere; but in all probability from the putrefying animal and vegetable substances. When such compounds containing nitrogen—all of which are of a highly complex character—undergo putrefaction, and are resolved into simpler and more stable combinations, it has always been found that the nitrogen, exerting a pre-eminent affinity for hydrogen, combines with the latter element to form *ammonia*, a mode of combination which, under the circumstances, is, as it were, the most easily effected. Thus, Kuhlmann in his experiments, was always able to produce ammonia, when hydrogen or carburetted hydrogen, at the moment of their evolution, were brought into contact with nitrogen in the nascent state. Hence the formation of ammonia must always have preceded that of saltpetre from animal matters; and, indeed, the same philosopher has shown that the production of nitric acid can only be effected by the decomposition of ammonia (always excepting cyanogen). A mixture of ammoniacal gas (or of carbonate of ammonia) with air, passing in a current over platina-sponge, produces (at 300° C.) peroxide of nitrogen in abundance ($NH_3 + 7\,O = NO_4 + 3\,HO$), which is easily converted by water into nitric acid. But even at ordinary temperatures, the oxidation of ammonia proceeds; C. de Martigny found ammonia which had been confined with air over milk of lime, converted, after six months, into nitric acid. Ammonia is peculiarly adapted, in being oxidized, to form nitric acid, because the water which is essential to the existence of nitric acid (the anhydrous acid being unknown), is formed simultaneously from the hydrogen of the ammonia.*

When the source of the nitrogen in the nitrates is attributed to the organic substances, it must be remembered that very considerable quantities are requisite to explain their production. Supposing even that no loss occurs, 260 to 866 lbs. of human excrement, 433 lbs. of urine, 2600 lbs. of cow-dung, or 1024 lbs. of fresh muscle are neces-

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* Kuhlmann has since confirmed the statements in the text by still more striking experiments: he finds that a mixture of bichromate of potash, concentrated sulphuric acid, and sulphate of ammonia, when heated in a retort, yields a large quantity of nitric acid. By heating a mixture of peroxide of manganese, or peroxide of lead with weak sulphuric acid, in the presence of sulphate of ammonia, the ammonia is converted, in like manner, into nitric acid.

M. Dumas has also shown, in corroboration of the results of Kuhlmann's researches, that, when a current of moist air, mixed with ammonia, is passed over chalk moistened with a solution of potash at a temperature of 212° F., there is formed, in the course of a few days, a considerable quantity of nitrate of potash.

sary to supply the nitrogen of 100 lbs. of saltpetre. It is, therefore, not easy to conceive how the saltpetre can be produced in many places, where organic remains are exceedingly scanty, or altogether wanting, as is the case, for instance, on Roche Guyon or Ceylon, where the excrement of bats, the presence of which has been adduced in explanation of the formation of saltpetre, is entirely absent in several caverns, which, nevertheless, afford saltpetre like the others. It is an established fact, that the numerous dead bodies of animals and vegetables in undergoing putrefaction, afford a constant supply of ammonia to the atmosphere, and, on the other hand, that the porous rocks on the surface of the earth, and the vegetable mould absorb and condense this ammonia with avidity. Thus, the nitrogen would still be derived from the organic matters, and assist indirectly in the formation of saltpetre. The experiment of the committee of French academicians with chalk, which, after being carefully washed and freed from all soluble matter, was hung up in a basket over putrefying blood, proved this beyond a doubt, for, after a few months, 2½ per cent. of nitrate of lime was obtained from it. Besides, all the nitric acid of spring water, in which it has often been found, must remain behind in the stone walls of those caverns, when the water trickles through their roofs and sides.

Although from what has been already stated, it appears almost proved, that nitric acid is derived, either directly from the oxidation of the ammonia of the putrefying organic matters, or from the air, the question naturally presents itself, why is not saltpetre found at all parts of the surface of the earth, where the necessary bases are present for fixing the acid? That which happens in many other cases of decomposition, is also the case here: all the necessary conditions for the exertion of chemical affinities may be prepared, and yet the action will not ensue, unless some impulse be given from without. This impulse proceeds most generally and energetically from some chemical action already in the course of operation. Thus the decomposition of a solution of sugar into carbonic acid and alcohol can be induced, by bringing it into contact with a body undergoing decomposition (yeast), before it would spontaneously take place. By carefully weighing all the circumstances, and comparing them with similar processes and phenomena, we are led to the assumption, that the production of saltpetre is always accompanied by the decay of other matters, and can only be induced by that process. The conversion of ammonia, in this case, into nitric acid is precisely similar to the oxidation of fusel oil, in potatoe spirit, into valerianic acid, which process occurs in the vinegar casks, where the oil is in the presence of alcohol, which, by the action of atmospheric oxygen, is being converted into acetic acid.

As has already been stated, the experimental conversion of ammonia into nitric acid has only succeeded at a temperature of 572° F., or by the intervention of a free base, both of which conditions either do not occur in nature, or are only exceptional. The impulse which decomposing bodies can thus communicate is, however, sufficiently powerful in all probability to give rise to the formation of saltpetre at ordinary temperatures, and the time which is allowed for its production in nature very much exceeds the duration of ordinary experiments. It appears that ammonia is oxidized to nitric acid immediately on its evolution from organic bodies, in the tropics only. It is highly probable also that ammonia plays a double part in the formation of saltpetre: first, in surrendering its elements to oxidation, and then, also, in saturating the acid, and producing nitrate of ammonia. To form a clear idea of the importance of this point, it is necessary to remember the general law, that a chemical decomposition or change is so much the more easily, and indeed, sometimes is only produced when the products find occasion to enter immediately into new combinations; thus zinc will only decompose water in the presence of an acid (sulphuric acid) which combines with the oxide formed.

The carbonates of the earths possess no basic properties, and cannot, therefore, exert any similar action; this, however, is not the case with the carbonates of potash and soda. Kuhlmann has shown that ammonia can also assume this function, so that in the decay of nitrogenized substances, when carbonates of the alkalies are not present, or only in insufficient quantity, nitrate of ammonia is formed, and can be shown to exist in all the liquors obtained from ordinary saltpetre earth. The nitrate of ammonia and the carbonates of the earths (lime, magnesia) or alkalies, afterwards exchange their constituents, so that carbonate of ammonia and salts of nitric acid with the earths and alkalies are formed. In those cases, where carbonates of soda or potash are entirely wanting, Kuhlmann is inclined to believe, that the ammonia, besides parting with its elements for the production of nitric acid, acts as a purveyor, like the nitric oxide in the sulphuric acid chambers. For, inasmuch as the moisture in the earth, and indeed all water, contains much air in solution, and in a condensed state, and this confined air is 13 per cent. richer in oxygen than common air, the union of this oxygen with the nitrogen (of the air) is by this means so much aided and facilitated, that the co-operation of the predisposing affinity of ammonia, even to a limited extent, can very easily determine it. The nitrate of ammonia would then resign its acid to the earths, become carbonated, and in this state—being a salt with basic properties—would resume the same function in a higher degree, on account of the presence of moisture, which is essential to the production of saltpetre, and which would preserve it from too rapid evaporation, &c. This process, performed through the medium of ammonia, might also possibly occur when organic matters are present in sufficient quantity.

It must not be forgotten, that the occurrence of saltpetre may sometimes be the result of a process long since finished; and for this reason its formation will appear inexplicable, as it is no longer going on at present, and the conditions which gave rise to it have long ceased to exist.

The successive operations to which the ripe earth is submitted, are undertaken for the purpose of *separating the nitrates* from it, *converting these into nitrate of potash, crystalizing* and *purifying* the product.

Lixiviation of the Earth.—The point which requires the greatest attention in dissolving out the nitrates, is the use of as little water as possible (as this must afterwards be almost entirely evaporated with a corresponding expense of fuel), so as to leave no more of the salt behind than is required for its after-application in the heap; this quantity should be about 1 or ½ per cent. Lye of 12 or 14 per cent. is generally considered fit for boiling. If the process of lixiviation is to be carried on with any degree of certainty, the operator must be furnished with instruments, which will indicate with sufficient accuracy at any moment, and with ease, the amount of saltpetre in the different lyes. For this purpose the saltpetre hydrometer is used, the scale of which consists of a series of divisions indicating the depths to which the instrument will sink when immersed in an artificial solution of 1, 2, 3, 4, 5, &c., per cent. of saltpetre in water. Each degree, therefore, indicates 1 per cent. of saltpetre, at that temperature at which the instrument was graduated; the indications are very accurate in pure solutions, and sufficiently so in *crude liquors*, which is the name given to the first solution from the earth.

The material for lixiviation is placed in casks with double bottoms covered with straw, and furnished with cocks (like those used in the potash works, page 294); these are arranged in the same manner one above the other in three rows, with gutters connecting them with the sunken lye cisterns. The mode of conducting the process depends upon the same principle as in the former case: the same quantity of water is passed through different casks containing earth until it has become fit for boiling, and the same quantity of earth is treated with fresh portions of water until it retains only ½ to 1 per cent. of saltpetre. The advantages of this method, which was described and particularly recommended for the saltpetre fabrication in the year 1820, by the *Comité consultatif des poudres et salpêtres de France*, will easily be perceived from the following observations. Suppose each cask charged with 6 cubic feet of earth, containing about 8 lbs. of saltpetre, and suppose further, that half the water poured upon it is each time retained, and that just enough water is always added to drench the earth nearly to its surface (3 cubic feet), then the process will be as follows, supposing each cask to be lixiviated four times, and sufficient time allowed for the water to dissolve all the saltpetre:

	Poured upon	There will remain	There are poured off
1st water = 3 C.F.	Cask A.	1½ C.F. of the 8 lbs.	1½ C.F. of the 8 lbs.
2d " = 1½ "	" A.	1½ " " 4 "	1½ " " 4 "

These make, together, 3 cubic feet containing 6 lbs., and are poured upon a fresh cask *B*, in which there is also 8 lbs. of saltpetre. When this has been dissolved, 1½ cubic feet will remain, and 1½ cubic feet, containing $\frac{6+8}{2}$ = 7 lbs., *i. e.* 14.9 per cent. of lye for boiling, wi flow off. It follows, that:

	Poured upon	Will leave	And there will flow off
3d water = 1½ C. F.	Cask A.	1½ C. F. of the 2 lbs.	1½ C. F. of the 2 lbs.
" " = " "	" B.	1½ " " 8 "	1½ " " 8 "
4th " = " "	" A.	1½ " " 1 "	1½ " " 1 "
" " = " "	" B.	1½ " " 4½ "	1½ " " 4½ "

The 3d and 4th water together, after flowing from *B*, make 3 cubic feet containing $\frac{8 + 4\frac{1}{2}}{2}$ = 6¼ lbs., and this is poured upon the cask *C* where 8 lbs. are again to be taken up, so that 1½ cubic feet of lye with 7⅛ lbs. = 15 per cent. flow off for boiling, and as much of the same strength remains. In this manner, the operation proceeds without interruption, the first cask *A* being now exhausted to 1 per cent., is emptied and charged again. But when the same quantity of earth is to be exhausted to the same extent, *i. e.* to 1 per cent. at once, 800 cubic feet of water must be poured upon it, of which 795 cubic feet of lye containing 1 per cent. will flow off. In this case, therefore, 5 cubic feet of lye contain 1.6 lbs., and on the improved method they contain 22½ to 23 lbs., so that, in order to obtain 1 cwt. of saltpetre according to the improved plan $\frac{310 \text{ cubic feet}}{13.8 \text{ cubic feet}}$ = 22½ times less water has to be evaporated.

In a work that produces yearly from 200 to 300 cwts. thirty-six casks are requisite, three rows of twelve each, therefore, so that the lye flows directly into the corresponding cask of the second row. Time must, of course, be allowed for the lye to dissolve the whole of the nitrates, and the cock is consequently kept shut during twelve hours. That the earth may be uniformly impregnated with the water, and *no channels may be formed* amongst the salt, all the coarser lumps, pieces of lime, &c., must be previously broken up; it is usual also to arrange the earth in the casks in the form of a funnel, and not with a flat surface, so that the water may flow through the middle, and effect a more complete solution. The water in the first operations flows from one cask to the other by itself, but when it has to be brought from the lowest row to the uppermost, to economize time, a pump may be used. The lixiviation of the ash is repeated three or four times according to the locality; but at every period of the operation one cask is charged with fresh earth, whilst another contains earth once lixiviated, and a third, earth that has been twice treated with water. The lyes of different strength are distinguished by the appellations, wash water, weak, strong and boiling lye.

Lixiviating troughs, Fig. 135, may be substituted for the casks, and have the advantage of occupying less space; they are made of oak-wood in the form of a baker's trough, 16 feet long, half as wide at the upper part, and 4 feet deep. In one of the longer sides (the front one in the Fig. 135, towards which the bottom slightly inclines) a number of holes *a a a* are bored between the stays *b b b* for the reception of tubes or cocks, to conduct the fluid into the groove *c c*. To keep back the earth, an inclined board pierced with holes *e e*, Fig. 136, is placed in the interior, which is covered with straw or willow twigs. The iron rods *f f* are to prevent the sides from bulging, and the hoops *n n* keep the single boards together. The capacity of these troughs, each containing 218 cubic feet, renders two quite sufficient for the largest work. Water is poured upon the earth from several channels at the same time, into which it is pumped up, until it stands about 4 inches above the surface; at the expiration of twenty-four hours, the water is drawn off and a fresh supply added, until that which runs off only contains 1 per cent. of saltpetre; the trough is then re-charged. The charge in troughs of the above dimensions, calculated at 8 lbs. in 5 cubic feet, must contain altogether 256 lbs. of nitrate, which must produce a lye of about 10 per cent., with rather more than an equal bulk of water. The subsequent weaker lye is concentrated in the second trough, until it is fit for boiling. The exhausted earth is used in the construction of the heaps or walls, in the manner already indicated.

Fig. 135

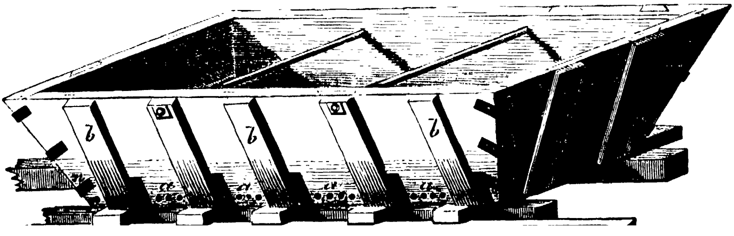
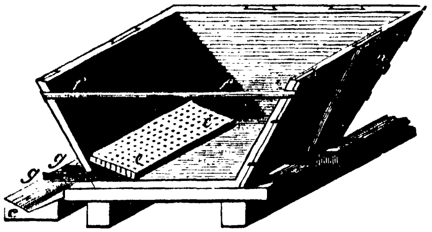


Fig. 136.



The Crude Lye.—The lye for boiling, technically called *crude lye*, is, as the method of preparing it indicates, not only a solution of saltpetre, but contains all the soluble portion of the saltpetre earth, and its state of concentration must be regulated by the price of fuel. Besides the nitrates of potash (soda), lime, magnesia and ammonia, it contains chloride of potassium, chloride of sodium, chloride of calcium, chloride of magnesium, carbonate of ammonia, and peculiar brown coloring matters of organic origin, which have not been examined, and which are usually classed together under the very indefinite term *extractive*. Thénard found in the dry residue of crude lye from the gypsum debris of Paris:

Nitrate of potash and chloride of potassium .	10
Nitrate of lime and magnesia	70
Chloride of sodium	15
Chlorides of calcium and magnesium . .	5
	100

The presence of carbonate of ammonia is not surprising after what has been made known, with reference to the production of saltpetre. It explains what would otherwise be remarkable, viz., the absence of nitrate of alumina in the crude lye, for alumina is more abundant in the saltpetre-earth than any other base. The precipitation of magnesia is prevented by the salts of ammonia, and that of lime is at least retarded by the presence of nitrate of ammonia; for no precipitate is produced when small quantities of carbonate of ammonia are added to a solution of nitrate of lime. The presence of nitrate of ammonia is explained by the observation of Kuhlmann, that carbonate of ammonia and nitrate of lime mutually decompose each other at a temperature of from 25° to 30° (77° to 86° F.) to form nitrate of ammonia and carbonate of lime. The brown color of the lye is derived from the extractive matter, and the alkaline reaction from the carbonate of ammonia. It has frequently been asserted that there is more nitrate of potash in the crude lye, than could have been produced from the potash present in the earth, that indeed potash itself has been produced. This may possibly not be an error, for by three years exposure to the atmosphere, a perceptible quantity of the insoluble earth, which itself contains potash, (grains of felspar, &c.) may have become disintegrated, and its potash would then unite with nitric acid, and be added to the whole amount of nitrate.

Treatment of the lye.—The nitrates in the crude lye have only to be entirely converted into nitrate of potash. The salts of potash used for this purpose are either potashes, sulphate of potash, or chloride of potassium. The quantity of potash to be added, must, of course, be proportional to the equivalents of the individual nitrates. On this account chiefly, the plan of combining this process with that of lixiviation, by mixing the ashes previously with the earth to be lixiviated, should be avoided; for we have no definite standard by which to regulate the addition of ash, and can only discover the proper quantity by the circuitous method of testing a number of samples. The mixture is, therefore, best made with the crude lye, kept for that purpose in large cisterns with cocks for decanting, and decomposed by a solution of potashes in two parts of water, from another vessel. A small quantity is first tried, in order to ascertain how much of the potash solution is necessary, that is, until a precipitate is no longer produced with a certain portion of the lye; from this, the quantity required for the whole is easily calculated. As soon as the solution of potashes is introduced into the precipitating trough, and well stirred, a dense precipitate of carbonate of lime and magnesia falls to the bottom, whilst nitrate of potash, with chloride of potassium and chloride of sodium, remains in solution. The proportion of chloride of potassium is much increased after this precipitation, for the decomposition is, of course, extended to the chlorides, as well as to the nitrates of the earths, at the expense of the chlorides of calcium and magnesium, for (if M represent 1 equiv. of calcium or magnesium), MO, NO_5 and KaO, CO_2 become KaO, NO_5 and MO, CO_2, but also MCl with KaO, CO_2 become MO, CO_2 and $Ka\,Cl$. Now, as chloride of potassium is of much less value than potashes, that portion of the latter which decomposes the chloride of calcium and chloride of magnesium is so much loss to the manufacturer, for a smaller quantity of potashes cannot be used, as the decomposition of the nitrates and chlorides of the earth is not consecutive but simultaneous. For this reason it is useless to calculate the necessary addition of potashes by the amount of nitrates only; and the nitrate of ammonia also requires an excess of carbonate of potash to decompose it. Neither is it advisable to concentrate the lye to 15 or 20 per cent., before adding the potashes, which is sometimes done, as that involves the necessity of repeatedly washing the precipitate, in order to remove the whole of the saltpetre. If, however, sulphate of potash is used, the lye must then be brought to this state of concentration. In this case, (MO, NO_5 and $KaO, SO_3 = MO, SO_3$ and KaO, NO_5,) sulphate of lime is produced, nearly the whole of which precipitates, and sulphate of magnesia remains in solution. To separate the sulphate of magnesia, a little excess of milk of lime may be added, when magnesia and sulphate of lime separate ($MgO, SO_3+CaO=CaO, SO_3+MgO$). The clear lye then contains saltpetre, chloride of sodium and potassium, with a small quantity of sulphate of lime; the coloring matters remaining nearly entirely with the precipitate.

Chloride of potassium, which is obtained in large quantity during the purification of saltpetre, may also be used as an addition to the crude lye, when sulphate of soda can be obtained at a low price. According to Longchamp, the whole should be first treated with sulphate of soda; all the nitric acid of the crude lye then enters into combination with the soda, and sulphate of lime is precipitated. After milk of lime has been used to separate the magnesia, nitrate of potash and chloride of sodium can be obtained by the addition of chloride of potassium. The same object is attained in a more simple manner, after the separation of the magnesia by lime, when the clear lye is treated with a solution of chloride of potassium, and crystalized sulphate of soda in equal equivalents (in the proportion of 1 : 2), which then produce the same effect as a mixture of common salt with sulphate of potash.

Whatever means may have been employed to decompose the crude lye, it must afterwards be allowed to stand until the precipitate has entirely subsided, and the clear liquors can be drawn off for boiling.

The Boiling.—The object of boiling is not only to concentrate the lye to the point of crystalization, but likewise to effect the separation of impurities. To understand the nature of the process, the different degrees of solubility of the salts contained in the lye must be taken into consideration. Thus 100 parts of water dissolve:

At	0° (32° F.)	— 7.5	parts	of saltpetre		(Gay-Lussac).
"	18° (65° F.)	— 29.	"	"		"
"	45° (113° F.)	— 74.6	"	"		"
"	97° (207° F.)	— 236.0	"	"		"
"	100° (212° F.)	— 400.0	"	"		(Riffault.)
"	0° (32° F.)	— 29.32	"	chloride of	potassium	(Gay-Luss.)
"	11.8° (53° F.)	— 34.5	"	"	"	(Kopp.)
"	15.6° (60° F.)	— 35.1	"	"	"	"
"	17.5° (64° F.)	— 33.3	"	"	"	"
"	100° (212° F.)	— about 57.0		"	"	(Gay-Lussac.)

and of chloride of sodium about the same quantity (27 parts) at all temperatures (see page 249). The solubility of nitrate of potash increases, therefore, to a much greater extent with the rise of temperature, than that of the chlorides; and the evaporation of water, to a certain extent during boiling, is not attended by any deposition of saltpetre, as the loss of water is compensated by the rise of the temperature to 100° (212° F.). This increase of temperature, however, has but little influence on the solubility of the chlorides, so that they are forced to crystalize and separate during evaporation. It must, nevertheless, be stated that the solubility of saltpetre is apparently increased by the presence of common salt.* This is explained by the fact, that these two salts cannot exist together in solution without mutual decomposition, so that the water in which they are dissolved really contains four salts, namely, chloride of sodium, saltpetre, chloride of potassium, and nitrate of soda, and the lye must consequently always contain some nitrate of soda, as common salt is never entirely absent; besides these, there are generally found chlorides, ammoniacal salts, lime and magnesia in the state of bi-carbonates, and also coloring matters.

As was the case in the preparation of common salt (pp. 256, 257), fresh lye is constantly allowed to flow into the boiler, until its contents have attained the proper state of concentration. That the temperature may not be lowered by each addition, the lye is previously warmed by the same fire in a separate pan.

Fig. 137 shows the manner in which the apparatus is arranged. Access is obtained to the grate *r*, by the door *a*, and to the ash-pit *s*,

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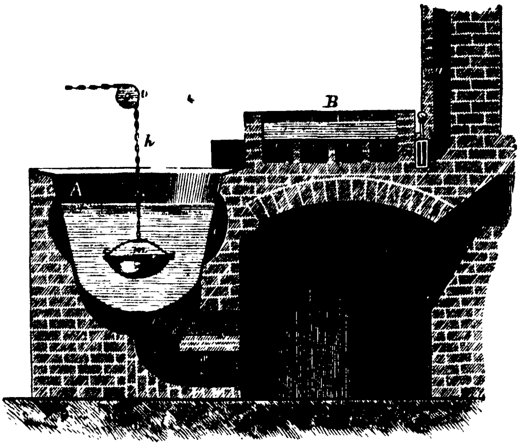
* A saturated solution of saltpetre (of 21.63 per cent., therefore), at 212°, is enabled to dissolve according to Longchamp, by the addition of:

5	10	20	25	parts of common salt.
0.75	1.27	1.83	2.58	parts more of saltpetre.

at *b*. The flame first plays upon the bottom of the copper boiler *A*, and passes from thence through two walled apertures to the flues *c*, *c*, *c*, *c*. These forming first a horizontal ring, heat the sides of the boiler, and extending upwards pass under the bottom of the warming-vessel *B*, traverse the space below it several times, and then open into the chimney *g*, which is supplied with a damper *x*, for regulating the draught.

Fig. 137.



At the commencement, and throughout the time of boiling, a thick, dirty skum rises to the surface of the fluid, which, from time to time is removed, and, that no loss of lye may occur, is emptied into the lixiviating vessels. This impurity is derived from the organic matters in solution, which gradually coagulate, and become insoluble. The change which they undergo is caused partly by the contact of air; and this explains why a less deeply colored lye is obtained from earth which has been kept for some time, and not moistened during the latter period with excrementitious matter. The second phenomenon which appears on boiling, is the decomposition of a portion of the carbonates of the earths, which are precipitated as the carbonic acid holding them in solution is dissipated, and render the liquid turbid. This decomposition is completed shortly before the lye is sufficiently concentrated. At the same time, when the evaporation has somewhat advanced, the difficultly soluble sulphate of lime begins to deposit as a crystaline powder. The phenomena are very similar to those which are observed in boiling the salt brine, and a deposit would attach itself to the bottom of the vessels, as in the saltpans, and give rise to the same disturbances and difficulties, if a method of prevention were not adopted, which is applicable to all similar cases. At the time when the earths begin to precipitate, a small, flat vessel *m*, is immersed nearly to the bottom of the boiler, by means of the chain *h*, and the pulley *o*. Whilst the great mass of the lye is boiling, and in violent motion, comparative rest exists in the interior of the vessel *m* so that the particles in suspension, which are in constant agitation in the external fluid, can deposit in it without being again thrown out. The vessel *m* must be drawn out occasionally and emptied. The scum is allowed to drain into the evaporating pan, from a box placed above it.

At a later period, when the concentration is more advanced, the chlorides of the alkalies (either common salt, or chloride of potassium, or both, according to the process adopted) are seen crystalizing in cubes on the surface, which then fall to the bottom. The fire should then be lessened, that larger crystals may form, which deposit more easily, and do not retain so much lye on removal. The same vessel *m* may be used for removing them, or as the crystals do not easily attach themselves to the pan, they may be scooped out with a colander. When the lye has attained the proper consistence, which is the case, when a drop placed in a cold plate soon becomes solid, a part of the chlorides has separated, but quite as much remains dissolved in the lye. The latter now indicates 48° to 50° on the saltpetre hydrometer, and is left to stand for 15 to 18 hours, that it may become perfectly clear; it is then poured off into the copper crystalizing pans, where, at a temperature of about 50° (122° F.), the saltpetre crystalizes, as *crude saltpetre* in small, yellow crystals, containing common salt and chloride of potassium. In those works where refined saltpetre is made at the same time, the crystalization is allowed to take place in the refining pans, and with the same precautions as if crude saltpetre were the only object of manufacture.

The mother liquor, which contains either an excess of potash, or undecomposed *nitrates, is added to the next boiling, until*, by *frequent* repetition of the process, it remains in such excess, that it may be treated for the salts contained in it, or returned to the heaps with the earths which deposit in the vessel *m*. The chlorides which crystalize, also contain much saltpetre that must not be lost. The manner in which this is extracted is ingenious, and deserves notice. It is done as follows: a small willow basket, filled with the salt, is suspended in boiling water, another basket full is then substituted in the place of the first, and this is repeated with the whole quantity of salt. There must be much less water used than is requisite for the solution of the whole salt. At first, therefore, a saturated solution of the chlorides is produced, which takes from the second and following baskets no more of these, but all the saltpetre, so that, at last, the water employed contains the whole quantity of saltpetre, but only a small portion of the chlorides. This solution is added to the boiling lye, and the chlorides are used for other purposes.

Refining Process.—The crude saltpetre contains no carbonates of the earths, but is contaminated with extractive matter, and a considerable quantity of chloride of potassium and common salt, which, together, amount often to 25 per cent. These chlorides are the most difficult to remove of all the impurities, and are exceedingly objectionable in all the applications made of saltpetre, both for the preparation of aqua-fortis, in medicine, and more particularly for the manufacture of gunpowder, which requires saltpetre containing no more than $\frac{1}{3000}$th of chloride. The reasons are, therefore, obvious, which render a most complete and careful purification necessary. The best process, introduced by the French, (Beaumé and Lavoisier,) is partly dependent upon the unequal action which heat exerts upon the solubility of saltpetre, and of the chlorides, and upon the effect produced by animal gelatine (glue) upon the extractive matters, which (like tannin) form with it insoluble combinations: partly, however, upon an ingenious method of avoiding the chief cause of impurity in the crystals. It is well known, that in a fluid containing several salts on the point of crystalization, only homogeneous crystals, *i. e.*, such as consist of one salt alone, will be formed, except in those cases where the law of isomorphism admits of two salts taking part in the formation of one and the same crystal. Saltpetre, however, and the chlorides, do not come under this category, and consequently, crystals of saltpetre deposited from a solution of chloride of sodium (or chloride of potassium), will contain none of the latter salt in their substance, but will only be contaminated by the mother liquor on their surface, from which, however, they can be freed without difficulty. Unfortunately, spaces are left in the larger masses of crystal, by the growth of new layers over the inequalities of those already formed, which remain filled with mother liquor. It is in consequence of this, that dry saltpetre, when pounded, gives a moist powder: these internal spaces being destroyed by pulverization, and the liquor then flowing out. In the refining process, this evil is avoided by causing purposely, the formation of very small crystaline needles, which contain few or no pores.

The process is generally commenced in the evening, by dissolving a sufficient quantity of crude saltpetre in a roomy copper pan. Care is taken, at first, to add no more water than is requisite to dissolve the crude nitre at the boiling temperature, 12 cwts. of water to 60 cwts. of the crude salt. The result will be seen to the greatest advantage by an example. Suppose the saltpetre to contain 6 per cent. of chloride of potassium, and 14 per cent. of chloride of sodium, then the charge in the pan, without taking the other impurities into account, will contain:

		The 12 cwts. of water are capable of dissolving at a temp. of 212° F.
Chloride of potassium .	360 lbs.	684 lbs.
Chloride of sodium . .	840 "	324 "
Saltpetre	4800 "	4800 "
	60.0 cwts.	

and there will remain, when the water has ceased to act, 840—324 = 516 lbs. of chloride of sodium, undissolved, whilst another portion, 324 lbs., will dissolve with the chloride of potassium and saltpetre. To save time, the whole of the water, and a portion of the saltpetre, are placed in the pan over night, and in the morning, when the first portion has dissolved at a low temperature, the remainder is gradually added (about ⅕th at a time), and the heat increased. The scum, which during stirring collects on the surface, is removed, and when the solution is effected, and has been boiled for some time, the chloride of sodium is scooped out from the bottom of the pan. The completely saturated solution would now deposit crystals during the following operations, for it must constantly be kept hot, and water consequently be evaporated. Before proceeding further, therefore, the solution is dilated with 8 cwts. more water,* and again boiled, with the addition of 2 lbs. of glue to the boiling solution. The remaining extractive matter immediately separates with the glue, and rises to the top, whence it is removed. When scum has ceased to rise, the whole is allowed to stand till the following day. During this time, nothing must be allowed to crystalize, and the fire is consequently regulated, so as to produce as constant a temperature of 88° (190° F.) as possible. Before proceeding to crystalize, the suspended matter must be allowed to subside, that no portion of it may be mixed with the crystals. The transference of the liquid into the crystalizing pan, Figs. 138 and 139, is therefore performed with the greatest care, and it is better to leave a portion of the lye behind than run the risk of contaminating the crystals. The pans are constructed of hammered copper, in the form of a flat three-sided prism, with the edge screwed firmly to a platform *a* of oak timber. The double inclination of the vessel, namely, the inclination throughout its whole length, and that of the bottom towards the centre, causes the deepest point to be at one of the narrow sides (at *n*): this is purposely so arranged. The lye requires six or seven hours to cool down to the temperature of the surrounding air; and then the formation of large crystals is prevented by constant stirring and agitation; the saltpetre is obtained as a snow-white powder, consisting of fine crystaline needles—"*saltpetre flour.*" As this increases in quantity, it is drawn out of the lye by the workmen, towards the higher parts of the pan, where it remains until the (still colored) lye,

Fig. 138.

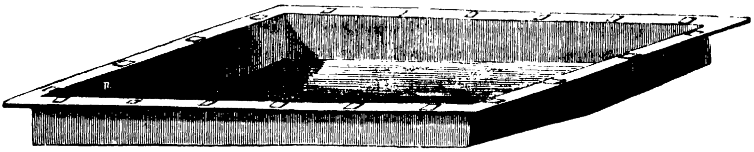
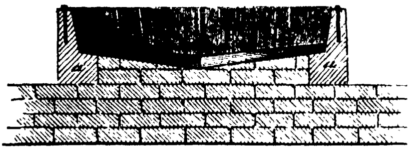


Fig. 139.



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* In most technical books—for instance, those of Dumas, Prechtl, Schubarth, &c., the addition of cold water is said to cause the precipitation of more chloride of sodium, in consequence of the reduction of temperature. This statement, which contains a palpable impossibility, is probably an oversight, if it is not the incorrect explanation of some phenomenon which occurs during the process.

inasmuch as it is not kept back by capillarity, has drained away into the lower part. When the upper layers become whiter and less colored, they are removed, with a colander, to the wash tub. About 12 cwts. of mother liquor remain. When the proportions stated have been attended to, only mere traces of chlorides can accompany the saltpetre-flour. Suppose the lye to cool down to 18° (65° F.), then in the above example, we shall have the following relations:

Dissolved altogether by the 12 cwts. of water,		The 12 cwts. of the mother liquor are capable of holding in solution at 18° (65° F.),	There will therefore crystallize,
Saltpetre	4800 lbs.	348 lbs.	4452 lbs. (flour).
Chloride of sodium	324 "	318 "	6 "
Chloride of potassium	360 "	396 "	0 "

i. e. the flour will contain in this case, 0.1 per cent. of chloride of sodium, and the quantity of this substance, even in the most unfavorable circumstances, for instance, by excessive cooling, will never much exceed 1 per cent. But this residue is also nearly entirely removed at the same opportunity, when the mother liquor is allowed to separate from the interstices of the flour, which mother liquor will be so much the more impregnated with chloride, as the crystals themselves are freer from it. The process of *washing*, that is, the removal of the mother liquor and the chlorides, is essentially the same as that called claying, or liquoring, in the sugar refineries. It consists in expelling the mother liquor from the interstices of the crystaline powder, by means of a *saturated solution of pure saltpetre.* A solution of this kind can, of course, dissolve no more saltpetre, and therefore none of the flour; but it dissolves the mother liquor and the chlorides, with as much ease as pure water would dissolve them. When these impurities have been removed, the interstices between the crystals are filled with a solution of pure saltpetre, which, on drying, solely constitutes the whole mass. In transferring the fresh flour to the wash-pans, Figs. 140 and 141, it should be heaped up in some measure, as it sinks together considerably in washing. The wash-tubs are 10 ft. long, 4 ft. wide, and in other respects like the lixiviating cisterns, only that they are provided with a second pierced bottom, so that the fluid running off from the holes *a*, which are furnished with plugs, may be conveyed away by the gutter *d*. Each tub requires 144 lbs. of water; of which, 60 lbs. are first poured with a watering-pot over the flour, and allowed to remain on the saltpetre, with closed plugs, for two or three hours. The whole of the chlorides are dis-

Fig. 140.

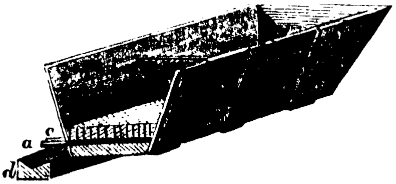
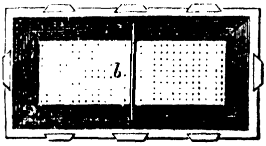


Fig. 141.



solved at the expiration of this time; the plugs are then removed, and the lye is allowed to trickle through during another hour. The operation is then repeated with the same quantity of water, and lastly, with the remaining 24 lbs. The first portion of water, and some of the second, contain the chlorides, besides saltpetre, and are allowed to flow into the crystalizing pans with the mother liquor. The remainder, and the third portion of water, together 60 lbs., which contain nothing but saltpetre, are used instead of fresh water for the next portion. It is, consequently, only the first time that 144 parts of water are requisite; afterwards, the washing is commenced with the pure solution of saltpetre from the foregoing process, and finished with 84 lbs. of fresh water, nearly the whole of which is again obtained as a pure solution of saltpetre. The wash flour remains for some days in the wash-tub, and is then dried in a pan heated very gently by the escaping smoke of the boiler, with constant agitation. The dry saltpetre must be sifted, to remove the lumps, before being sent into the market. On an average, 60 cwts. of the crude salt, produce 35 to 36 cwts. of refined saltpetre, which is now fitted for all purposes, and particularly for the manufacture of gunpowder.

When sufficient mother-liquor has been collected, it is submitted to a separate treatment. It is evaporated, with a constant addition to the boiler, as was the case with the crude lye, to ⅔ds of its original bulk, the crystalizing common salt and skum are removed as before, and, at last, it is clarified with glue. It must be borne in mind, that this mother-liquor contains nitrates of the earths, besides the chlorides, and that these former will have increased to such an extent, that it becomes necessary to decompose them by an addition of solution of potashes. When this has been done, the clear liquid is poured into the crystalizing pans, and the process repeated as before.

The older process of purification differs from the French method, in not producing any saltpetre flour, but in submitting the crude salt to two successive crystalizations, each of which affords a cake of salt composed of *large crystals. For the first crystalization* the same quantity of water is employed as in the French method, namely, ⅕th of the weight of the crude saltpetre, so that a portion of the chlorides remains undissolved. In the second recrystalization, the once purified salt is dissolved in ⅓d its weight of water, so that the residue of chlorides may remain dissolved. The second crop of crystals, after being dried, is considered sufficiently pure for commercial purposes. The use of glue was originally peculiar to this older process, and adopted from it into the more recent method.

In Austria, milk of lime is added to the solution of the crude saltpetre in ⅜ths water, with the intention of decomposing the extractive matter, and the whole is crystalized without previously separating the deposit. A saline mass is obtained from which the lowest impure layer is scraped off, and the mother-liquor drained away. Instead of recrystalizing this crude product, the whole is placed upon a substratum of wood ashes covered with bibulous paper, which absorbs the residue of mother-liquor with avidity, provided care has been taken to prevent the mass from previously becoming too dry. The mass is left covered in this manner for fourteen days, when it is dried. It is hardly necessary to point out the inefficiency of this process.

In Sweden, where saltpetre is prepared on a small scale by individuals, the refining is not made a distinct process (see p. 327). The crude lye is boiled, until the greater part of the extractive matter and the chlorides have separated, and the concentrated liquor is treated, after having been strained, with as much water as will serve to hold the chlorides which have not separated in solution; the whole is then recrystalized. The production of saltpetre flour, and the method of washing it differ in no way from the plan already described. The washed flour is, however, melted in iron vessels in order to obtain a cake on cooling. In this state, the saltpetre is more easily conveyed to a distance, as it occupies $\frac{1}{3}$d less space: and the collector is enabled to judge in some measure of the purity of the salt by the appearance of the fractured surface; pure saltpetre has, in the melted state, a coarsely fibrous structure, and is very translucent. The $\frac{1}{80}$th part of common salt can be detected in this manner, when $\frac{1}{40}$th is contained in the saltpetre, the nucleus is no longer fibrous, and if the common salt amount to $\frac{1}{30}$th, the fibrous texture is perceptible only at the edges of the cake. As the great heat requisite to fuse saltpetre, and portions of carbon inadvertently falling into the fusing salt, always occasion partial decomposition, and give rise to the production of the deliquescent nitrate of potash, it is not desirable to fuse it, as it dissolves afterwards with difficulty, and is by no means easily pulverized.

Production from Chili-Saltpetre.—In some localities, where potashes are not too expensive, Chili saltpetre is converted by their means into potash saltpetre; the whole process is then reduced to a simple purification ($NaO, NO_5 + KaO, CO_2 = NaO, CO_2 + KaO, NO_5$). One evil is with difficulty avoided in this decomposition, and that arises from the presence of common salt in Chili-saltpetre; for, as soon as a little more of the potashes is added, than corresponds with the quantity of pure nitrate of soda, the excess decomposes chloride of sodium to no purpose, and in the opposite case the product is easily contaminated with portions of undecomposed soda-saltpetre. By previous recrystalization of the cubic nitre, this evil is diminished.

Testing for purity or Refraction of Saltpetre.—In most countries, those persons who are commissioned to purify saltpetre for the use of the army, obtain the crude saltpetre from individuals who make it their business to prepare it. As a considerable portion of the weight of this product is always due to foreign matters, and its value is solely dependent upon the amount of pure saltpetre which it contains, it becomes important to have some means of ascertaining its value with sufficient accuracy in a speedy manner, that the course of business may not be impeded by the investigation. The object in testing the crude material is, therefore, to ascertain the amount of pure nitrate of potash which it contains; it is also sometimes desirable to know how much nitrate of soda there may be in it, as that salt adds to the value of crude saltpetre. The methods which are generally employed, afford no scientific accuracy, nor is that absolutely necessary for practical purposes.

In Sweden, where saltpetre is levied as a duty upon every landed proprietor, the samples for testing accumulate to such an extent, that the easiest, though not the most accurate, plan has been necessarily adopted. The method was introduced by G. Swartz, and consists in casting the melted salt in the form of a cake, 1 inch in thickness, by means of a small tin box, and examining its fracture in the manner indicated above. This casting is, of course, only necessary when the crude saltpetre is not delivered ready cast by the producer, and he is not legally obliged to return it in that state. That which shows a radiating fracture, or is found to present it on fusion, must be accepted; that which does not, is valued by the collector, who is at liberty to take a larger quantity as compensation for the inferior quality.

In France, saltpetre is tested in the humid way by a process introduced by Riffault. A weighed quantity of the dry crude saltpetre is gradually washed, at the temperature of the testing room, with a saturated solution of pure saltpetre in water. When as much of this solution has been used for washing, as would be sufficient to dissolve four or five times as much chloride as can possibly be contained in the worst sample of crude saltpetre, it is then quite certain, that nothing but pure saltpetre can remain. For a sample consisting of 12⅜ oz., 18½ oz. of a pure solution of saltpetre is used, which will dissolve 8½ oz. of common salt, or 66 per cent. of the sample, a quantity which is never actually present. Nothing now remains to be done but to weigh the saltpetre remaining upon the filter; there is, however, some difficulty attending this, as the solution which clings to it must first be removed. To effect this removal, the filter is spread out upon blotting paper placed upon a porous substance (a slab of gypsum, for instance), that at the expiration of twenty-four hours the saltpetre may be taken out and dried. From the weight found, which indicates the *amount of saltpetre in the sample*, 2 per cent. must always be deducted, as that quantity has been found by experiment to remain in the wash water, and which it is impossible wholly to remove. It is obvious that this process must be both tedious and inaccurate; Gay-Lussac has, consequently, proposed the use of his alkalimeter as a means of testing saltpetre. With this view, the saltpetre must be converted into carbonate of potash, by fusion with charcoal when all the nitrogen is evolved. That the evolution of gas may not be too violent, and thus a portion of the test ejected, 4 parts of common salt, which in no way affect the test, are mixed with ½ of charcoal powder or soot by way of dilution, and the whole is brought into a state of fusion in an iron spoon. The fused saline mass gives a solution of carbonate of potash and chloride of sodium, which must be filtered, and treated with the test-acid in the manner previously described, (p. 302.) Every per cent. of potash indicated by the alkalimeter, proves the presence of 2.14 per cent. of saltpetre, every per cent. of carbonate of potash, 1.46 of saltpetre in the sample tested. The only objection that can be made to this method is, that it requires as much care and dexterity in its execution as any regular chemical analysis, and this rather unfits it for practical use.

A very different method from either of the two preceding is that proposed by Husz, Colonel of Artillery, and introduced by him into Austria. His method is a physical analysis, and is founded upon the fact, that the temperature at which a cooling solution of saltpetre loses the property of dissolving more saltpetre, or what is the same thing, the temperature at which it begins to deposit crystals, (in fact, its point of saturation,) is a fixed temperature, and depends solely upon the relative proportion of water to that of the saltpetre dissolved, whether chlorides are present or not.

If, therefore, the quantity of water remains the same in different cases, the point of saturation will solely depend upon the quantity of saltpetre, and the temperature at which saturation occurs, will be a means of ascertaining the amount of saltpetre in a given specimen. Experiments must have been previously made to determine the point of saturation of solutions containing different quantities of saltpetre in an equal amount of water. Such experiments have been made in sufficient number, and arranged in a tabular manner, showing for all the points of saturation from every ¼ of a degree C., the quantity of saltpetre contained in 100 parts of water, or the per centage of the solution. Thus, for instance, when

In 100 parts of water there are dissolved	The point of saturation (or crystallization) will be
22.27 saltpetre	at 10° C. = 50° F.
23.36 "	" 11.25° " = 52¼° "
26.96 "	" 15° " = 59° "
32.50 "	" 20° " = 68° "
39.51 "	" 25° " = 77° "

In order, therefore, to ascertain the value of a specimen of crude saltpetre, a weighed quantity must be dissolved in 100 parts of water at about 60° C. (140° F.), and the sinking of the temperature must be watched with a thermometer indicating ¼th of a degree, until crystals begin to deposit. The point of saturation is then attained, (or, in reality, is a little exceeded,) and the temperature observed at the moment, compared with the table, will indicate the quantity of saltpetre contained in the solution. The quantity indicated by the table calculated for the actual quantity employed, gives the real value of the specimen. Suppose the test to have been made with 40 parts of crude saltpetre, and the point of saturation to have been attained at 17¾° C. (63°.95 F.), this solution would contain, according to the table, 30 parts of saltpetre; these 30 parts were obtained from the weighed specimen, which consequently contains $\frac{30}{40}$ths = 75 per cent. of pure saltpetre. It is self-evident, that the specimen must be thoroughly dry when used, or more water would be present, than is conformable to the results given in the table. The mutual decomposition of chloride of sodium and saltpetre, which has already been noticed, and which, by the production of nitrate of soda, causes an apparent greater solubility of saltpetre in water containing chloride of sodium, may give rise to a slight inaccuracy in this method, which, in other respects, comes next to the Swedish in rapidity of execution.

No suitable means have as yet been discovered of ascertaining the amount of nitrate of soda, which frequently accompanies the first crop of crystals obtained in preparing saltpetre from cubic nitre and potashes. According to the observations made by the Prussian officers of artillery, the action of air saturated with moisture, may possibly lead to some method of determining this point. Pure nitrate of potash exposed over the surface of water for fourteen days, remained comparatively dry, whilst nitrate of soda placed under the same circumstances, absorbed 25 per cent. of water. When artificial mixtures of the two salts in a pure state were subjected to the same treatment, the quantities of water absorbed were as follows:

Mixture with per centage of nitrate of soda	0.5	1	3	5	10	
Absorbed in 14 days	2.5	4	10	12	19	Water, per cent.

All gunpowder containing this variety of saltpetre would, of course, become moist in the same proportions, and would thus be rendered useless; hence, the necessity for ascertaining the absence of nitrate of soda in saltpetre for all purposes connected with gunnery.

The only test for the chloride (the usual impurity) in purified saltpetre, is nitrate of silver, which produces a precipitate of chloride of silver, corresponding to the quantity of chloride present.

The ease with which nitric acid converts a protosalt of iron into a persalt of the metal, has been made available by M. Gossart as a means of testing the purity of crude nitre. The nitrate under examination is heated with sulphuric acid to liberate the nitric acid, and this is caused to act upon protosulphate of iron: when ferricyanide of potassium indicates the presence of an excess of protosalt, the operation is finished, and the amount of nitric acid in the nitrate, is estimated by the quantity of the protosalt which has been peroxidized.

There is some practical difficulty experienced in adding the exact quantity of protosalt of iron required in this process, and if any excess of protosalt has been used, it will of course give rise to an error indicating too much nitric acid in the substance analyzed. Pelouze obviates this difficulty by employing a known excess of the protosalt of iron in the preceding process, and then estimating the quantity of iron not peroxidized by the nitrate, in the manner proposed by Marguerite for analyzing iron ores. Marguerite has shown, that a dilute solution of protochloride of iron is instantly peroxidized when a solution of permanganate of potash is added to it at the ordinary temperature, and that the addition of the smallest quantity of mineral cameleon to a salt of iron thus peroxidized, communicates a rosy tint to the liquid, which indicates distinctly the completion of the peroxidation.

Having previously ascertained that 2 grms. of pure iron, dissolved in a considerable excess of hydrochloric acid, require, on an average, 1.216 grms. of pure nitrate of potash to peroxidize them, the process is then as follows: 2 grms. of harp wire are placed in a flask capable of holding 150 cubic centimetres, and from 80 to 100 grms. of pure strong hydrochloric acid are poured upon it; having closed the flask with a cork furnished with a tube drawn out to a point, the iron is dissolved at a gentle heat. When the whole is dissolved, 1.200 grms. of the nitre under examination is introduced, the flask is immediately closed, and the liquid boiled; it soon becomes of a brown color, dense vapors of hydrochloric acid, mixed with deutoxide of nitrogen, issue from the orifice of the tube, and prevent the access of air. The liquid soon loses its brown color, becomes yellow and clear, and after having boiled for 5 or 6 minutes, and become perfectly transparent, the flask containing it is removed from the fire, and the liquid is poured into another flask capable of holding about 1 litre, which is then completely filled with ordinary water; into this, a solution of permanganate of potash of known strength is cautiously added from a graduated jar. The flask is agitated, in order to mix the liquid, and as soon as this assumes a faint rosy tint, the addition of permanganate is discontinued, and the quantity employed to peroxidize the iron read off on the jar.

Now, supposing that the strength of the solution of permanganate were such as would require 50 cubic centimetres for the peroxidation of 1.0 grms. of iron, and that 10 cubic centimetres had been employed in the example above, we should then have the equation:

$$50 \text{ c. c.} : 1.000 :: 10 \text{ c. c.} : x = 0.200.$$

On deducting, therefore, 0.200 from the whole amount of iron used, we obtain the quantity of iron peroxidized by the agency of the nitrate, or 2.000 — 0.200 = 1.800; but as 2 grms. of iron correspond to 1.216 of pure nitrate, and 1 grm. consequently to 0.608, the quantity of salt corresponding to 1.800 of iron, will be found by the following calculation:

$$1.000 : 0.608 = 1.800 : x = 1.0944.$$

In the 1.200 of crude nitre submitted to analysis there was, consequently, 1.0944 pure nitrate of potash, or $\frac{1.0944}{1.2000} = 91.2$ per cent.

Access of air to the flask, during the operation, should be avoided, as the nitric oxide which is generated would, by its means, become converted into a higher oxide, and thus peroxidize a further portion of the salt of iron. The protosalt of iron, dissolved in an excess of muriatic acid, is oxidized with great difficulty on exposure to the air, and no error need be apprehended on that account.

The base, of course, is not indicated by this process, but it is peculiarly adapted for analyzing mixtures of sulphuric and nitric acids, used in the manufacture of gun-cotton, for mixtures of nitric acid with water, and more particularly for saltpetre. The process scarcely requires 20 minutes for completion, and is accurate to within from two to three thousandths.*

GUNPOWDER.

History.—The early history of gunpowder is very obscure, and the ordinary tradition which attributes its discovery to the Franciscan, Berthold Schwartz, is by no means historically authenticated. It is, moreover, known that heavy artillery was used in the 11th century, and that Roger Bacon (born 1214), makes mention of powder in his writings as a substance generally known. Few inventions have exerted such prominent influence upon civilization as that of gunpowder; its introduction completely changed the art of war, and so far modified the institutions and forms of government, as to form an era in the history of the world.

The peculiar action of Gunpowder.—That gunpowder is a mixture of saltpetre, sulphur, and charcoal, that its action, on ignition, is dependent upon the instantaneous evolution of a large quantity of heated gas, which communicates a sudden, powerful shock to everything in the vicinity, is well known to everybody. But the reason why not one of the similar substances, exerting still greater power, of which chemistry can produce so many, is capable of replacing gunpowder, is worthy of more minute investigation. Several of these substances, like the chloride of nitrogen, explode upon such slight occasion, that they cannot be handled without the greatest danger. The same is the case with the material used for lucifer matches (see Appendix), and with detonating powder. Independently of this, there are several other important circumstances to be taken into consideration. Imagine the ball in a gun-barrel, at the moment of ignition, when it is forced forward by a sudden impulse, it is evident that a certain, although hardly appreciable, space of time, is necessary to overcome the inertia of the ball. An open door can easily be shut by the little finger, time being allowed for this slight force to overcome the inertia of the door, whilst bullets from a gun will pierce it, but have no power

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* Among the important properties of saltpetre, that of deflagrating with carbonaceous and hydrogenous compounds, is of course the basis of many of its useful applications, and not less so of its dangerous reactions when exposed in contact with these materials to the action of a red heat. According to the views of Messrs. A. A. Hayes, Prof. B. Silliman and Dr. Hare, the tremendous explosions which occurred during the great fire in New York in 1845, may be attributed to the ignition of the saltpetre, and its suddenly being brought into contact with the other combustibles stored in the same building such as shellac, and similar materials. As a bright red heat alone causes nitre to yield up gaseous oxygen, and as the same cause would rapidly generate carburetted hydrogen from shellac or other resinous substances, it is certain that if a fire were raging in a *closed* building having nitre in one part, and resinous materials in another, the gases generated in one apartment mingling by degrees with those formed in the other, would at length constitute with them an explosive mixture. When the first portions thus formed had exploded, a temporary calm would follow until the space again became filled with a mixture able to explode. As the heat increased, these periods would be shorter and the explosions become at each repetition more and more violent. This increasing energy is what actually happened at the extensive stores referred to, containing 360,000 lbs. of nitre.—[AM. ED.]

to move it. The same is the case in the barrel of a gun. When the velocity of the explosion does not allow time for the gases to communicate their motion to the ball, it remains nearly immovable, and becomes, as it were, one of the sides of the barrel, which must then burst like a bomb. Fulminating silver, and fulminating mercury, are, for this reason, useless as powder; the application of chlorate of potash, instead of saltpetre, in powder, also renders its action too rapid, and is attended with danger in the preparation. An experiment, instituted with that substance by Berthollet, at the powder mill of Essonne, cost two workmen their lives. The most explosive of all substances, is the chloride of nitrogen; a drop in an open saucer makes a hole in the bottom of the vessel, and in the support, because all its particles are decomposed at the same instant. Gunpowder, on the contrary, burns with a certain degree of tardiness, so that the time during which the combustion is proceeding, can be observed and measured. In addition to this, powder has the incalculable advantage, that all its constituents are cheap products, and are capable of being manufactured, independently, in every country. It can, therefore, be stated with certainty, that theory could not have indicated a more proper material than the practical experience of former centuries has discovered; for independently of the irresistible power of gunpowder, its gradual action is that which has made it subservient to the uses of man.

Products of Decomposition.—Mixtures of saltpetre and charcoal detonate with a considerable evolution of gas, but combustion does not proceed through their mass with sufficient rapidity to render them fit to be used as gunpowder. In both cases, whether sulphur is present or not, the evolution of gas is caused by the oxidation of the carbon, at the expense of the oxygen of the saltpetre. When charcoal alone is used, then the oxygen of the nitric acid only is consumed, that is, only $\frac{5}{6}$ths of the whole, carbonate of potash remaining. Sulphur, on the contrary, so far changes the process, that it combines with the potassium, forming with it sulphuret of potassium, and the whole 6 parts of oxygen from the saltpetre then combine with the carbon. The sulphur augments, in short, the action of the saltpetre, and what is of quite as much importance, it increases the combustibility to that degree which produces the greatest action, on account of its point of ignition being below the temperature at which saltpetre and charcoal detonate. The presence of sulphur has only one evil attending it, which is, that an excess of it, or even of the sulphuret of potassium, which is always produced, attacks the metallic sides of the fire-arms, and particularly those of guns.

For such purposes it is, therefore, advisable so to proportion the sulphur, that simple combinations with potassium shall be formed, which retain their sulphur with the greatest tenacity. An excess of saltpetre would, of course, be still more injurious, but there is not much chance of its ever being used, as it is the most expensive of the ingredients, and there is no reason why a little more carbon should not be employed than is actually required by the oxygen of the saltpetre.

The action of gunpowder is dependent upon a purely chemical process, which can easily be studied by the products of decomposition. This has been done by Chevreul and Gay-Lussac, who found in the mixture of gases, after the combustion of powder in a copper tube:

	Chevreul.	Gay-Lussac.
Carbonic acid	45.41	53
Nitrogen	37.53	42
Carbonic oxide	— —	5
Nitric oxide	8.10	—
Carburetted hydrogen	0.59	—
Peculiar gas, containing carbon, hydrogen, and oxygen	8.37	—

The large quantities of the first three gases prove clearly that the three last are only adventitious, caused partly by the incomplete action of the ingredients upon one another, and partly by moisture. On firing the powder, therefore, the elements of the saltpetre are dispersed; the oxygen combines with the carbon, the potassium with the sulphur, and the nitrogen is liberated in the gaseous state. It is dependent upon the proportions of the elements, and hence, upon the will of the manufacturer, whether carbonic acid, or carbonic oxide, whether the simple, or a higher sulphuret of potassium, and whether carbonate of potash are produced. Now, although the extreme force of the powder may remain unimpaired by modifying the proportions of the mixture, yet differences in its mode of action frequently arise, which require further elucidation.*

Theoretical Relation of Ingredients.—Gunpowder, which is to be entirely converted into carbonic acid, sulphuret of potassium, and nitrogen, must consist, as $KaO, NO_5 + S + 3\,C = N + KS + 3\,CO_2$, of

No. I.		and would produce:		thus 1 vol. of gunpowder† (sp. gr. = 0.9).	
1 eq. saltpetre =	1267	1 eq nitrogen . . .	177	94 parts by weight	74 vols. of gas
1 " sulphur =	201	3 " carbonic acid . .	825	439 " " =	221.3 " "
3 " charcoal =	225	1 " sulphuret of potassium	691		
	1693		1693		296 " " total.

Gunpowder producing carbonic oxide, instead of carbonic acid, according to the formula, $KaO, NO_5 + S + 6\,C = N + S\,Ka + 6\,CO$, must contain:

No. II.		and would give:		or from 1 vol. of powder,	
1 eq. saltpetre =	1267	1 eq. nitrogen . . . =	177	83 parts by weight =	66 vols. of gas.
1 " sulphur =	201	6 " carbonic oxide . =	1050	493 " " =	391 " "
6 " carbon =	450	1 " sulphuret of potassium =	691		
	1918		1918		457 " " total.

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* Dr. R. Hare has proved that, among the fixed products of the decomposition of gunpowder by explosion, the sulphocyanide of potassium is always found.—Am. Ed.

† In this and the following calculations, it is assumed with Gay-Lussac, that 1 measure or volume of powder weighs 0.9 times as much as an equal bulk of water. [Capt. Mordecai tried 53 specimens of powder, of which he found the weight per cubic foot to be on an average 900 ounces. The maximum was 1047, the minimum 751.]—Am. Ed.

The composition of No. I. is the more expensive; it requires 1½ per cent. of sulphur, and 8½ per cent. of saltpetre more than No. II., which latter affords, likewise, nearly twice as much gas; but *the heat* produced, on combustion, is only *half as great*, and the gas, consequently, not so much expanded. This expansion is of very much more importance than the original quantity of gas; for 200 volumes of gas at 1330° C. (= 2426° F.), take up as much space as 300 measures at 797° C. (= 1466° F.), namely, 1170 volumes. The experience of several centuries, after a great variety of experiments, has accorded the preference to No. I., as the best mixture for powder to be used in fire-arms; this will be evident from the following statement:

	No. I.	Prussian	French	American	Austrian rifle powder.
		military powder.			
Saltpetre	100	100	100	100	100
Sulphur	15.86	15.3	16.6	16.6	15.0
Carbon	17.76	17.8	16.6	16.6	17.5

which proves that experiment and theory agree with reference to the proper mixture of ingredients. Most of the various kinds of gunpowder are so nearly constituted in these proportions, that the same kind of decomposition is evidently aimed at in all of them. The deviations are easily explained by the fact, that pure carbon can seldom be used, but such only as contains hydrogen and oxygen, and an excess of sulphur is carefully avoided. Yet it cannot be denied, that some kinds of powder are calculated for another mode of decomposition. Thus, blasting powder (French), in which the injurious action of an excess of sulphur upon metallic surfaces is not of moment, and economy is the chief thing to be studied, can be so constituted that ½ of the carbon shall be converted into carbonic oxide, the other half into carbonic acid, and at the same time a higher sulphuret of potassium produced ($KaO, NO_5 + 2 S + 4 C = N + KaS_2 + 2CO + 2 CO_2$). Hence the mixture must consist of:

No. III.		or quantity actually used:	
1 equiv. saltpetre	= 1267	100	100
2 " sulphur	= 402	31.73	30.8
4 " carbon	= 300	23.68	23.
	1969		

No. III. would give:		therefore, 1 measure of powder:
1 eq. bisulphuret of potassium	= 892	
1 " nitrogen	= 177	64.2 volumes of gas.
2 " carbonic oxide	= 350	126.9 " "
2 " carbonic acid	= 550	164.3 " "
Total	1969	356 " "

Certain other kinds of powder, like the French sporting powder, may be regarded as mixtures, which produce, on ignition, sulphuret of potassium, carbonate of potash, carbonic acid and nitrogen, for

$8\ KaO, NO_5 + 6\ S + 23\ C = 8\ N + 6\ KaS + 2\ KaO, CO_2 + 21\ CO_2$. Hence the powder must contain:

		No. IV.	or	there are actually mixed:
8 equiv. saltpetre	=	10136	100	100
6 " sulphur	=	1206	11.9	12.8
23 " carbon	=	1725	17.0	15.4
		13067		

According to theory there should be obtained:

			from 1 measure of powder:
21 eq. carbonic acid	=	5775	192 measures of gas.
8 " nitrogen	=	1416	74 " "
6 " sulphuret of potassium	=	4146	
2 " carbonate of potash	=	1730	
Total		13067	266

In solving the problem as to which is the best mixture for the composition of gunpowder, by the way of experiment, Proust has earned the most credit. This philosopher classified the results of his observations in three series. The first series contained the observations upon mixtures of saltpetre and charcoal in different proportions, with reference to the duration of the combustion, and to the amount and nature of the gases evolved. They show clearly, that with less than ⅙th of carbon, nitrate of potash is left; and that the mixture, with more than ⅙th of carbon, produces, on the whole, somewhat more gas, but that carbonic oxide then begins to form (with a diminution of the carbonic acid), and a corresponding smaller amount of heat is generated during combustion. With ⅙th of carbon the action is most complete, carbonic acid only is produced, and the best result is obtained. From the second series of experiments, it appears that of all the proportions of sulphur, even with different mixtures of saltpetre and charcoal, the action of ⅙th (sulphur) is the most powerful. In the third series of experiments, several different kinds of real powder were examined, and the following results were obtained:

100 parts of powder, consisting of:			Produced cubic feet of gas.
Nitre.	Sulphur.	Charcoal.	
70 per cent.	12 per cent.	18 per cent.	107
73.2 "	12.2 "	14.6 "	100
75 "	12.5 "	12.5 "	113
76.2 "	12.8 "	11 "	112

It appears, on the whole, by direct experiment, that the proportion 8 : 1 : 1 is the best. This proportion corresponds very nearly with the mixture No. 1., and this is consequently to be preferred to all the others, when other objects, as is the case with blasting powder, do not require a particular mixture.

Actual Constitution of Gunpowder.—In the following table, the constitution of several other kinds of gunpowder, not yet mentioned, is given:

Kind of powder.	To 100 parts nitre.		According to
	Charcoal.	Sulphur.	
Milan war powder	15.7	15.7	Meyer.
Würtemburg cannon powder	16.0	17.2	"
" musket "	14.3	19.8	"
Grand duchy of Hesse cannon powder	14.4	20.4	"
" " musket "	14.5	21.2	"
Swedish war powder	12.0	21.3	"
Princedom of Hesse war powder	18.2	18.2	"
Hanoverian " "	15.2	25.3	"
Russian cannon "	25.0	16.6	"
Dutch " "	22.9	20.0	"
Austrian musket "	17.3	15	"
Italian war powder	15.8	15.8	Prechtl.
Chinese " "	37.4	25.2	"
French sporting powder from Angoulême and Le Bouchet	17.5	12.5	"
Italian " "	24.8	11.7	"
French round powder, Essonne	21.6	13.5	"
English Waltham Abbey powder	18.0	13.3	Ure.
Dartford powder	15.6	9.8	Meyer.
Powder from Curtis and Harvey	16.3	11.8	"
" " Champy	24.75	6.25	"
" " Grenelle	15.7	15.7	"
Bernese powder	18.4	13.1	"
Miethen, 1684	21.2	12.0	"

Statements of this kind often vary to a great extent; nevertheless, many well-known kinds of powder are found constituted so contrary to all theory, that they must either contain an excess of saltpetre or of sulphur. The former is the case with the powder of Champy, the latter with the Chinese powder, which contains 3 equivs. of sulphur to 2 equivs. of potassium.

The quality of the powder depends (apart from the relative proportions of the constituents) very much upon the choice of the materials, and, particularly as all three constituents are solid, upon the degree of intimacy with which they are mixed. These two points, therefore, must dictate the method of preparing it.

The Material.—Saltpetre.—Crude saltpetre cannot be used in the manufacture of gunpowder. The crystaline flour obtained in the refining process free from all chlorides, (p. 372,) is the best material for this purpose. In France the amount of chloride must not exceed $\frac{1}{3000}$th; and in the celebrated powder mill, at Waltham Abbey, in England, the washing process is carried so far, that nitrate of silver produces no precipitate in a solution of the purified saltpetre. The flour is the more applicable to the manufacture of powder, as it requires no further grinding or preparation, which is the case with all that is employed in the state of large crystals.

Sulphur.—Sulphur can likewise be used in the state in which it leaves the purifying process described at p. 218. But as the flowers of sulphur always contain a little sulphuric acid, the stick or roll sulphur is preferred, which, at some period of the process, must be pulverized.

The influence which the *charcoal*, by reason of its porosity, inflammability, &c., exerts upon the quality of the powder, is very considerable. The quality of the charcoal, again, depends upon the material from which it is prepared, and upon the method of its preparation. Proust's experiments have also thrown light upon the former of these points. He found that a mixture of 72 grains of saltpetre was consumed with

12 grains of carbon from	In seconds	Leaving a residue of
Hemp stalks	10	12 grains.
King's spear	10	12 "
Vine branches	12	20 "
Chick-pea stalks	13	21 "
Pine-wood	17	30 "
Common bird-cherry tree (*Rhamnus frangula*)	20	41 "
Maple (*Evonymus europ.*)	21	27 "
Hazel	23	30 "
Horse chestnut wood	26	36 "
Walnut	29	33 "
Coke	50	45 "
Sugar	70	48 "

whilst carbon from rice, starch, albumen, blood, leather, &c., would produce no detonation. It is obvious from the table, that the soft, woody parts of plants produce the best charcoal, and nitrogenized animal matters the worst. For the same reason, paper is not applicable in consequence of the size it contains, whilst the fibre of flax and old linen is an excellent material for this purpose. The wood of the bird-cherry is now very frequently used, also that of the elder, poplar, maple, and walnut. In Spain the preference is given to hemp charcoal. Whatever kind of wood is employed, those parts must be thrown aside, which carbonize in the manner of starch, or albumen, &c. For this reason, the bark, which is impregnated with gummy, mucilaginous and extractive matters besides salts, must be peeled off from the wood for charring, all the leaves and smaller branches removed, and wood which is not too old, and yet fully developed, should be selected. Branches, from one to two inches in thickness, are best for this purpose. It is also found advantageous to expose the peeled boughs to the rain for some time, which removes still more of the extractive matter.

The degree of inflammability of charcoal, depends mainly upon its power of conducting heat. If this is slight, the heat communicated to one part, will be the less easily taken from it; it will be extinguished with greater difficulty, and *vice versâ.* Experience has shown the black-charcoal, produced at a high temperature, to be more dense and a better conductor of heat than the product of unfinished carbonization, or the so-called red-charcoal (*charbon roux*), of which mention has been made before (p. 64). In fact, a particular kind of charcoal belonging to this class, is now expressly prepared for the manufacture of gunpowder. It can only be procured in a manner which admits of the most accurate regulation of the heat throughout the whole operation. Furnaces are used for this purpose, with cylinders walled into them, Figs. 142 and 143, somewhat resembling the gas furnaces. The three cylinders *C*, *C*, *C*, are of cast-iron; the front part projects out of the furnace, and can be closed air-tight by the three discs *o*, *o*, *o*. The hinder part is let into the back of the furnace, so that the wall both supports and closes it. The pipes *a*, *a*, which are seen walled in at this part, and which connect the cylinder with the space *t* immediately before it, are intended partly for the reception of the test-woods, and partly for conducting the gases and vapors through walled channels to a separate cistern. The flame-fire, which is made upon the grates *r r*, is more uniformly disseminated by the pierced arch *m;* it first surrounds the lower halves of three cylinders, and then the upper ones, by the flues *e*, *e*, *e*, and escapes, lastly, by the chimney *h*. At *f* there is a damper. When too much ash has collected, it can easily be cleared away through the channels *c* and *d*, which at other times are kept closed. The wood for charring fills the middle, narrow portion of the retorts; the larger pieces being placed on the outside, and the smaller in the interior, having been previously cut to the proper lengths. That the regulation of the process may not be impeded, and a uniform quality of charcoal obtained, it is not advisable to place more than three retorts in one furnace, and these are made only just large enough to hold 100 lbs. of wood; the charcoal is, therefore, rendered somewhat expensive. When all the crevices are luted, the fire is lighted. To effect the decomposition with as little heat as possible is the first object, and the interior must never attain a red heat. The progress of carbo-

Fig. 142.

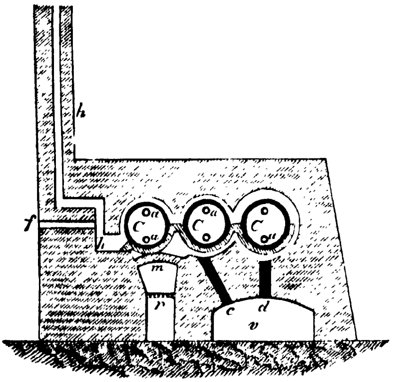
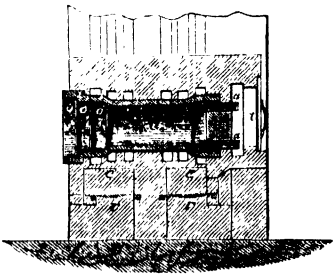


Fig. 143.



nization is estimated by the color of the escaping vapors, and by the appearance of the test-woods, which are frequently broken lengthwise, in order to see whether the decomposition has progressed uniformly from end to end. In about five hours the distillation is in full progress. When the vapors appear yellow, and the tests are brittle, and present a yellowish brown, shining fracture, it is time to extinguish the fire, as the heat of the furnace will then suffice to complete the carbonization. When the vapors cease to escape, the lids *o o o* are quickly removed, and the charcoal is allowed to cool in well-closed vessels of sheet iron. To avoid long interruptions, the wood is sometimes enclosed in sheet-iron cylinders, which are inserted into the retorts, and exchanged when the operation is finished, for fresh ones. It is questionable whether this method is profitable, as a larger amount of fuel is requisite to cause the heat to penetrate the double casing.

In a well-conducted operation, 34 to 35 per cent. of charcoal should remain. This is the usual amount of produce in the charcoal furnaces of Le Bouchet, for instance, where the carbonization is continued during twelve hours for good sporting powder, and for ordinary kinds from eight to nine hours.

Good powder-charcoal (*charbon roux*) should be brown, with veins of a lighter color, smooth, with a number of cross fissures, but none lengthwise; when pounded, it should have the appearance of black shot velvet, should burn with a bluish flame, be slightly flexible, and dissolve almost entirely in caustic potash. It is not found advantageous to extinguish the charcoal with water, as, if it is to be used immediately, which is always desirable, a calculation must be made for the amount of water, or the proportions in the mixture will not be accurate.

One circumstance, which always occurs during charring, requires particular notice. In the cooler parts of the distilling apparatus, tar is constantly condensed, and on dropping back upon the hot charcoal, is decomposed, leaving a difficultly combustible coal as residue. This, and the half-charred portions, must be carefully separated. They amount, sometimes, to 5 per cent. In furnaces of the best construction, as at Spandau, for instance, this quantity is reduced to ½ per cent.

By another process, the wood is charred in furnaces resembling those used in the coking of coal (p. 72). These are constructed with a flat hearth, covered over by a half-cylindrical arch, and with two doors, one at each end. In the beginning, when the wood with which the furnace has been charged is ignited, both doors are left open. When the fire has burnt up sufficiently, one of the doors is closed; the other, from which the wood was ignited, is left open for the escape of the smoke, and in order that the wood may be reached with the rakes, and those pieces, which no longer burn with flame, may be pushed to the back part of the furnace. When the flame is nearly extinguished, the second door is also closed, to diminish the glowing heat. The charcoal may then soon be drawn out and extinguished, in boxes of sheet-iron.

Notwithstanding the saving of time which is effected by the use of these furnaces, they are, nevertheless, not the most profitable, partly on account of the great waste, and production of half-charred wood and tar-charcoal, and chiefly because no definite amount of carbonization can be attained in them. Black charcoal is the only produce they afford.

The ordinary mounds are not adapted to produce charcoal for the powder mills, as the smallest particles of sand introduced into the powder-mixture might strike fire under the machines, and give rise to great danger. Yet, from a very ancient period, a kind of pit carbonization has been practised. These pits are quadrangular and flat; they are lined with bricks, which are placed upright. A pit 6 ft. deep, and 12 ft. diameter, is large enough to char 20 cwts. of wood. The margin of the pit must be firm and even; soft, clay-like sand, which is easily formed into balls, and woolen cloths, must also be at hand. The wood is bound up in fagots, consisting of some hundreds of pieces, which are arranged with some degree of regularity in two layers, one upon the other, and project about 4 ft. out of the pit. By means of a pole, previously inserted crossways, one row of fagots is easily made somewhat higher than the adjoining one; a channel is thus left, which must be open in front, as it serves for the admission of the materials for igniting. Straw and shavings are inserted and ignited, and the whole contents thus set on fire; the mouth of the channel is then immediately stopped up with fagots, to avoid the admission of an excess of air. The flame gradually makes way, consumes at last the pole, the channel becomes closed, and the mass of wood sinks together. When the fire is extinguished, the pit is no longer filled by that which remains; the same number of fagots are, therefore, gradually added, as were at first used. The regular stratification being thus destroyed, it becomes necessary, in order to obtain a uniform state of carbonization throughout, to loosen the mass in some parts, and force it together in others. When the flame is everywhere extinguished, the process is finished. The air is then quickly excluded, by throwing the wetted woolen cloths upon the even surface of the charcoal. On the top is thrown a layer of sand, which is firmly stamped down. In three or four days the charcoal may be drawn, and must be carefully separated from half-charred pieces, and from earthy particles. As much as 16 or 17 per cent. of charcoal is obtained by this very imperfect process. Neither the form of the pit, nor the use of sand, can be recommended. Sometimes round iron pans with lids are employed, instead of the pits, which afford a similar kind of coal, and a produce of 23 per cent.

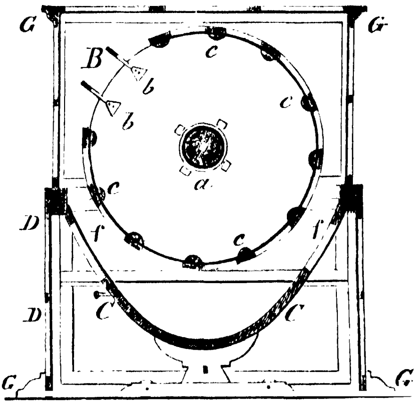
The charcoal from the pits, furnaces, and pans, is black-charcoal, and is in the form of long, sonorous rods, which must not be contaminated with tar-charcoal. In contradistinction to this, the charcoal from the cylinder is called "*distilled charcoal.*"

It is always advisable to separate any sand or other impurity from the charcoal, before putting it through any further operation; this is either done by hand, or, as at the period of the French Revolution, when no time was to be lost, by being thrown with shovels against a current of air, which carried away with it sand and dust.

Preparation of the Mixture, and further Operations.—It has been stated before, that the intimate mixture and consequent minute state of division of the particles, are of as much importance to the quality of the powder, as the proper proportion of its ingredients. Hence the great care expended in mixing and pulverizing, and the peculiar arrangement of the apparatus for this purpose. In whatever way it is effected, the object is always the same, namely, to pulverize and mix the constituents into a moist paste, of as great density as possible, which is afterwards separated into grains of equal size. These must be sifted, dried, and sometimes glazed.

The Pulverizing Drum, and the Revolutionary Process.—Since the period of the French Revolution, the pulverizing drums, invented during those pressing times, have come into very general use. These consist of barrels, like those in Fig. 149, suspended on one axis, 44 inches long, and about the same in diameter, and furnished on their internal surface with a series of ridges (about twelve), which project about 8 lines. These barrels are sometimes made of wood, but more generally of leather, which is nailed to a skeleton of wood. A barrel of this kind is shown in Fig. 144: *a* is the axis, *c*, *c*, *c*, &c., are the ridges. At *B* there is a flap, or door, which is kept closed by the straps *b*, *b*, and by bolts. To prevent the dust from escaping, the drum is surrounded by a frame of wood *G*, *G*, *G*, upon which leather is nailed in the interior. In the lower part of this covering, the side *D*, *D* is movable, and fastened by bolts, that the trough *C*, *C*, which moves upon rollers, may be moved in and out when the barrel is emptied. To prevent the contents of the barrel from falling at the side, the trough is so shaped that its edge exactly fits the inner funnel-shaped appendage *f f* of the covering. The pulverization in this machine, is effected by a number of small bronze balls, of the size of the balls (marbles) used by children ($3\frac{1}{2}$ lines in diameter), which are kept in motion by the revolution of the barrel. The velocity must only be sufficient to carry the balls to a certain height, and allow them to fall back over the ridges; too much velocity would cause them to remain firmly pressed against the side, on account of the centrifugal force. For example, in the manufacture of French sporting powder, 36 lbs. of charcoal are placed in the drums

Fig. 144.



with 3 cwts. of bronze balls, and allowed to revolve for 12 hours, with 30 revolutions per minute. At the expiration of this time, the sulphur is added (30 lbs.) in rolls,* which is reduced to powder in this manner, and mixed at the same time with the charcoal. On emptying the barrel, the flap is removed, and a sieve of brass placed before the aperture, which is then brought to the lowest position. Thus, the mass only is precipitated into the trough, and the balls remain behind.

Fig. 145.

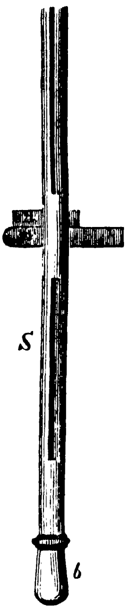


Fig. 146.

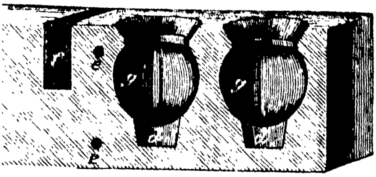
The saltpetre-flour is added to the mass thus prepared; and that it may be thoroughly mixed, and more finely pulverized, it is made to revolve just as long in another barrel, with tin instead of brass balls. The mass is then formed into cakes. It is first moistened with $\frac{1}{10}$th water, and made into a thick paste; this is spread 4 lines thick upon a copper plate, and covered with wet linen, upon which is placed a second layer, and so on, until a sufficient quantity has been prepared to be brought under an hydraulic press. The layers are there reduced by pressure to $\frac{1}{8}$th of their former thickness, which is easily done, if they are surrounded with wooden frames of the proper dimensions.

The bronze balls are subject to wear away in this excellent method of pulverization, (which is, in part, attributed to the chemical action of the sulphur upon them,) and they should be cast of as hard a metal as possible (4 copper to 1 tin).

Powder Mills with Stampers.—The old and still very general method of pulverizing, mixing, and pressing the mass, is that of the stamping mills, Figs. 145 and 148, in which all three operations are done at once, and on a large scale with pestles set in motion by machinery. The mortars *g g* are a series of nearly circular hollows, cut in a solid oaken block in which the pestles move up and down. These pestles are fitted with a bronze shoe *b* at the end, into which the rod is fixed, by driving up the wedge *c* and the shoe *b* at the same time. The stampers are moved by the cogs of a wheel catching the cross pieces *m*, which are fixed into *a* by the wedges *n*. It is well known that wood offers much less resistance in a cross direction to the fibres, than in the same direction with them; whilst, in the former position, the fibres easily split away; they wear out much less rapidly in the latter. From the position of the mortar-block, the blows of *b* would naturally fall across the grain; for this reason a piece of hard wood *d d* is inserted at that part. To give greater strength to the block, it is surrounded with strips of metal *f*, and holdfasts *e e*, which must all be covered with wood, that no sparks may be struck. The form of the stampers, and of the mortar, is by no means a matter of indifference, as the uniform mixture of the ingredients of the paste is mainly dependent upon it. When both parts have the form represented in the figure, the mass is then squeezed by every blow towards the sides, rises higher and higher, until at last it bends over and comes again under the stamper. The mortars are 14 inches in diameter, and 9 inches at the mouth; they are placed 17 or 18 inches apart from centre to centre. A mill has generally two rows, each consisting of ten mortars. The stampers weigh 80 lbs., the half of which weight is that of the bronze shoe, which is composed of an alloy made up of 100 copper to 22 tin; the other half is the weight of the rod, which is grooved to prevent its being too heavy. The vertical motion is kept up by two parallel beams of the wood work, between which the stampers move up and down. When a wooden bolt is inserted in the hole *v*, at the highest position of the stamper, this remains supported by the cross beams, and the cogs of the wheel no longer touch it; each single stamper may thus be put out of action.

Fig. 147.

Fig.



In weighing the mixture, it is divided into portions of 20 lbs. each, that being the quantity worked in each mortar. Saltpetre and sulphur are placed in one vessel by themselves, the carbon in another, apart. The process begins with the pulverization of the latter. All the mortars are first charged with charcoal, which is thoroughly moistened with somewhat less than an equal quantity of water. The stampers are then set in motion. These are raised twice by each turn of the wheel, and to a height of 1½ feet, giving about sixty blows per minute. In twenty or thirty minutes the charcoal is reduced to a soft paste. The machine is then stopped, the charcoal thrown out upon the sides is carefully scraped back into the mortars, and the saltpetre and sulphur added with about ½ as much water as was used before. It is quite impossible, by the mere action of the machine, to obtain a perfectly uniform mixture, for this reason, that a crust always attaches itself to the bottom of the mortar, which, inasmuch as it no longer follows the course of the other parts of the charge, cannot be thoroughly powdered or mixed. The workmen must, therefore, lend their aid. To ensure a thorough mixture, it is necessary to exchange, from time to time, the contents of the mortars with each other. In this operation, all that has attached itself to the sides is carefully scraped out, and so much water added as is considered sufficient by the superintendent to retain the doughy consistence of the mass. It is evident that the proper motion of the charge in the mortars, must depend upon this state of humidity; if the charge is allowed to be too wet, it will cling with excessive tenacity to the sides of the mortar;

and if too dry it will be easily thrown out. The first exchange is made after 2000 strokes of the stampers, and the following after each 4000. The contents of the first mortar is scraped into a spare vessel, that of the second into the one which has been first cleared, that of the third into the second, and so on, until lastly, that contained in the spare vessel is emptied into the last. To save time, the first and sixth are emptied at the same time. After the last exchange, the stampers are allowed to work without interruption for two hours, to give density to the mass. The whole process in the mortars lasts fourteen hours, four hours of which time are employed in transposing the charges. When the pulverization has been previously effected in the drums, and the mixing and thickening have only to be done by the stamp-mills, the requisite time is, of course, proportionately shortened.

In Italy heavy metallic mortars are used; in Switzerland, for instance, at Bern, where a celebrated kind of powder is made, hammers moved by water power are employed instead of stampers.

Powder-mills with edge-stones.—The method in which edge-stones are used in the mills is very different from those yet described. This apparatus is the same as that employed for crushing oil seeds, &c. Two upright stones turn upon a common horizontal axis, which again, together with these two stones, turns upon a vertical axis placed in the centre of the round flat bed-stone. The edge-stones are hewn from a kind of stink-stone, like the French stone found near Namur, or are constructed of marble, copper, or as in England, of cast iron, and, to avoid sparks, enclosed in a ring of bronze. The diameter of these edge-stones is 6 feet and less, up to 10 feet; their weight from 50 to 100 cwts.; but they are sometimes above and sometimes below that weight. They revolve from eight to ten times per minute, and carry a wooden scraper behind them, to bring back that part of the mass which has been pushed aside, into the track of the stone. When one of the edge-stones is brought nearer to the vertical axis by the length of its own thickness, than the other, that part of the mass which is squeezed by the one stone into the interior, will then come exactly into the course of the other. The action of these stones is much more appropriate than that produced either by the mortars or drums, as will be easily understood by considering the kind of motion which they undergo. This motion is first a rolling motion round the horizontal axis, by which the stone acquires a tendency to roll on in a straight line (with the tangent). This tendency is counteracted by the revolution of the whole round the vertical axis, which every instant forces the stone away from the straight direction, and gives it a circular motion. Hence two actions are produced which obtain simultaneously at every instant: one, caused by the rolling motion, which merely crushes the matters, and another by the sliding motion, which tears them to pieces. Mills of this kind, therefore, unite the action of simple rollers with that of grinding mills in which the stones move in a horizontal direction. It must be admitted that the process is more dangerous with mills of this construction, but the powder is never ground in a dry state.

In the beginning, a more rapid motion is given to the stones, as the chief object is to reduce the mass to a fine powder. At a later period, when this has attained a uniform salve-like consistence, the velocity is slackened, that the stones may act more as a press, in order to give density to the mass. That it may not form too thick a layer, 40 or 60 lbs. should be the greatest quantity worked at once.

In Belgium and Germany the saltpetre and sulphur are crushed together under the stones, and the charcoal is then added in lumps. In England, the sulphur is ground by itself; the charcoal, together with the sulphur, both under different rollers, and the mixture is afterwards brought under the edge-stones. At Le Bouchet, in France, where the mill-stones are used principally for sporting powder, the pulverization is generally effected in drums, the mixing and thickening under mill-stones.

The object of making the Powder dense.—As the action of gunpowder, on being ignited, depends upon the enormous increase of space occupied by the gases, as compared with the original bulk of the powder, the action must necessarily be augmented in both cases, either by the increase of the amount of gas, or by the diminution of the original space occupied by the same weight of powder. This diminution in bulk is sought to be attained by pressing or condensing, and must necessarily be done at this period of the process, as the operations which follow can do nothing towards it. The condensing is considered of such importance, that machines have been invented especially for the purpose. These consist of three rollers, through which the mass is passed in endless cloths. One of these surrounds the two upper rollers, the other the lower one only. A funnel conveys the paste between the cloths, with which it passes through the rollers, and appears at the other side in the form of a cake, which breaks off by its own weight and falls down. The cakes are at first 8 lines thick, and are reduced to $\frac{1}{4}$ of their original thickness.

The Granulation, or Corning, why necessary.—All the processes here described, produce a cake which varies both as regards thickness and hardness; and this has now to be resolved into grains, as that is the only form in which powder can be used. The reasons for this are many, and are all of equal importance. Why lumps and larger pieces cannot be used requires no further notice: but it may be as well to state what advantages the granulated powder, first introduced by the French, has over the dusty or flour-like powder which was the only form in which it was known prior to the 14th century. In the first place, powder-dust is inconvenient to handle and colors too much; it affords likewise no guarantee for the constant relation of the proportional quantities in the mixture. Again, when exposed to long carriage, not only would a larger portion be dispersed as dust, but the saltpetre and sulphur, which are much heavier, would sink to the bottom of the boxes or sacks, whilst the lighter charcoal would be left at the top.

Moreover, experience has shown that a mass in dense grains attracts much less moisture than when it it is in the form of fine dust. And lastly, the less degree of inflammability of the fine dust is a material point, *i. e.* when two equal charges of dust and grain-powder are fired, the latter burns much more rapidly, and has a proportionally greater action. In a mass of powder, the combustion proceeds, although with extreme rapidity, from particle to particle. This takes place either by means of the red hot matters themselves, in which case it is much more slow, or by means of the flame, provided sufficient space is left for it to penetrate the mass. The former is the case with dust, the latter with corned powder; when, therefore, only a few grains of the latter are ignited, the same action will result, on account of the flame spreading through the charge, as if the remainder had been ignited at several places simultaneously. According to the experiments of Piobert, with powder of density = 1.5, layers of 5.2 to 8 lines in thickness can be inflamed in a second, whilst with dust or meal powder these layers cannot exceed 3.6 lines. The same is proved by the experiments made with percussion caps; for the same charge carries farther when fired by a cap than when flint and steel are used. Percussion caps, therefore, effect a saving of powder for the same range; for the flame, which upon the old plan with flint and steel, chiefly acquires an outward direction, can only escape when percussion guns are used, from the cap to the interior, or in the direction of the charge; it therefore penetrates with great velocity the interstices between the grains, and ignites in the same time a much greater proportion than could possibly be ignited by the spark from flint and steel. The action is, therefore, increased in a similar manner as would have occurred, if the charge had been fired on the old plan from several touch-holes at once. Connected lumps of powder offer the greatest obstacle to the penetration of the fire; this is the case to such an extent, that powder in that state burns with a great evolution of sparks, without giving rise to a powerful explosion. With coarse grained powder the explosion is, therefore, weakened and less sudden. These facts are all known and are attended to in the adaptation of powder to fire arms. For sporting purposes, where the barrels are most carefully made of the purest and toughest iron, and consequently offer the greatest possible resistance, a more rapid explosion need not be feared. Sporting powder has consequently the finest grain. Cannon, on the contrary, are made of a brittle material, which would more readily burst from any sudden explosion. Cannon-powder is generally made very coarse in the grain, and musket-powder is intermediate between the two.*

Ordinary Process of Granulation.—The granulation consists in crushing the cake of powder into grains of about the size of coarse sand. Three kinds are always obtained, namely: grains of too large a size, such as have the right dimensions (in several gradations), and dust; these are separated from each other by sieves. It depends upon the use to which they are destined, whether these three kinds must be separated or left mixed, as they are in blasting powder. In the ordinary process, the cake is broken up with hammers and then

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* Diminished quantity may replace coarseness of granulation, as will be seen below in a note (p. 376) relative to Capt. Mordecai's experiments.—Am. Ed.

brought upon the *shot sieves*, which serve rather to convert the lumps into grains, than to separate these latter from each other. The sieves are made of parchment or leather, in which round holes of uniform size are accurately pierced. A lens-shaped disc of hard wood is placed upon the sieve together with the cake, and is sometimes weighted with lead, a rotary motion is given to this by the workman, and the lumps of cake are crushed with a slight pressure until the grains are small enough to pass through the holes of the sieve. Sieves of brass-wire and others of hair separate the coarser grains and the dust from the proper sized grains.

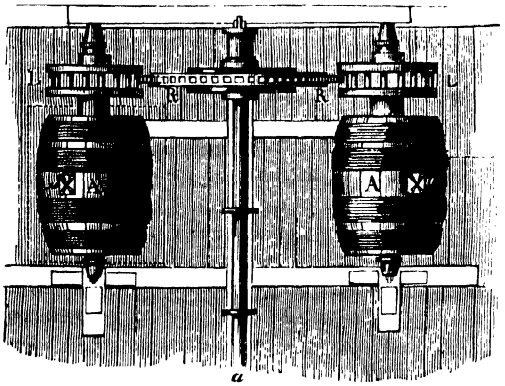
Sporting powder, which realizes a higher price and admits of more costly apparatus being used in the manufacture, is granulated in France by a separate machine, consisting of eight sieves, set in motion at the same time, each of which granulates independently of the others. Leather pipes convey the dust to a separate box. If sieves with such narrow holes were used in the first instance, which would only admit of grains of the proper size and dust passing through, too much of the latter would be obtained. For this reason wider sieves are chosen which allow a mixture of coarse-grained powder, sporting powder and dust to fall upon a second sieve; the two latter pass through this, but the coarse-grained powder is carried back by an ingenious contrivance to the upper sieve. The crushed mass is kept in constant and rapid rotary motion, whilst a scoop of copper is made to project into the sieve and oppose itself to the current, in the direction, therefore, of the tangent, towards which the centrifugal force tends to throw out the grains. These, therefore, collect in the scoop, and with the existing velocity are carried back into the first sieve. In the same manner, the proper sized grains are carried from the machine into leather bags.

Process of Champy.—It would be foreign to our purpose to describe all the apparatus and machinery invented and employed in different places, but not generally adopted, for the granulation of powder; yet it may be noticed that all these contrivances only afford angular and irregular grains. The process applied at Bern makes, however, an exception, and has been introduced with some alterations by Champy in Le Bouchet for the manufacture of blasting powder. The granulation is here effected in quite a different manner. Through the hollow axis of a rotating wooden drum, the exit tube of a water cistern passes and terminates in the middle in a finely perforated rose, which sprinkles a thin rain over the powder dust, with which the drum is filled. Each drop then forms the centre of a small but perfectly round grain, which may be increased to any desired dimensions. The separation of the dust and the larger grains is performed in the usual manner with sieves.

Glazing.—Angular powder can also be rounded by a subsequent process, *glazing* or *polishing*, the only object of which is to render the surface of the grains firm and shining, and prevent the powder from imparting color to the touch. Sporting powder is always glazed, but war powder in some European States only, as the other advantages attending it are very problematical.

A successful glazing operation requires that the powder should be moistened to a certain extent, which may be attained by previously drying it partially in the sun, or with greater certainty by mixing a portion of dried powder with a sufficient quantity of the same kind undried. In this state, it is admitted through the flaps *u u*, into the revolving barrels *A A*, Fig. 149, which are turned by a toothed wheel, *R R*, fixed to the long axis *a* of a water-wheel, and the shafts with drum-wheels *L L*. Too much velocity would destroy the grains instead of polishing them, and the barrels must only rotate sufficiently to cause the grains to roll over each other, and become polished by attrition. The barrels should only be ⅓ or ¼ full, so that a barrel 64 inches long and 48 inches in diameter may contain 2 cwts. of powder; 4 rods are also fixed in each cask from end to end to increase the friction.

Fig. 149.



At first the barrels are caused to revolve slowly, and the velocity is gradually increased. In France, for instance, where the glazing process lasts 36 hours, the barrels revolve in the first 12 hours, from 9 to 10 times, in the second 12 hours, 30 times, per minute; and in the last 12 hours, the velocity again diminishes. In England, the rotation is also slow at first, then for 5 hours, 38 revolutions are made per minute, in the next 3 hours, 20 revolutions, and at last during 2 hours the rotation is very slow. The diminution of velocity at last is necessary to cool the powder, which becomes warmed up to 50° or 60° (122° or 140° F.), and in this state would lose much of its polish when exposed to the air. Glazed powder absorbs less moisture from the air, and can be better preserved, but with the firmness of its surface, the inflammability is diminished. For this reason, in Austria, the powder is removed from the barrels in about 8 or 10 hours, when it has acquired a dull lustre. It is remarkable, that the less degree of inflammability noticed above, is compensated by greater density, and this increases with the humidity of the grain employed. Experiments made at Le Bouchet have proved this fact very clearly; it was found, that when compared with the weight of an equal bulk of water, the weight of a certain bulk of powder was:

Before glazing	0.810
After 4 hours' exposure in the barrels	0.833
" 8 " " "	0.846
" 20 " " "	0.869
" 25 " " "	0.870

After 30 hours' exposure in the barrels .	0.889
" 42 " " . .	0.893

The drying.—All freshly corned or polished gunpowder is too moist for immediate use, and must consequently be dried. It is of consequence, that the firmness of the grain should not be destroyed by too rapid drying, and for the production of powder that does not easily absorb moisture from the atmosphere, slow, gradual desiccation is an important point.

The proper temperature for drying is obtained in the open air by exposure to the sun, or in the shade; but this practice is inconvenient on account of the changeableness of the weather, and the hygrometric state of the atmosphere. Powder spread out upon drying cloths in layers of 1½ to 3 lines in thickness, and occasionally turned over, requires four hours to dry in the sun at a temperature of 60° to 70° (140° to 158° F.), and nine hours in the shade where the temperature does not rise above 25° (77° F.). A decidedly safer plan is to dry the powder in a chamber heated by steam, in which the temperature is at first 19° (66° F.), and gradually rises to 50° (122° F.). But the most effectual plan of all is unquestionably that practised in France, where the necessary heat is applied, and care is taken to conduct away the aqueous vapor by proper ventilation. A ventilator drives a current of air through a box, where it is warmed by steam pipes traversing the box, and then permeates the woolen cloths, containing the layers of powder 1½ inches in thickness, which form, as it were, the lid of the box. In this manner, fresh dry air is passed every instant between the grains.

The finished powder is packed either in sacks, which are placed in casks, or in double casks, the inner one of which is pasted over with paper; or lastly, in tin canisters (sporting powder). For naval purposes, copper boxes covered with wood are employed. These packages always hold quantities consisting of 1 cwt. or less.

The outward appearance and character of the powder afford a pretty safe criterion by which to estimate its quality. It is generally slate-colored, dark bluish gray, more brown when the powder has been made from distilled charcoal. A pure black color indicates either too much, or too hard charcoal. The color must, in every case, be quite uniform; light spots, or glittering points, visible with the magnifier or the naked eye, prove a want of uniformity in the mass. This may have been caused by bad preparation from the beginning, or by the efflorescence of the saltpetre on the surface, when moist powder has been re-dried. Properly dried powder, freed from dust, ought not to color the hand or paper; it must give a grating sound when squeezed together; the grains should be difficultly crushed, and on being ignited in the open air, as little residue as possible should remain. Burnt upon paper, the paper ought neither to be much blackened nor burnt.

Another very important property of powder, its density, has already been noticed. With reference to this, it must not be overlooked, that it is not so much the sp. gr. of the single grains that is of consequence—although this, by the way, is closely connected with it—as the weight of the quantity of powder which is necessary to fill one measure (for instance, 1 litr. or 1 cubic foot). Now, as two opposite properties depend upon this density, *i. e.*, the relative quantity of gas produced, is augmented with the density, whilst, at the same time, the inflammability is diminished, it is necessary to keep a proper mean between the two. Ure found in four samples (see below) the spec. gr. (of the single grains) to be 1.793—1.800, and that 1 volume of powder of the first kind weighed 1.02 times as much as an equal bulk of water, the same quantity of the second 1.03, of the third 0.99, and of the fourth 1.05 times as much.

The inflammability of dry powder by a mere blow without fire is a well known fact, and has more than once been the cause of accidents. That this property is not always due to an accidental admixture of other matters, as sand, &c., but is really a property of the powder itself, was proved by the experiments instituted at Freiberg with blasting powder made from chemically pure ingredients, namely 63.3 saltpetre, 20.0 sulphur, and 16.7 charcoal. Out of ten samples, which were wrapped in paper, and struck upon an anvil with a heavy hammer, seven of the corned powder exploded, and nine of the powder in the form of flour. Other kinds of powder behaved in the same manner. It is of importance, in the construction of powder mills, to know that the explosion occurs most easily by a blow from iron upon iron, iron upon brass, brass upon brass, even from lead upon lead, and lead upon wood, but not so easily from copper upon bronze or upon wood.

Although powder contains all the requisites for combustion, (not only carbon but also oxygen,) yet it does not take fire at temperatures below a red heat. When the heat is cautiously and gradually raised, the sulphur first melts, and at last burns at a temperature of 150° (302° F.), as if it alone were present, and thus communicates the flame to the other constituents of the powder. If the air is withheld, and the heat is applied to the powder in a vessel void of air, the sulphur can not only be melted, but entirely distilled over. After the separation of the sulphur, the residue is affected as usual by the increase of temperature, the saltpetre melts, and is at last decomposed by the charcoal. Any sudden rise of temperature causes an explosion, just as if the experiment were made in the air. Powder is most rapidly and surely ignited by the contact of red hot bodies, such as sparks of iron from a galvanic battery, glowing tinder, or when surrounded by a very hot flame (percussion caps). The phenomena observed by Hearder, not only with gunpowder, but with other similar mixtures, are exceedingly remarkable and difficult of explanation, should they be hereafter confirmed. He found, that powder exposed in vacuo to a platina wire heated to redness by the passage of an electrical current, was not ignited. The sulphur melted and volatilized, just as if the powder had been slowly heated from below. A small quantity of air left in the vessel was sufficient to cause the explosion. The same occurred, and even more quickly, when nitrogen only was present, so that it would appear as if the ignition were dependent, not merely upon the presence of oxygen, but upon that of some gaseous body.

It has been shown, that, by the rapidity with which powder is ignited under ordinary circumstances, its action is dependent partly upon the relative proportions of its ingredients, but more particularly upon the mechanical nature of the mixture, and the character of the grain. That kind of powder may be called the best, which does not ignite too rapidly, and in which the ignition is nevertheless complete, before the gases produced have had time to escape, *i. e.*, before the ball has left the barrel. Powder is often met with, which, from being badly prepared, burns too quickly, and is dangerous, from its tendency to burst the barrel of the gun. It is of the same character as the so-called detonating powder, a mixture of 3 parts saltpetre (3 equivs.) 1 part carbonate of potash (2 equivs.), and 1 part sulphur (5 equivs.), which explodes with a fearful report, and blows the strongest vessels to pieces. Its composition is such, that sulphate of potash is formed with the evolution of nitrogen and carbonic acid, for: $3\,KaO, NO_5 + 2\,KaO, CO_2 + 5\,S = 3\,N + 2\,CO_2 + 5\,KaO, SO_3$. The quantity of gas produced (nitrogen and carbonic acid) is less than in ordinary gunpowder, and the danger lies in the manner of its evolution, which occurs in a single second, and is consequently too sudden.

Force of Powder.—The knowledge of the force exerted by ignited gunpowder—a force capable of blasting the firmest rocks, and of propelling a four-and-twenty pound ball with greater velocity than that of sound*—would, doubtless, be a very important addition to science, and to the practice of artillery and blasting; unfortunately, however, the only two methods of ascertaining this, calculation and direct observation, are equally uncertain. By this force, we understand nothing more than the pressure, exerted by the gases evolved on ignition upon the bodies in their immediate vicinity (the sides of the barrel). To calculate this force, and compare it with the pressure of the atmosphere, it would be necessary to know:

1. The quantity of gas produced from a given amount of powder,
2. The temperature of combustion, and
3. Whether the gases at that high temperature expand in the same ratio as at lower temperatures.

Of the two latter points we know literally nothing; it may, however, always be assumed that the temperature is at least between 1000° and 1200° (1800° and 2160° F.) Of the amount of gas produced, we are equally ignorant. Although it may be calculated what amount of space the nitrogen, carbonic oxide, or carbonic acid of a given charge of powder will occupy, yet it must be borne in mind, that the powder always contains moisture, and that the aqueous

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* Sound travels at the rate of 1130 feet, the ball at the rate of 1404 feet in the first second.

vapor,* and the products of decomposition to which it gives rise with carbon will exert an influence, as well as the sulphuret of potassium, which, doubtless, assumes the form of vapor at that high temperature. To what extent the volume of gas is augmented by the aqueous vapor and sulphuret of potassium, it is not possible to estimate. These irregularities explain why such different results have been obtained, on collecting and measuring the gas; thus there have been obtained from 1 measure of powder:

Robin.	Saluces.	Hawksbee.	Gay-Lussac.	Brianchon.
244	264	232	450	400 measures of gas,

which gas, being measured cold, does not include any aqueous vapor or sulphuret of potassium.

Besides, there are two other influential circumstances which cannot be included in the calculation. The first of these is the air, which is enclosed with the charge, and expands by the heat with the other gases evolved from the powder, and augments the action to such an extent, that when the pellet or the ball is not tightly rammed down, the barrel often bursts; in blasting, this circumstance has been made use of with a great saving of powder;† the second is, that all the powder is never consumed, but partly expelled with the ball. Rumford has shown, that a ball of powder (instead of a leaden ball) placed upon the charge, will penetrate several sheets of stretched paper, and generally without any appearance of ignition. If a piece of red hot iron is dropped into the barrel of a pistol, and upon it powder balls of this kind, they are projected like luminous balls into the air; for, by the combustion of one portion, the remainder is propelled before it has time to take fire. Hence, it appears, that no accurate calculation can be made for the force of ignited powder, nor for the quantity of gas produced by it. Nevertheless, approximate estimations of this kind are well calculated to demonstrate the cause of the effects produced by powder. War powder, according to p. 353, produces theoretically 296 volumes of permanent gas, blasting powder 356 volumes. Suppose the temperature of combustion to be 1200° C. (2160° F.), and the expansion to take place in accordance with known laws, then, at the temperature of 1200° C., war powder would produce $296\,(1+.003665\times1200)=1597$ volumes of gas; blasting powder $356\,(1+0.003665\times1200)=1922$ volumes; in the first moment, when these are compressed into the space of 1 volume, they will exert a pressure of 1597 and 1922 atmospheres, which will, however, rapidly diminish with the decreasing resistance. To project a 12 inch ball 19720 fathoms from a marine mortar, 30 lbs. of

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* Rumford took great pains in his time (1800), to prove the unfounded assertion, that the action of powder depended solely upon its moisture, *i. e.* upon the sudden formation of aqueous vapor, according to which, there would be none but steam guns and steam cannon.

† To form an idea of the extent of this saving, the cost of blasting must be known; thus, for instance, in erecting water-works at Philadelphia $12000 were expended in powder; in cutting through the Carlton Hill, at Edinburgh, $6000. Even in common granite quarries, a single charge of powder often costs from 18 to 20 dollars.

powder = ½ a cubic foot will be required, which, according to this calculation, would produce on ignition 798 cubic feet of gas.

With reference to the determination of the force of gunpowder by observation, we have to thank Count Rumford for a series of experiments instituted at Munich in the year 1800. He endeavored to determine the weight with which the mouth of a very massive gun must be closed, in order to prevent the escape of the gases evolved from the powder. This weight would then be in direct proportion to the pressure exerted against the section of the mouth, and would thus furnish a means of ascertaining that pressure. To ensure the greatest accuracy, the gun was fired by inserting the barrel into a piece of red hot iron, which closed at the same time the touch-hole. Nevertheless, great discrepancies resulted. In one case 17 grains of powder, in another 11¼ grains were, required, to produce a pressure equal to 9431 atmospheres.* When the weight was lifted in these experiments, it always occurred with a powerful report; when, on the contrary, it was sufficiently heavy to retain the gases in the barrel, on lifting the weight by a lever, a remarkably small quantity of gas escaped with a very slight noise; the products of combustion were found for the greater part condensed on the inner sides of the barrel, in the form of a hard, coaly, difficultly inflammable mass. It is evident, that no accurate results can be expected from this method.

Although theory is not capable of estimating the force, or what is the same thing, the quantity of powder necessary to produce a certain effect, long experience has established the relative quantities of powder which are necessary, under different circumstances, with sufficient accuracy for all practical purposes. These different circumstances are always of the same kind with reference to artillery, where the range is the only thing that varies; whilst in blasting they are very various, loose earth has frequently to be blown up, and at other times, solid rock; sometimes the object is to destroy and hurl the fragments to a distance, and at others to get rid of them in a manner as little dangerous as possible, as for instance, in cases of civil engineering. For the latter purposes, the use of powder has very much increased since the introduction of railroads has given occasion to so many excavations, and since the use of the galvanic battery in igniting the charge, has rendered the operation so free from all danger, and removed all chance of failure from the modes of blasting under water. A few examples will serve to illustrate the magnitude

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* An experiment, in which the barrel burst into two pieces, with a charge of $\frac{1}{10}$th cubic feet, was used by Rumford as a means of ascertaining the force generated by the powder. He calculated, from the size of the fractured surface, and the known weight which is required to rupture iron wire of a given thickness, that the pressure under which the barrel burst was equal to 412529 lbs., or 35000 atmospheres. But the conditions here, are quite different from those in dissevering the wire, inasmuch as the air was heated, and very unequally heated, and the bursting of the barrel could hardly take place at all parts at once, but probably proceeded from one part in particular, so that the force was exerted in the manner of a lever, and under much more favorable circumstances than is the case when wire is ruptured. The calculation is therefore probably very much too high.

of such operations, and bear witness to the successful result of the undertakings.

The line of railroad coming from Folkestone, after passing several viaducts, tunnels, and cuttings, traverses the Abbot's Rock Tunnel. To reach from thence Shakspeare's Cliff (near Dover) in a direct line, the projecting rock at Round Down, an immense mass of chalk, which exactly intercepted the line, had to be removed. The project for removing this rock, which occupied the space of 2400 cubic fathoms, and weighed one million tons, by one single blast, was successfully carried out by Mr. Cubitt. For this purpose, a channel, 36½ fathoms long, was made in the direction of the railroad, and perpendicular to this, three shorter side channels. At the end of each side channel, a perpendicular shaft was sunk to the powder chambers, each of which was 13.4 ft. long, 6.1 ft. in height, and 5.5 ft. broad. In the chamber towards the east, 5510 lbs. of powder (50 barrels) were placed, in the middle chamber 7714 lbs. (70 barrels), and in the west chamber 6612 lbs. (60 barrels), together, therefore, in the three chambers, 19,836 lbs. of powder. The thickness of the mass of rock from the middle chamber was 85.4 ft., from the two others 67 ft. At the back of the rock, in a perfectly secure situation, a very powerful galvanic battery was placed under a shed, the covered copper wires of which, extending 1219 ft. over the top of the rock to the chambers below, and always resting on the ground, terminated in very fine platina points in the middle of the mass of powder. By making connection with the battery, these points were brought to a red heat, and the enormous charge of powder ignited in the same moment. When all was arranged, care was taken to stop up the entrances to the chambers with dry sand. Besides the charge of powder, a considerable quantity of air was enclosed in the chambers. It would have been quite contrary to the desired result to have actually blasted the rock into the air, or hurled the fragments about with a great loss of powder; the only object was to separate the mass of rock, and allow it to roll into the sea. The accuracy with which the necessary quantity of powder had been estimated, was proved by the wonderful success of the experiment. After firing the powder, neither smoke was evolved, nor report heard; no other noise than that occasioned by the tearing asunder of such an immense mass of chalk, was audible to announce the result. The blasted portion of the rock, 500 ft. in breadth, began to sink, and slide gradually into the sea, which was distant 36 fathoms. In four or five minutes all was over. That which was here effected by the force of powder in an instant, would otherwise have taken six months' labor, and have cost $35,000. The circumstances attending the explosion, the absence of smoke and report, prove that the charge was just sufficient to overcome the resistance. The gases evolved had sufficient power to sever the mass of rock, without being able to force a passage for themselves at the moment. The same occurred, therefore, here, as in Rumford's experiments, in which neither smoke nor report was perceptible. In both cases, the sulphuret of potassium, and the nonpermanent gases, had time to condense, and the other gases to cool, before the walls of the chambers gave way. In most cases, for instance, in shooting with guns or cannon, the sulphuret of potassium is condensed by the cold air, and forms the smoke; the forcible expulsion of the other gases occasions the report by the vibrations of the air. A second combustion also ensues when the hot sulphuret of potassium, and the combustible gases come into contact with the air (p. 350); sulphate of potash, carbonic acid, and water, are formed with the flame which is always seen at the mouth of the barrel.

The blasting of the Royal George, a ship of the line, is not less interesting. This vessel was sunk whilst repairing, about sixty years ago, in the harbor of Spithead, through the obstinate ignorance of a lieutenant, in water of 90 fathoms, and as a wreck, rendered the otherwise excellent anchorage unsafe. After some smaller experiments, at first with 198 lbs., and afterwards four successive times with 49½ lbs. of powder, had been partially crowned with success, Colonel Pasley caused, on the 22d of September, 1839, a cylinder containing 2552 lbs. of powder, to be fixed to the firmest part of the wreck by the divers. From the well-protected cylinder the conducting wires, covered with a mixture of pitch and tallow, ascended to the surface, and from thence to the galvanic battery, situated in a boat at a distance of 500 ft. The protection against the water is so complete, that a charge may be ignited in this manner after having lain under water for ten days. Explosions under water are never accompanied by a report, for reasons already mentioned; smoke can still less be produced. This was also the case here: three or four seconds after firing, the water was seen to rise in the form of a beehive to the height of 30 ft., it then spread itself out in the form of a sheaf, and lastly, sunk together in numerous muddy rings of waves. On the ships in the neighborhood a shock was felt, as if from an earthquake. The wreck was, in great part, shivered to pieces. The remaining portion was, afterwards, removed in the same manner, May 12th, 1840, by the same engineer. On this occasion, the cylinder with 2328 lbs. of powder, was attached to the keel. The result was similar, but the sheaf of water only rose to half the height, although the shock communicated to the water was greater. When the water had settled down, dead fish and fragments of the wreck were seen floating on the surface; even butter and tallow candles, from the stores of the wreck, were taken up.

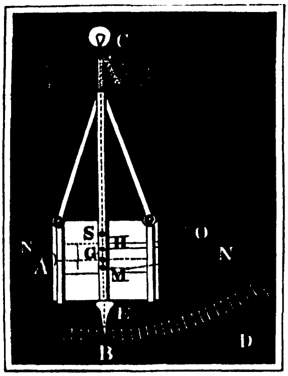
Methods of Testing the Force of Powder.—For practical purposes, chiefly connected with military operations, it is necessary to obtain a thorough knowledge of the force of powder by actual experiment. By this means we are enabled to determine, *à priori*, the action of fire-arms, and to compare the effects of different kinds of powder with each other. The instruments used for this purpose, are called *powder-triers* ("*eprouvettes*"). On firing a charge, not only the ball is set in motion, but also the barrel, and whatever is attached to it. Each time that a cannon is fired, the cannon itself is thrown back several feet, and its motion is slight only because its mass (weight) is exceedingly large as compared with that of the ball. In the different powder-triers, which, in fact, are only small cannon or mortars, both motions are measured in estimating the force of the powder, viz.: that of the ball, as well as the backward motion of the barrel.

By the method of proof employed in Austria, the height is measured to which a certain weight, inserted between two graduated rods, is raised, on being fired from the mouth of a mortar with a given weight of powder. With the *testing-mortars*, on the contrary, the distance is measured to which a ball of known weight is thrown, when the mortar is inclined at an angle of 45°, and loaded with a certain charge of powder.

The *pendulum-test* differs from these, and can be performed in two ways. The barrel is either suspended as a pendulum, which is then moved by the retro-active impulse, or the ball is fired from a barrel at the side, and lodged in a box containing sand suspended as a pendulum. In both cases, the arc has to be measured, which the pendulum makes on receiving the shock.

[*The ballistic pendulum*, or *the pendulum of Robins*, consists of a mass *MH*, turning about a horizontal axis *C*, Fig. 149½, which is set into oscillating motion by a ball *A* projected along *NN* against it, which serves for the measurement of its velocity. *M* is its centre of oscillation, of which the path is *M O*. That as inelastic a blow as possible may ensue, there is an opening made on the further side, which from time to time is filled by fresh wood or clay, &c. The ball remains after each projection sticking in this mass, and oscillating in common with the whole body. For the measurement of the velocity of the ball, it is requisite to know the angle of elongation of this pendulum, on which account there is further a graduated arc *BD* applied, and an index *E* fixed to the centre of gravity of the pendulum, which slides along with the former.*]

Fig. 149½.



[* For extensive series of experiments on both cannon and musket pendulums, and on a great variety of powders, see the "Report of Experiments on Gunpowder, made at Washington Arsenal in 1843 and 1844, by Capt. Alfred Mordecai, of the Ordnance Department. Washington, 1845." Eight modes of proof or kinds of eprouvette were used, and in a table at pages 316, 319, is found a general view of the results, and comparative numerical values of each species of powder. It is there seen that a powder which had a larger proportion of saltpetre than any other of the 60 varieties tried, having in fact the constitution of 77 saltpetre, 13 charcoal and 10 sulphur, gave the highest average result. Its particles were exceedingly minute. It took 7281 of them to make a grain troy weight. It was highly glazed, and had been incorporated 5 hours in dust barrels, and 4 hours under heavy rollers. Its weight was 1047 ounces per cubic foot or 47 ounces heavier than water. Powder of the same constituents, and in all respects of the same character, except being granulated of the size of coarse cannon powder, of which it took only 9.2 particles to make the weight of a troy grain, gave results in all the modes of proof inferior to those of the fine powder. The average of the 8 modes of testing, proved that its relative force compared with that of the fine powder was as 867½ to 1000, or it was

The method invented by the Citizen Regnier, in the Year VII. of the Republic, and named after him, applies simultaneously both the backward and forward impulse. A small brass cannon is attached in such a manner to a freely suspended steel spring with two shanks, that it rests with its mouth against the one shank, whilst the back part is connected with the other shank by an iron fork. The one shank on firing, therefore, is moved by the forward impulse of the ball, whilst the other is effected by the backward tendency of the cannon, and both forces act in such a direction, as to cause the two shanks to approach nearer to each other. The amount of this approach, which serves as the measure, can be read off by means of the indicators upon a graduated arc.

The *hydrostatic proof test* is founded on the retrograde action: it is performed by means of a barrel fixed upon a swimming support. In consequence of the retrograde impulse, this is forced down into the water to a certain depth, which is then observed.

Analysis of Powder.—It frequently happens, when powder of good quality, but of which the composition is unknown, has to be imitated, that a sample must be analyzed. Thus R. Brandes has analyzed and compared a brownish black English powder from distilled charcoal, with a black powder from ordinary charcoal, from a mill in the principality of Berg, he found:

	English.	From Berg.
Saltpetre . .	75.40 . .	75.8
Sulphur . .	10.75 . .	8.5
Charcoal . .	13.00 . .	15.0

The method of determining the saltpetre in such experiments is always the same, whilst the sulphur and charcoal are estimated in a variety of ways. By softening the powder in seven times its weight of warm water, and well washing the insoluble portion, a fluid is obtained, which, evaporated and dried, gives the weight of the saltpetre, and the residue, when dried, gives the weight of the sulphur and carbon together. Gay-Lussac proposes to separate the two latter constituents, by mixing 1 part of dry gunpowder with 1 part of carbonate of potash, and deflagrating with 1 part of saltpetre, after the previous addition of 4 parts of common salt, to prevent too sudden an evolution of gas, or loss by projection. In the clear solution of the fused mixture, the whole of the sulphur is contained as sulphuric acid (sulphate of potash), and can be precipitated by chloride of barium,

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the mere effect of coarse granulation rendered 13¼ per cent. less effective than if it had been in the finer state of granulation. In another case, cannon powder, of 7.7 particles to the grain troy, gave a force compared with the musket powder of the same manufacture, of which it took 113.4 grains to make the same weight—as 821 to 916. Loss from coarse granulation 10.3 per cent. In another case, the relative force of powder in particles so fine that 534.9 made a grain troy, was to that of the same powder so coarse that 11.1 particles only were required to make the same weight as 959 to 879. Loss from coarse granulation 8.2 per cent. In a fourth case, powder of 17.4 particles to the grain, gave a force of 850, and with 1160 particles, a force of 978, loss 13 per cent. Hence from 1/12 to ⅛ of the effective force of powder is lost by too coarse a granulation.—AM. ED.]

and its quantity determined. This method is much more tedious and complicated than that proposed by Berzelius, who heats the above residue in an apparatus with two glass bulbs, in a current of dry hydrogen. The sulphur then distils over without igniting, and condenses in the second bulb. When both bulbs are separated from each other by cutting, the weight of the sulphur and the charcoal can each be determined separately. This method is simple, but not very accurate; for some sulphuret of carbon is always formed, which is exceedingly volatile and escapes, causing a loss both of sulphur and carbon; the amount of loss in the latter, is also increased by the evolution of the volatile matter contained in it, principally in distilled charcoal, which escapes, and is lost.

Bolley obviates this evil, by boiling and washing the mixture of sulphur and charcoal, with a solution of 20 to 24 parts of sulphite of soda. What remains after this treatment is charcoal; the sulphur which is dissolved is calculated from the loss. This process depends upon the property of sulphurous acid (SO_2), of dissolving another equivalent of sulphur, and becoming hyposulphurous acid ($S_2\ O_2$), which remains in combination with the soda.

The amount of nitre may also be ascertained, according to Marchand,* by determining the nitrogen in the powder; a portion of the sample is weighed off, reduced to a fine powder, and intimately mixed with oxide of copper, and then filled into the combustion tube, which is charged posteriorly with carbonate of lead, and then with oxide of copper; oxide of copper and metallic copper are placed in front of it.

Marchand recommends the estimation of the sulphur as sulphate, in the following manner, 1 part nitrate and 3 parts carbonate of baryta are intimately mixed with $\frac{1}{12}$th of the gunpowder, and heated in a tube closed at one end. A layer, 3 to 4 inches in length, of the barytic salts is inserted in front of the mixture, and the whole is heated in the furnace for the combustion of organic substances, beginning with the anterior portion. The mixture does not fuse, and is easily removed from the tube, the latter is rinsed with dilute muriatic acid, which afterwards serves to dissolve the ignited mass. The liquid is retained in a beaker-glass for several hours at a temperature of nearly 212°, and the sulphate of baryta is then collected on a filter.

Sulphuret of carbon is often employed for removing the sulphur from the mixture of charcoal and sulphur. The gunpowder, after having been exhausted with water to remove the nitre, is treated with absolute alcohol which displaces the water, sulphuret of carbon, which has been rectified over oxide of lead, is then poured over it, until what passes through leaves no sulphur on evaporation. The powder is finally treated with alcohol. It is still better to use the sulphuret of carbon mixed with absolute alcohol; as soon as the charcoal is washed, a current of dry air is drawn through the tube by means of an aspirator, the tube itself being confined in an air-bath at a temperature

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* V. Journ. für prakt. Chem. xxxviii., p. 192, or Chem. Gaz., Oct. 1st, 1847.

of 248°. The dried charcoal may then be weighed. The nitre, which is obtained should be tested with nitrate of silver for chlorine, and the sulphur for arsenic, by washing with ammonia, and the addition of an acid. It is also important to determine the composition of the charcoal. The mixture of sulphur and charcoal obtained by exhaustion with water is burnt in a current of oxygen, or with chromate of potash, and the water and carbonic acid weighed. A tube containing peroxide of lead should be inserted between the chloride of calcium tube and the potash apparatus, in order to absorb sulphurous acid.

GUN COTTON.

Much interest and excitement have been caused during the last two years, by the announcement of a substitute for gunpowder, which is said to be four times more powerful than that substance, weight for weight, to ignite at a much lower temperature, to be uninjured by water, and to burn without smell, smoke, or residue. This substance is the gun-cotton of Professor Schönbein, to whom the entire credit is due, of discovering and making known the various useful purposes to which this remarkable body may be applied, although its actual discovery dates from a period prior to that when Schönbein published his experiments.

In 1833, M. Braconnot observed, when starch was heated for a short time in strong nitric acid, until complete solution had been effected, and the solution was poured into a large quantity of cold water, that a white pulverulent amorphous substance gradually subsided, which, on being dried, was highly combustible, and burnt without leaving any residue. This substance was called xyloidine.

M. Pelouze, in 1838, repeated the experiments of Braconnot, and found that paper, linen, cotton, and other ligneous substances, when submitted to the action of strong nitric acid (sp. gr. 1.5), for a few minutes, and then well washed with water and dried, possessed the same properties as xyloidine, without having lost, however, their original form and appearance. M. Pelouze was inclined to believe with chemists in general, that this was only another form of the same substance; he also threw out a surmise, that the substance might be applicable to certain useful purposes, especially in artillery. The same chemist, in conjunction with others, has, however, since shown, that these two substances are not identical. That the substance prepared by immersing paper, linen, cotton, &c., in nitric acid, contains more oxygen, and consequently more nitric acid than the xyloidine of Braconnot, and the name of pyroxyline or pyroxyle has consequently been given to it. The gun-cotton of Schönbein is probably this latter substance, or some body closely allied to it.

The plan adopted for the manufacture of this compound is as follows: cleansed cotton is immersed in a mixture composed of equal parts of concentrated nitric and sulphuric acids for about 10 or 15 minutes,* and in order to prevent accidents, no portion of the cotton should be above the level of the liquid. The acid should then be pressed out, and the cotton which remains impregnated with it is well washed with water, until no acid reaction is perceptible to the tongue; it is now dried rapidly at a temperature not exceeding 212° F. Care should be taken in drying this substance, to allow a free current of air to pass over it, and to spread out the cotton as much as possible, in order to prevent its forming into dense masses, which, according to Mr. Oxland, (see Chem. Gaz. for September 1, 1847,) are much more liable to explode. It is, indeed, probable, that the method of drying in stoves, practised at first in Messrs. Hall's manufactory, was the cause of the explosion which occurred there, and which cost several persons their lives.

No minute description of the mode of preparing gun-cotton upon a manufacturing scale has been published up to this period, and the foregoing notice, which indicates the plan practised by M. Susane at the *Direction des Poudres et Saltpêtres*, must suffice to give a general view of the process, which is no doubt carried out with slight differences, although the same in principle, in the different manufactories.

With regard to the composition of gun-cotton, nothing certain is established. The analyses which have been made of it, and which are numerous, do not accord, and tend rather to prove that several products may result from the action of nitro-sulphuric acid upon cotton, paper, &c., depending, amongst other things, upon the state of concentration of the acids used, the time of immersion, &c. The table below contains the results obtained by different analysts.

Substance analyzed.	Carbon.	Hydrogen.	Nitrogen.	Oxygen.	Analyst.
Cotton wool . . .	44.5	6.1		49.4	Pettenkofer.
Xyloidine . . .	36.76	4.79	5.65	52.80	Ditto.
Ditto	37.29	4.99	5.17	52.55	Ballot.
Gun-cotton . . .	27.43	3.54	14.26	54.77	Schönbein and Böttger.
Ditto	26.08	2.52	5.10	66.30	Pettenkofer.
Ditto	26.28	3.16	10.20	60.36	Ransome.
Ditto mean of 5 Anal. .	25.3	2.7	15.5	59.3	Hecker.
Ditto	20.0	2.22	15.56	62.22	Porret and Teschemacher.
Pyroxyline† . . .	26.66	3.70	10.36	59.28	Pelouze.
Ditto‡	26.23	2.73	12.75	58.29	Gladstone.

Pelouze considers pyroxyline to be the only product of the action of nitric acid upon cotton, and he also thinks the numbers given in the table above, sufficiently near approximations to the calculated results, to warrant the assumption that the body consists of 1 equiv. of

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* Schönbein recommends the use of 3 parts sulphuric acid, and 1 of nitric acid, of sp. gr. 1.5.

† Obtained by the action of nitric acid (sp. gr. 1.5) on cotton wool.

‡ Obtained by immersion in a mixture of 3 parts sulphuric acid, and 1 part nitric acid, of sp. gr. 1.5.

cotton + 2 equivs. hydrated nitric acid—1 equiv. water; its composition would then be expressed by the empirical formula:

$$C_{12}H_{11}O_{22}N_2 = \overset{\text{Cotton.}}{C_{12}H_{10}O_{10}} \quad \overset{\text{Hydrated nitric acid.}}{+2(NO_5, HO)} \quad \overset{\text{Water.}}{-HO}$$

Mr. Ransome deduces from his experiments the following formula for gun-cotton:

$$C_{12}H_8O_{20}N_2 = C_{12}H_{10}O_{10} - 2\,H + 2\,NO_5.$$

The formula for gun-cotton, deduced by Messrs. Porrett and Teschemacher from their experiments is $C_{12}H_8O_8 + 4\,NO_5$, and they are inclined to consider it a combination of nitric acid with lignin, as is indicated by the formula.

The properties of gun-cotton are very extraordinary. It is insoluble in water both hot and cold, and when removed and dried, is found to have lost none of its original properties; acids have also no action upon it, and this effectually distinguishes it from xyloidine. The best solvent for gun-cotton is acetic ether, and this substance may be used for rendering it perfectly pure.* It explodes violently when heated to 356° F., or on ignition, leaving scarcely any residue, and creating very little smoke. The temperature at which it is thus decomposed, is so much below that at which gunpowder explodes, that the cotton may be lightly placed upon the surface of gunpowder, and detonized by a red hot wire without setting fire to the powder. Friction of the ordinary kind will not explode gun-cotton, but when placed on an anvil, and powerfully struck with a hammer, the heat generated by the stroke causes it to detonate. The gases generated when gun-cotton is exploded, have been examined by Messrs. Teschemacher and Porrett, and found to consist of carbonic acid, cyanogen, nitric oxide, carbonic oxide, nitrogen, and the vapor of water. With reference to the projectile force of gun-cotton, as compared with gunpowder, official statements have been made public by Capt. Mordecai in this country; and there appears reason to apprehend that its action, in its present form, is too rapid, and resembles too much that of the fulminates, to render it applicable to the purposes of gunnery. The gaseous products from its combustion are also such as cannot be altogether resisted by fire-arms, although, if air be absent, no great amount of corrosion can ensue; and as it has been found, that gun-cotton impregnated with chlorate of potash or nitre has a still more powerful effect than that prepared in the usual manner, the addition of these substances would at the same time tend to modify the corrosive action of the acid products of combustion. As a substitute for gunpowder in all mining and blasting operations, however, the superior local force of the powder-cotton will be highly valuable; and it has indeed been found to effect as much as four times its weight of powder. In the pyrotechnic art it will probably also be extensively used, and paper prepared by the method of Pelouze, and moistened with solutions of nitrate of strontia,

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* [It may also be dissolved in sulphuric ether, and constitutes a transparent liquid which has been applied to the purposes of surgery, in dressing wounds.—Am. Ed.]

sulphate of copper, and nitrate of baryta, yields very beautiful red, green, and white fires.

AQUAFORTIS.—NITRIC ACID.

Nitric acid in a certain state of concentration, is called "*aquafortis;*" although this appellation is very generally given to all commercial nitric acid, without reference to its strength. A closer distinction is drawn between the acid with 40 per cent. water (specific gravity 1.42, and boiling point 253° F.), which is called "*double aquafortis,*" and the acid with ⅔ds water, which is that in common use. In these different degrees of concentration, the acid is used for many different purposes in the arts, particularly for the purification of gold, for etching copper plates, &c.

Theory of its Production.—All the nitric acid of commerce is obtained either from nitrate of potash, or from nitrate of soda, by means of sulphuric acid. The former, or ordinary saltpetre, contains only 53.4 per cent. of anhydrous nitric acid, whilst the latter, or Chili-saltpetre, on account of the smaller equivalent of soda, contains 59.6 to 63.1 per cent. In addition to this, Chili-saltpetre is the cheaper salt. The sulphuric acid, exerting its greater affinity, takes possession of the alkali in both cases, and the nitric acid is liberated. It should be borne in mind, that sulphuric acid can unite in two proportions with the alkali, and it is by no means unimportant which of these two is ultimately formed. Whether 1 or 2 equivalents of acid, to 1 of alkali are used, the bisulphate is always produced; but in the former case, with 1 equiv., the saltpetre is only half decomposed, whilst with 2 equivs., the decomposition is complete; this will be obvious from the following equation for potash saltpetre:

$$\text{2 equivs. hydrated sulphuric acid} \left\{ \begin{array}{l} HO.\ SO_3 \\ HO,\ SO_3 \end{array} \right. \text{ and } \left. \begin{array}{l} KaO,\ NO_5 \\ KaO,\ NO_5 \end{array} \right\} \text{2 equivs. saltpetre.}$$

produce:

$$\begin{array}{l} \text{1 equiv. bisul-} \\ \text{phate of potash} \end{array} \left\{ \begin{array}{l} KaO,\ SO_3 \\ HO,\ SO_3 \end{array} \right. \text{ and } \begin{array}{l} HO,\ NO_5 = \text{1 equiv. hydrated nitric acid.} \\ KaO,\ NO_5 = \text{1 equiv. (undecomposed) saltpetre.} \end{array}$$

The one-half only of the producable nitric acid is consequently obtained, and this distils over at a temperature of 132° (270° F.). If the temperature be raised still higher, a second decomposition ensues, the second portion of saltpetre being forced by the action of the bisulphate of potash, to relinquish its nitric acid. This acid, however, cannot resist the influence of the high temperature, and is resolved into oxygen and peroxide of nitrogen, which dissolves in the hydrated nitric acid already distilled, and forms *fuming* nitric acid. It has been found, when Chili-saltpetre and 1 equiv. of sulphuric acid are employed, that the temperature at which the second equiv. of nitric acid separates, is not nearly so high, so that only a portion of it is decomposed, and instead of fuming acid, a colored acid is obtained, which, by dilution with water, and a slight application of heat, may be easily freed from all peroxide of nitrogen, and converted into ordinary nitric acid. This constitutes a third advantage attending the use of Chili-saltpetre for the manufacture of nitric acid; the greater cheapness of the salt, and its greater amount of acid have already been mentioned.

With ordinary saltpetre, 2 equivs. of sulphuric acid are, therefore, absolutely necessary, and the decomposition occurs as follows:

Before decomposition.			After decomposition.	
1 eq. nitrate of potash	1 eq. nitric acid	→	1 eq. hydrated nitric acid.	
	1 eq. potash			
1 eq. hydrated sulphuric acid.	1 eq. water			
	1 eq. sulphuric acid	→	1 eq. sulphate of potash	1 eq. bisulph. of potash.
1 eq. hydrated sulphuric acid		→	1 eq. hydrated sulph. acid	

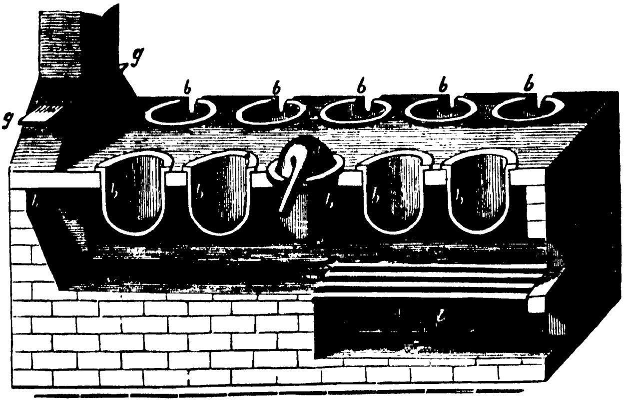
Adopting these proportions, which correspond with 96 to 97 parts of oil of vitriol to 100 parts of saltpetre, the whole of the nitric acid is obtained, and according to calculation, 100 parts of nitre ought to produce 62.25 nitric acid; somewhat more is in fact obtained, for the oil of vitriol contains rather more water than the proportion corresponding with the hydrate, and the saltpetre is always more or less damp, so that sufficient water passes off to produce eventually the second hydrate of nitric acid. It is not desirable to dilute the sulphuric acid, as the oil of vitriol contains the quantity of water required by bisulphate of potash and nitric acid. This, however, is not the case when Chili-saltpetre is used with 2 equivs. of sulphuric acid, for bisulphate of soda unites with 3 equivs. of water, and these it must obtain from the nitric acid, which is consequently decomposed. Water must, therefore, be added in this case, and the proportions best suited to prevent any overflow during ebullition are: 100 Chili-saltpetre to 117 oil of vitriol, and 30 of water. The production of bisulphate of soda being in this case unnecessary, as was previously stated, the simple proportions of 58 oil of vitriol to 100 of Chili-saltpetre may also be substituted for those above.

In consequence of the high price of oil of vitriol, clay was employed in former times, and at a later period green vitriol (see p. 245). In the former case, the silica in the clay effected the decomposition, but, as the necessary quantity of water was not supplied to give stability to the acid, which can only exist as hydrate, a great portion of it was lost by decomposition, the same occurred with green vitriol, the nitric acid being derived from the nitrate of iron, first produced, undergoing decomposition at a high temperature.

Distillation of Aquafortis.—In the manufactories of aquafortis, glass or earthenware retorts are used, or vessels of cast iron.

The retorts *a* are sunk in sand-pots *b b b*. The sand-pots are placed in a row in a so-called gallery furnace (*Galereenofen*) Fig. 150. A furnace of this kind comprises two firings with a common chimney, the damper of which is seen at *g*, separated by a thin partition. Above the ash pit *l* is the grate *o*, from whence the flame traverses the whole length of the furnace, heats the five sand-pots, and escapes into the chimney at *h*. The pots can be removed and replaced at pleasure, and the fire advanced to such a position as will communicate a uniform heat to the pots. On charging the retorts, great care is necessary to prevent any saltpetre or sulphuric acid from remaining in the necks, which would, if not removed, be carried into the receiver with the acid. The saltpetre which remains attached, is shaken into the retort by gentle tapping, and the sulphuric acid is introduced by a long necked funnel. The receiver should be kept cool by a stream of cold water, but as this is too troublesome, the use of water is dispensed with, and a very large receiver is employed that an extensive surface may be exposed to the cooling action of the air. When the charge begins to get warm, an empty receiver is applied, for the first portions of acid are very impure, and mixed with red vapors. These arise, partly, from the decomposition of a portion of nitric acid by dust, and organic matter which is always present, but are chiefly caused by the sulphuric acid. For, at the moment when the first portions of nitric acid are evolved, the whole of the sulphuric acid is not in contact with saltpetre, a portion is consequently free, this portion takes water from the nitric acid, and converts it into oxygen and peroxide of nitrogen. Another source of impurity is owing to the chlorides of sodium and potassium contained in the nitre, which evolve muriatic acid when acted on by sulphuric acid. This reacts upon the nitric acid, producing chlorine, nitric oxide (which, with the air in the retort forms the red vapors of peroxide of nitrogen) and water. The hydrate of nitric acid is decomposed to a slight extent, by mere distillation with the evolution of red fumes, which are never entirely absent, but soon after the commencement of the operation, they become almost imperceptible. At this period of the distillation, the receiver with the impure acid is exchanged for another, containing as much water as is required to bring the acid to the proper strength (40 per cent. of the saltpetre for acid of 1.4 sp. gr.). The heat must be cautiously applied at first, as the contents of the retort swell, and threaten to flow over. The pasty mass afterwards sinks down, and boils steadily at a temperature of

Fig. 150.



132° (270° F.), with a constant evolution of nitric acid. Towards the end, when the mass has become very stiff, and the heat can no longer permeate it uniformly, the sides of the retort become overheated, and cause the reappearance of ruddy fumes. The distillation should now be stopped, for very little more nitric acid passes over, even when the residue is brought into a state of fusion, and at this period it can be most easily removed from the retort.

The use of iron vessels was first introduced in France, and their form and mode of arrangement are similar to those adopted in the production of muriatic acid, when this is made the object of a special manufacture, and not obtained as a waste product.

The decomposing vessels are cast-iron cylinders—retorts with moveable lids, which are closed in the same manner as the gas retorts (p. 164). Each pair of retorts is fixed over a common firing, of which one furnace contains several, Figs. 151 and 152, and is surrounded by the flame which, reverberating in the dome, escapes by the flues *o*, to the common horizontal channel *p*, and from thence to the chimney. The cover of each retort is supplied with a mouth-piece ; the hinder lid and its aperture, situated above the door of the furnace, is for the introduction of the sulphuric acid; the front mouth-piece, or aperture, is for conveying the acid, by means of a tube, to the three-necked receivers of earthenware *A* and *B*. The tube must be of glass, that the color of the vapors may be observed, unless glass vessels are employed as receivers. The cylinders are adapted for 170 lbs. of saltpetre ; as soon as they are charged, the covers and tubes are luted on,* and the sulphuric acid is poured into the aperture *a*, which is then immediately closed. The fire must be regulated in a slow and uniform manner; the greater part of the acid is condensed in the first receiver, which is placed in cold water; whatever escapes from this is condensed in *B*. Safety-tubes are inserted at *c c*, to avoid any accidents, which, in consequence of too great condensation towards the end, might be caused by the atmospheric pressure, and in order that the air may escape in the beginning.

Fig. 151.

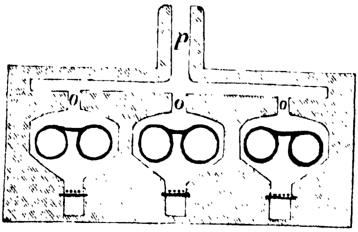
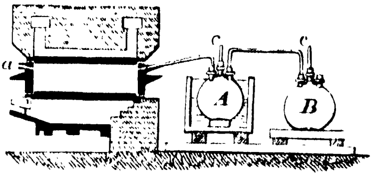


Fig. 152.



With an apparatus of this description, much acid may be obtained in a short time; it is, however, less pure, and accompanied by a greater quantity of the ruddy fumes, and the cast-iron, particularly in

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* The latter is formed of clay, linseed oil, and a small proportion of oil-cake meal, and may be long and repeatedly used.—Am. Ed.

the colder parts, is somewhat attacked by the acid. This occasions a loss of acid, and at the same time a constant demand for new retorts.*

Commercial nitric acid is never pure. When too much sulphuric acid has been employed in the preparation, or cleanliness has not been observed, it will contain sulphuric acid, which may be precipitated by nitrate of barytes. Salts of potash, soda, and oxide of iron, are also carried mechanically over into the receiver. Chlorine and peroxide of nitrogen, are likewise present in ordinary nitric acid. The presence of the latter is indicated by the brown color, which the protosalts of iron assume in the acid, or by the green color of yellow prussiate of potash; it is the chief cause of the yellowish-brown color of much nitric acid, and is not entirely absent in colorless acid. Chlorine is detected by a solution of nitrate of silver. Both chlorine and peroxide of nitrogen can be separated, for the greater part, by distilling a small portion of the acid; these being more volatile, they pass over with the first portions. The chlorine can only be removed completely by a solution of silver, and the peroxide of nitrogen, by allowing the strong nitric acid to boil for a time exposed to a current of carbonic acid, or, according to Pelouze, by digesting with it the peroxide of lead, no oxide of lead being dissolved by the concentrated acid. Weaker acid may be digested, according to Millon, with $\frac{1}{100}$ of bichromate of potash, with the same result. According to the observations of Lembert, the iodine in Chili-saltpetre (p. 321) accompanies the acid, and may be detected in it when that salt is employed in its production.

THE MANUFACTURE OF SOAP.—SOAP BOILING.

By the term *soap*, in ordinary life, we understand the product resulting from the action of potash and soda upon the fats, a substance, in which these alkalies are combined with certain constituents of the latter class of bodies. In scientific language, this term has been extended to all similar combinations of the basic metallic oxides, so that in chemistry we meet with soaps of baryta, magnesia, iron, copper, &c. Besides *soap*, in the limited sense of the word, or the soaps of the alkalies, there are only one or two others that have any technological interest, these are *lime soap* in connection with the manufacture of stearine (p. 123), and *lead soap* used in pharmacy, when it is called *plaster*.

History.—The use of soap is nearly as old as history; the assertion, that soap is mentioned in the Old Testament, however, is an error, and was probably first circulated with Luther's translation, for, when we read in Jeremiah II. 22: "For though thou wash thee with *nitre*, and take thee much *sope*," and in Malachi III. 2: "For he is like a refiner's fire, and like fuller's *sope*," in the Hebrew text the words *borith* (vegetable lye salt, potashes), and *nether* (mineral lye salt, soda)

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* De Sussex has pointed out a new plan of obtaining nitric acid in the specification of his patent for soda, which consists in heating nitrate of soda or potash to redness with lime or some other of the earths, and condensing the nitric acid, which is then evolved.

are used, which could never be intended to denote soap. *Pliny, on the contrary, makes particular and distinct mention of soap, which he declares to be a Gallic invention, and states that it is best prepared in Germany. He also distinguishes between hard and soft soap, and was acquainted with the mode of its preparation from the ashes of the beech tree and goat's tallow. Galen mentions soap with the like assurance, as do also Paulus Ægineta and Aëtius. Homer describes fully and accurately, what Nausica took with her for washing at the river, but makes no mention of soap, which was, doubtless, unknown to him.

Crude Materials for Soap Boiling.—The fats used by the soapboiler are partly fluid and oily, as olive, hemp-seed, rape-seed, linseed oil, train oil, and less frequently poppy-seed, beech-nut, nut and almond oil; partly solid, as tallow, cocoa-nut and palm-oil, and sometimes hogs'-lard, oil of Elipe, and Galam butter.

Tallow.—Of tallow we have already spoken at length, in treating of the materials for illumination (p. 119). For the manufacture of soap, remelted tallow is preferable, but crude tallow can also be used, and the clarification is not absolutely necessary. When the production of soap and candles is carried on in separate departments of the same manufactory, which is usually the case, the firmer kinds of tallow should be made into candles, and the softer varieties boiled for soap. In northern countries, tallow is the chief fat used by the soap boilers.

Lard.—*Hogs'-lard* produces a very soft soap, which is too readily dissolved by water. For this reason, and on account of its high price, being much used as food, lard is seldom made into soap; but when employed, it should always be previously melted.

Hemp-seed oil.—Hemp-seed oil is obtained chiefly in Russia from the seeds of *Cannabis sativa*. It is of a greenish yellow color, has a sharp smell, but mild taste. At — 27° (— 16° F.) it is solid. It is quite as soluble in alcohol as the following oil.

Linseed oil.—This oil, obtained from the seeds of *Linum usitatissimum*, is also a product of the north. When freshly pressed, it has a golden yellow color, which becomes brown on keeping; it has a peculiar smell quite different from that of all the other oils, and becomes solid at a temperature of — 16° to — 20° C. (+ 3° to — 4° F.)

From the experiments of Sacc, it appears to be a mixture of oleate and margarate of glyceryle, containing no stearate.

It is frequently adulterated with colophony. Oil adulterated in this manner, generally parts with the resin to alcohol, which then produces with acetate of lead a white precipitate.

Train oil.—Mention has already been made of *fish oil* (p. 117).

Olive oil.—Olive oil, which is used in large quantities for the production of soap, replaces tallow in the countries of the south. The manner in which it is obtained from the ripe fruit has already been described (p. 116).

The extensive trade carried on in olive oil, in the countries of southern Europe, renders it a matter of great importance to be able to detect the adulteration, which is frequently practised in its preparation. The high price of this oil is a strong inducement to mix it with other vegetable oils, and poppy oil is generally selected for this purpose on account of its low price, mild taste, and nearly imperceptible smell. Several methods have been successively advanced for ascertaining the amount and the nature of such adulterations, but only one of these affords results of sufficient accuracy. The others, however, being frequently employed, merit here a passing notice. Poutet, a chemist and druggist in Marseilles, was the first to introduce a process which has been very generally adopted, and is founded upon the fact, that pure olive oil shaken with $\frac{1}{12}$th of a solution of 6 parts quicksilver and 7½ parts of strong nitric acid, is converted into a solid white body. This conversion is dependent upon the presence of hyponitrous acid, and can be produced by that acid alone without the use of quicksilver. Hyponitrous acid converts the oleic acid, which is in combination with glycerine in the oil, into *Elaidic acid* ($C_{32}\,H_{132}\,O_6 + 2$ Aq.), which remains, as *Elaidine*, in combination with the glycerine. The measure for the purity of the olive oil is, therefore, by Poutet's method, the degree of firmness which it assumes after a short space of time. Whilst pure oil becomes solid and sonorous, that which is mixed with $\frac{1}{20}$th of poppy oil only acquires the consistence of tallow, and with $\frac{1}{10}$th it is hardly firmer than lard. These degrees of consistency, however, are so indefinite, and pass so easily the one into the other, that they afford no accurate measure of purity, when the amount of poppy oil is below $\frac{1}{10}$th. Boudet first discovered that the solidification was due to hyponitrous acid, and starting from that, he advocated the use of a mixture of 3 parts nitric acid, and 1 part nitrous acid (peroxide of nitrogen) instead of the quicksilver, and made the time, which a specimen took to become solid, or at the expiration of which it could be poured from an inverted vessel at 10° (50° F.), the measure of its purity. He found, that the time at which solidification occurred, with pure olive oil, was generally 55 to 60 minutes, and that this was retarded 40 minutes by the addition of $\frac{1}{100}$th poppy oil, 90 minutes by the $\frac{1}{20}$th, and very much more by the presence of $\frac{1}{10}$th. On examining this method of testing, Soubeiran and Blandeau found that pure oil required between 43 and 59 minutes to solidify; oil containing $\frac{1}{20}$th of poppy oil, 45 to 59 minutes; and that from 48 to 97 minutes elapsed before an oil containing $\frac{1}{10}$th of poppy oil became solid. The times of cooling are, therefore, so uncertain that many pure oils require more time to become solid, than others which are adulterated with poppy oil, and all conclusions drawn from experiments of this kind, even when executed with the greatest care, can consequently never indicate the degree of purity of the oil; moreover, the method was only intended for the detection of poppy oil. Other adulterations are, however, seldom met with, partly on account of the smell and taste, or the costliness of the other oils. In tests of this kind, where two oils are compared, the same quantity of acid must, of course, be taken to each specimen, for the time required by one and the same oil to solidify is different with a variable amount of acid. Thus, a mixture of 1 part nitrous acid (peroxide of nitrogen) with

33 parts of olive oil becomes solid in 70 minutes.
50 " " " " " 78 "
75 " " " " " 84 "
100 " " " " " 130 "
200 " " " " " 435 "
400 " " will not solidify at all.

Fauré fancied that he had found a better test in ammonia, $\frac{1}{10}$th of which, when shaken with pure olive oil, produces a milk white, uniform thick soap (the volatile salve of the druggists in Germany), whilst poppy oil forms a granular mass. Similar differences are observable in the combinations of ammonia with the pure and mixed oils; but they are still less definite, as modes of testing, than those obtained by Boudet's process.

A very different method of examining oil has been introduced by Rousseau, and is carried out by means of his so-called *Diagometre*. This test is founded upon the different powers of olive and poppy oil in conducting a galvanic current, the former conducting much less readily than the latter, without being a perfect non-conductor. The construction of the diagometer is such, that the power of conducting in the specimens, their purity, therefore, may be seen by the deviation of a magnetic needle, under the influence of a galvanic current passing through the specimen of oil. This method is, however, of no practical utility, on account of a certain difficulty in making the observation, and still more because the power of different kinds of olive oil to conduct electricity is variable, and in some instances is even greater than in oil which has been mixed with poppy oil.

The old well-known plan of shaking, which depends upon the difference in the viscidity and consistence of olive and poppy oils, is still very much practised. When large bubbles of air are introduced by violent shaking below the olive oil, these are observed to vanish from the surface with a certain degree of rapidity. The duration of these bubbles gives an idea of the amount of poppy oil present. At least, Soubeiran and Blandeau found, in comparing 27 samples of olive oil which were in part pure, partly mixed with $\frac{1}{10}$th, and partly with $\frac{1}{20}$th of poppy oil, that $\frac{1}{10}$th could be pretty accurately detected in this manner, but not $\frac{1}{20}$th.*

Palm oil is a vegetable fat, extracted, according to some, from the fruit of a kind of palm, *Avoira Elais*, or *Elais guianensis*, according to others from *Cocus butyracea*. Both plants may possibly produce

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* M. Heidenrich recommends three distinct tests for detecting the adulterations in commercial oils. The first test is the smell produced by the oil when gently heated, which is said to resemble that of the animal or plant from which the oil has been obtained. The second has reference to the change of color experienced by the oil, when treated on a glass plate with sulphuric acid. The third experiment consists in ascertaining the density of the oil by Gay-Lussac's alcoholmeter; the density of pure oils being changed by an admixture of the other inferior kinds. For further particulars respecting the modes of testing, v. *Chem. Gaz.*, vol. i. 382.

similar kinds of vegetable fat. Palm oil is the produce of the tropical parts of Africa, and is brought to Europe from the west coast of that continent; from being extensively used in the manufacture of soap, it has become a very important article of merchandize. Although the existence of palm oil has long been known, it was always classed among the curious products of nature, and not among those substances which are of importance in the arts, and it has only attained its importance by a remarkable concurrence of circumstances, in connection with the most praiseworthy action in modern British history, viz.: the abolition of slavery. Since the slave trade has been subjected to the restrictions of the English, the natives of the coast, instead of bartering human beings for the supply of their foreign wants, have been forced to substitute the useful produce of the soil, or palm oil, as payment. As many as twenty slave ships were to be found at the mouth of the Bony river, (an arm of the Niger,) until the blockade of the English put a stop to the traffic, and made an opening for the exportation of palm oil to the amount of 20,000 tons yearly from this port alone. The greatest consumption of this oil is in England, where two hundred times as much is consumed as in France; the palm oil used in the latter country amounting to only ½ per cent. of the fats saponified.

The fruit of the palm is of the size and form of a pigeon's egg, and contains a hard stone, surrounded by a fleshy integument. The oil is obtained from the latter, not from the stone. The fleshy part is boiled with water, when the oil separates on the top, and can easily be collected. On cooling, it assumes the appearance of a reddish-yellow fat, of the consistence of firm butter, melting at 29° (84½° F). As the word oil is used to express the fluid fats, it is not appropriately applied to this substance, which should be called Palm-butter. It has a strong but agreeably aromatic smell, very much resembling that of the violet root. Palm oil, as it occurs in commerce, is in that state in which the ordinary fats are called rancid, *i. e.* it contains free fatty acids, instead of the whole of these being in combination with oxide of glyceryle. The amount of these free acids increases with the age of the oil, and its fusing point rises at the same time. Pelouze and Boudet found ⅓ of its weight in fresh palm oil ½ in such as melted at 31° (88° F.), and in a specimen which fused at 36° (96½° F.), ⅘ths of its weight. Stenhouse found the fusing point of very old palm oil to be at 37° (99° F.). The researches of Fremy, and the other chemists named above, have shown, that this vegetable fat contains free oleic acid, a peculiar fatty acid, palmitic acid ($C_{32}H_{62}O_3 + Aq.$[*]), also in the free state, free hydrated oxide of glyceryle, and a small quantity of *palmitine* (palmitate, of oxide of glyceryle$=C_{32}H_{62}O_3 + C_3H_4O$[†]). The latter can be obtained as a white wax-like mass, by pressing palm oil in large quantities at a temperature of from 10° to 12° (50°—54° F.), and a second time at about 24° (75° F.);

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[*] The same acid as has been found in Japanese wax (v. p. 122).

[†] The researches of Retenbacher upon Acroleine, ($=C_6H_8O_2$) tend to show, that hydrated oxide of glyceryle, which is intimately related to the former, must be considered as $2\ C_3H_4O + 4\ H_2O$ instead of $C_6H_{14}O_6 + H_2$, which is the constitution usually assigned it.

it is then used for preparing a kind of stearine candles, whilst the fluid yellow oil is saponified.* This separation is, however, seldom effected before saponification. The cause of the rapid decomposition (becoming rancid) of palm oil, a decomposition which occurs so much more readily in this than in the other oils, has not been satisfactorily explained. It is remarkable also, that the quantity of the hydrated oxide of glyceryle diminishes, in consequence of this rancidity, in very old palm oil.

Bleaching of Palm Oil.—The yellowish-red coloring matter of palm oil is not destroyed by the process of saponification, so that the soap prepared from crude palm oil, assumes a yellow color. If the oil is previously bleached, however, it loses the greater part of its color, and a white soap is obtained. The bleaching of palm oil is, therefore, a matter of importance to the soap boiler, and can be effected in a variety of ways with very different results. Up to this time, the coloring matter has been destroyed by the action of chlorine, oxygen, powerful acids, or lastly, by heat and light.

Davidson's process consists in melting the palm oil in an iron vessel lined with lead, with the addition of from 6 to 11 per cent. of chloride of lime previously stirred up with 12 parts of water. When the ingredients have been thoroughly mixed, and the whole has become cold, it is cut into small pieces, and exposed to the air for two or three weeks. The chlorine liberated from the chloride of lime by the carbonic acid of the atmosphere, then gradually bleaches the oil. The lime is separated from the oil at the expiration of this time, by melting it with dilute sulphuric acid, until the sulphate of lime is deposited at the bottom of the vessel, and the oil swims on the surface of the liquid. The sulphuric acid evolves the remainder of the chlorine, and completes the process of bleaching. The same result is obtained, when chlorine is evolved in contact with the melted oil by the agency of manganese, common salt, and sulphuric acid. The only objection to the use of chlorine is, that it attacks the oil itself at a high temperature, decomposing the palmitic acid with ease, and itself taking the place of the hydrogen of the acid. All excess of chlorine, therefore, which can never be avoided, impairs the quality of the fat. When palm oil is melted over a dilute solution of nitric acid, or a weak solution of saltpetre, and sulphuric acid is slowly added, the oil is rapidly bleached, but not in a permanent manner; for when mixed subsequently with the lye in the boiling pan, the color again appears. The coloring matter of palm oil is destroyed by sulphuric acid, added in the proportion of 4 per cent. to the melting oil, just as the mucus was destroyed by the same agent in rape-seed oil.

The use of oxygen for bleaching, derived from sulphuric acid and manganese, was first introduced by Michaëlis. He mixes palm oil

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* It appears from the experiments of Schwartz. that palmitic acid, which melts at 60° (140° F.), is converted, on exposure to the air, at a temperature of 250° to 300° (514° to 472° F.), with the simultaneous formation of carbonic acid and water, into a new acid, the palmitonic, which fuses at 53° (127° F.), and that the latter acid is frequently the substance contained in the candles prepared from palm oil.—*Annalen der Chemie und Pharmacie*, lx. 58.

with $\frac{1}{18}$th of finely powdered manganese, adds to the mixture $\frac{1}{2}$ its weight of boiling water, and with constant agitation slowly pours concentrated sulphuric acid to the amount of $\frac{1}{32}$ of the weight of the oil upon the mixture; the mass is then allowed to cool. The solidified fat is of a greenish hue, but becomes white in a short time by the action of air and light.

Zier first observed that palm oil slowly poured over a heated iron plate, absorbs oxygen from the air with the evolution of an acid vapor, and becomes converted into a clear colorless fat. In England, this observation has been applied upon a large scale. At first, the crude palm oil was heated, 40 or 60 cwts. at a time, in cast-iron boilers, to the high temperature of 232° C. (450° F.) But before the whole mass could attain this temperature, the bottom of the boiler was often heated to 300° C. (572° F.), giving rise to an intolerable smell from the evolution of vapors blackening and charring the oil, and not unfrequently causing explosions. As soon, however, as it was discovered that the decomposition of the coloring matter began at a temperature of 110° C. (230° F.), the decolorization has been carried on at that temperature, although with a greater expenditure of time. When the melted oil has attained 110° (230° F.) over the open fire, the heat is kept up by the introduction of a current of high pressure steam (15 lbs. pressure to the square inch) during the whole operation, and the decomposition is promoted by constant stirring. For the decolorization of 4 tons of palm-oil, ten hours are required.

Fig. 153.

Zier's observation has been carried into practice in the following manner with great advantage. The apparatus consists of a large steam-pipe open at *A*, over which the bung-hole of the cask is inverted, and as the oil melts, it runs out into the cistern *B*, where any sediment is allowed to deposit. It is then syphoned off into another cistern *C*, where it is kept in a liquid state by the steam-pipe *D*. The melted oil is pumped into the cisterns *EE*, by the pumps *FF*. The bottoms of these cisterns are pierced with a number of small holes, through which the oil flows down the shafts *GG*, in a shower of small streams, as shown at *H*, into the cistern *C*, at *LL*. The oil is pumped up again, and heated in the manner described until perfectly free from color.

The pumps are enclosed in a copper pipe, as shown at *K*, between which and the shaft of the pump, a jet of steam is admitted at *L*.

The whole apparatus is constructed of copper, as tin will not resist the action of the acid in the palm oil.

The cost of this method is very small, being only the wear and tear and the expense of the fuel for raising the steam.

Far more advantageous, and, indeed, the very best plan, is that in which the action of air and light is associated with that of heat. With this object in view, several very large square or flat boxes, or cisterns are prepared, which may either be constructed simply of wood, and are still better when lined with lead. These boxes are 12 inches deep, and are furnished at the bottom with a serpentine leaden tube, in connection with a steam boiler. Into these cisterns, which may be freely exposed to the air, or at all events must be so situated as to admit of the free access of air and light, after they have been filled to the height of 8 inches with water, palm oil is introduced in sufficient quantity to form a layer of two inches after being melted by the admission of the steam. The current of steam must be regulated and conducted, so as to afford a uniform temperature of 212°. At the expiration of ten or fifteen hours the decolorization is finished; the length of time required depending very much upon the power of the sun's rays. Payen found that the decolorization was not impeded by covering the cisterns with glazed frames, but in such a manner that the air continued to have free access. It is probable that palm oil might be bleached with great advantage by the tropical sun of Africa, before its importation into Europe. A slight yellowish hue cannot be removed from the oil even by the most perfect process of bleaching, which, on cooling, gives it a dirty white appearance; this, however, is no longer perceptible in the soap.

The most complete, most rapid, but at the same time the most costly method of decolorization is that introduced by Watt, who uses bichromate of potash, and strong mineral acids. Watt's process is, therefore, an oxidation of the coloring matter by chromic acid. The process begins by melting the palm oil, and allowing it to stand, when it deposits the suspended impurities mechanically. The clear oil is drawn off into wooden vessels, mixed with a concentrated solution of 25 lbs. bichromate of potash, 8 lbs. oil of vitriol, and about 50 lbs. of strong muriatic acid to the ton of oil, and the whole is well stirred together. Instead of muriatic acid, common salt, with an appropriate addition to the quantity of sulphuric acid may be used. In a few minutes, the mass having been well stirred, the light green appearance of the oil, and the rising of a thick skum to the surface indicate the completion of the process. It can easily be seen by the color of specimens allowed to cool, whether a sufficient quantity of the bleaching materials has been used. The chemical decomposition attending this process of bleaching is easily understood. The sulphuric acid combines with the potash, and liberates the chromic acid, which, parting with the half of its oxygen to destroy the coloring matter, becomes converted into oxide of chromium. The muriatic acid forms a *soluble* compound with this green oxide, chloride of chromium. The bleached oil has now to be separated from the aqueous solution of chloride of chromium (and of sulphate of soda, when common salt was used). This separates as the heavier liquid, upon which the oil swims, when the warm mixture is allowed to stand quietly for half-an hour. The fat collected from the surface is then washed in a second vessel with water made to boil by a current of steam. The process of bleaching the above quantity, 20 cwts., is finished in not more than five minutes.

It would be quite superfluous to bleach palm oil by so costly a process when it has to be used as an addition to rosin soap, which already possesses a yellow color. The cost of the process can only be repaid, when very white soap is required.

The cost of bleaching by Watt's method is estimated to be as follows. About ½ a ton is operated upon at a time, and the temperature of the oil is maintained at about 100° F.

Materials cost,	At English prices, *s.*	*d.*	At American prices,
10 lbs. bichromate potash .	6	8	$3.70
10 " common salt . . .	0	0	.04
15 " oil vitriol	1	7	.52

8*s.* 3*d.* = $2.00. 4.26 = $8.52 per ton.
Or about $4.00 per ton.

Oil of Illipa.—*Illipa oil* (Illipay and Ellipe oil) very much resembles palm oil, both as regards its origin and nature, but it is much less known in commerce. It is said to be obtained by pressure from the fruit of a tree that grows on the coast of Coromandel and Bengal, which the natives call Makwah or Mawy, and which is considered by the botanists, Roxburg and Hamilton, to be the *Bassia latifolia*, a species belonging to the family of the *Lapoteæ*. (Order *Sapotaceæ*, Lind.) The fruit has the form of a lengthened olive. A single Makwah tree, though growing in the most sterile mountainous districts, is said to produce 2 tons of fruit, affording 60 lbs. of oil yearly. According to Henry, the oil is not extracted by pressing, but by boiling with water. It is of a light greenish yellow color, has an aromatic smell, resembling olive oil or cocoa butter, and is solid at moderate temperatures, its melting point being 22°—23° (72°—73½° F.). At 28° (82½° F.), it forms a lemon yellow liquid, from which reddish brown flocks like tannin are deposited. In alcohol it is but slightly soluble. Its taste is at first mild, becoming gradually more and more acrid, from rancidity, to which it is very subject. Pelouze and Boudet found this fat to consist of oleine and stearine.

Galam Butter.—*Galam butter*, also the produce of a species of Bassia, but indigenous to the interior of Africa, is so similar to palm oil, that it is often confounded with it. It has a greater resemblance, however, to tallow, and is more solid than Illipa oil, its smell and taste are not so piquant, and it possesses a dirty yellow color. It forms a permanently turbid oil when melted. As the product of rancidity, Galam butter contains free acid, and free oxide of glyceryle.

Cocoa-nut Oil.—More important than the two vegetable fats just described is the so-called *cocoa-nut oil* or *cocoa-butter*, a white rancid fat, as it is imported, of the consistence of hogs'-lard, but lamellar in texture, and possessing a disagreeable smell. It is extracted, according to existing statements, from the kernels of the cocoa palm, (*Cocos nucifera* and *butyracea*), either by pressure or by boiling. This palm is indigenous to the two Indian peninsulas, viz., the coasts, chiefly, of Malabar and Bengal, as well as to Ceylon, the Maldives, and Siam; it has also been found in the Brazils. The kernels of the cocoa palm, called *Copperah* in commerce, are now found in commerce, and the oil is extracted by the aid of heat, the kernels having been previously ground or cut into small pieces. Tindall, in working upon 420 lbs. of copperah in portions of 7 lbs. each, obtained different kinds of oil by pressing the fruit in sacks and mats made of the cocoa-nut fibre, every rise of temperature causing the melting point of the extracted oil to be raised. The whole having been divided into five portions, each of which was treated at a higher temperature than the preceding, the following results were obtained:

1st portion	85¾ lbs.	pressed	at a	temperature	of from	11° to 15° C.	(57½° to 59° F.)
2d "	13⅜	"	"	"	"	18° to 19° C.	(65° to 67° F.)
3d "	21¼	"	"	"	"	24°	(75½° F.)
4th "	26¾	"	"	"	"	29° to 30° C.	(84½° to 86° F.)
5th "	91¼	"	"	"	"	40° to 41° C.	(104° to 106° F.)

Together 238⅜ lbs.

The cake which remained, weighed 155 lbs.; the difference, 26⅝ lbs., was chiefly oil, which ran down the sides of the press, and was collected in a separate vessel. Thus, it appears, that the kernels contain 60 per cent. or more of oil, in all probability consisting of two varieties, a fluid and solid fat, which are distinct and separate in the seeds, but become mixed under the press, and so much the more, the higher the temperature is raised, so that fluid or solid fat, or such as possesses a medium consistence, may be obtained at pleasure. In the above experiments, indeed, the first and second portions were quite liquid and transparent; the third was semi-transparent and milky; the fourth, solid, and of a dirty white color; the fifth was of a pure white color, and very firm. The cocoa-nut oil that is prepared in Bengal, is said to be better than that from Ceylon. The melting point of the commercial oil is about 20° (68° F.), which is probably the temperature at which it was extracted. Pelouze and Boudet considered the solid fat to contain Elaidic acid,* until Brandes and Bromeis proved this substance to be a combination of a peculiar fatty acid, cocoic or cocostearic acid ($C_{27}H_{52}O_3$) with oxide of glyceryle (Cocine). In the rancid oil of cocoa-nut, this acid is partly free, *i. e*, in the form of hydrate ($C_{27}H_{52}O_3$ + aq.).

Oleic Acid.—The mixture of oleic acid with portions of stearic and margaric acids, which is obtained in the manufacture of stearic acid by pressure (p. 125), affords an excellent soap, the production of which is generally a secondary process in stearic acid manufactories, and is prepared so much the more readily, as the fat has not first to be decomposed, but merely neutralized with alkali.

The acid which is formed by the action of nitrous acid on the liquid fat oil.

Resin.—The resin which is left after the distillation of turpentine, the origin and chemical properties of which have been described under the head of illuminating materials, (p. 129,) and which is generally known as colophony, is a no less important substance in the soap manufacture than the foreign vegetable fats.

Tallow, the olive, palm, and cocoa-nut oils, oleic acid and resin are used for the production of hard soaps; train oil, and the seed oils, on the contrary, for soft soaps.

The Lye.—The alkalies, as well as the fats, constitute one the crude materials employed in the soap manufacture, and the former are of importance in a double point of view: firstly, as they themselves form constituents of the soap, and secondly, as they are the chemical agents concerned in the decomposition of the fats, which must always precede the actual production of soap. Commerce merely supplies the soap boiler with ashes, potashes and soda, in which the alkalies are contained as carbonates. In this state of combination, neither potash nor soda is able to effect that which the soap boiler requires;* his object cannot be attained by means of the salts, but only by the hydrates of potash and soda, and these are always employed in solutions of variable strength, and known as *lye* or caustic *lye*. One of the most important operations of the soap boiler, is that of rendering the alkalies caustic, (*i. e.*, the conversion of the carbonates of the alkalies into hydrates,) and it is effected by means of slaked lime or hydrate of lime. By a simple process of substitution, the carbonic acid combines with the lime, whilst the alkali assumes its water of hydration, and becomes thus converted into a compound possessing the most powerful chemical activity, which no substances of organic origin can withstand, and by which many others are decomposed. This it is, which is meant to be expressed by the term "*caustic.*" It has been observed, that very concentrated caustic lye will decompose carbonate of lime, combining itself with the acid, so that hydrate of lime and carbonate of the alkali are produced, or just the very opposite to that which it is the object of the manufacturer to obtain. Hence, it is explained, why carbonate of potash dissolved in 4 parts of water is not at all affected by lime, is but slightly acted upon when dissolved in 5 to 8 parts of water, and is only rendered completely caustic when dissolved in more than 10 parts of water. The best and most speedy method of obtaining caustic lye, is by slaking 2 parts of burnt lime in 6 parts of hot water (converting it into hydrate), and adding it gradually to a boiling solution of 3 parts carbonate of potash in 12 parts of water. When the fluid, which has become clear by the subsidence of the carbonate of lime, no longer effervesces with acids, nor renders lime water turbid, we have proof that all the carbonic acid has entered into combination with the lime, and that the lye has been rendered perfectly caustic. It is necessary to use only half as much water with carbonate of soda, which is made caustic

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* There are some few exceptions to this general rule, which will be mentioned in the sequel.

with greater ease. Carbonates of the alkalies can even be rendered caustic in the cold, by means of lime; but more lime must then be employed, with weaker solutions of the carbonates, and the action must be allowed to continue for a longer time. In this manner, lyes of a certain strength, only indicating from 10° to 12° B. can be obtained, but with less expenditure of fuel. The loss of time is of no moment, as the substances can be left to themselves, and require no attention. According to theory, 100 parts of carbonate of potash should require 53 parts, and the same quantity of carbonate of soda, 40.5 parts of burnt lime; yet it is advisable, in practice, to use 50 parts for soda, 60 to 80 parts for potash, and for ash, from 8 to 10 parts of lime.

At present the soap boilers always produce caustic lye in the latter manner, by digestion in the cold, partly because strong lyes cannot be used in the ordinary method of boiling, partly because ash was originally the only source of alkali, (at least in northern countries)—which, when treated with boiling water, would impart too large a proportion of foreign salts to the lye—and lastly, because they are accustomed to the process of boiling with lye prepared in the cold. The manipulations are the following.

In purchasing and collecting ashes, the great object is to obtain pure wood ashes without any mixture of peat ash, which not only contains no carbonated alkali, but is injurious from the large amount of gypsum which frequently accompanies it. This substance exchanges its acid for that of the carbonate of the alkali, so that carbonate of lime is produced, and sulphate of potash, which is useless in the preparation of lye. It has been found, that many kinds of peat ash will, in this manner, spoil three times their weight of wood ashes. In all common ashes there are portions of unburnt charcoal and wood, which would impart coloring and empyreumatic substances to the lye, and must consequently be separated by a sieve. The sifted ash is moistened upon a smooth stone floor with water, or weak lye; it is then well raked about, and allowed to remain until all parts of the ash are thoroughly soaked. The heap is then hollowed out in the middle, so as to form a pit. In this pit the lime is slaked, and when it has fallen to pieces, is covered from all sides with ash, and afterwards both ash and lime are well mingled together. For lixiviating the mixture, wooden, or better, cast-iron casks, with false bottoms, pierced with holes, and covered with straw, are used, and these are furnished with a stop-cock, as is represented in Fig. 125. In these *ash-tubs* the ingredients are mixed as thoroughly as possible by a stirring rod; the mixture is then covered with straw, brushwood, or basket-work, and as much water as is necessary to induce the action of the lime, is added. The cock is first left open, that the air may easily escape from the interstices, and water (or weak lye) is poured very gradually over the ash, that it may slowly sink down. As soon as the lye threatens to flow out from the cock, the latter must be closed, and the rest of the lye poured in. The action is now allowed to go on for 24 hours, and the lye is then drawn off; the strongest lye flows out first, containing potash to the amount of 20° or 25° B.; a second lixiviation affords lye with 8° to 10° B. of potash, and a third yields *weak* lye, indicating 3° to 4° B. The following portions are very weak lyes, and are employed as the first addition to a fresh quantity of ash.

The treatment of potashes is more simple, and consists in adding water to the mixture of dry potash and slaked lime in the ash-tubs. The ingredients are more easily and better mixed in the dry state. The lye is frequently not so clear on being drawn off, as in the former case; and the lime is apt to pass through the straw and the pierced bottom. For this reason, potashes are often worked together with wood ashes, by which means the evil is avoided. Both may be mixed with the lime, or the ashes only, and then the potashes should occupy the highest place in the ash-tubs, or may be dissolved in the lixiviating water.

The *soda-salt* is treated in the same manner, but never with an addition of ashes. It is best to spread it above and upon the lime in the ash-tub.

It is not convenient to render solutions of potash, or soda, caustic, by stirring them together with milk of lime; for the carbonate of lime, which is in a state of extreme division, is very long in settling down from the liquid.

The production of lye from ashes is becoming less frequent in the soap manufactories, as the scarcity of wood increases, and as soda is more generally introduced. The production of lye from soda by boiling, in which case very little foreign matter has to be removed, is certainly a gain to the soap manufacturer, inasmuch as he can obtain at once strong lye, which is now so frequently needed—for instance, in the saponification of cocoa-nut oil—without being obliged to concentrate weak lyes by evaporation.

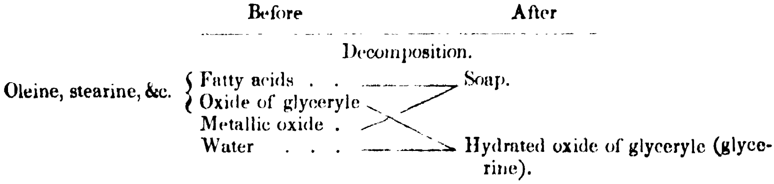
It is not advisable to employ crystalized, or even crude soda for the production of lye, as needless expense is incurred in carriage, and these contain but a small amount of soda; besides which, the latter is always more or less contaminated with sulphuret of sodium, and this has to be removed by artificial means. A serious objection to the preparation of lye in the cold, is the uncertainty attending the action of the lime, which cannot be ascertained previously, nor can the quantity added be subsequently increased or diminished at pleasure. Thus an excess of lime has sometimes to be remedied, and at other times too little lime is employed. The first evil is corrected without any great difficulty; but when the lye passes through in the state of carbonate, there is no other alternative than to pour it again through the lime.

The caustic lye of the soap boiler, obtained from ashes or potashes, contains some sulphate of potash, a good deal of chloride of potassium, and some silicic acid in solution, which latter precipitates in combination with the lime on boiling, but not in the cold. Soda, particularly that obtained from marine plants, imparts common salt and sulphuret of sodium to the lye. In preparing lye in the cold, hydrate of lime is found in solution, particularly in weak lyes, and this, notwithstanding its slight degree of solubility, $\frac{1}{600}$ to $\frac{1}{700}$ of the water, is, nevertheless, of some moment, in consequence of the large quantity of water used, as it destroys, on boiling, a portion of the soap, converting it into insoluble lime soap. Lastly, it must not be overlooked that caustic lye, at the boiling temperature, particularly when concentrated, attacks and dissolves iron.

Testing the Lye.—The soap-boiler is only in a position to judge his process correctly and proceed with safety, when, during the lixiviation in the ash-tubs, and whilst boiling the fat, he is enabled at any moment to ascertain accurately the strength of his lye. He uses for this purpose, a rather precarious but easily managed instrument, Beaumé's hydrometer (in other parts Stoppani's, and in France Gay-Lussac's hydrometer is used). In this instrument (that which is used for liquids heavier than water) the space between the point to which the instrument sinks in pure water—the zero point, and the point to which it sinks in a solution of 1 part common salt, in 9 parts of water, is divided into 10 equal parts, or degrees. This graduation is carried on throughout the whole length of the spindle. The indications of such an hydrometer are in no kind of connection with the chemical nature of the fluid; and as the graduation is perfectly arbitrary, nothing more can be established by the instrument than a comparison of the densities of different liquids. When, therefore, the hydrometer sinks to the same depth in syrup of sugar, and in a caustic lye, no other conclusion can be deduced from the observation, than that both fluids are of like density. But as the correspondence has already been established between the degrees of Beaumé's hydrometer and the specific gravities, and it is also known what proportions of potash and soda correspond to the specific gravities of different solutions, the hydrometer may be used, with the aid of tables, as a means of ascertaining the amount of alkali present. A lye of 18° B., for instance, has a specific gravity = 1.138, which is equivalent to 15 per cent. of potash, or 12.8 per cent. of soda, always supposing the lye to contain no other matters, or salts, which also influence the hydrometer. This, however, is never the case with soap boilers' lye, so that the indications of Beaumé's hydrometer are mere approximations, with reference to the amount of alkali, or are altogether fallacious. Nevertheless, they are useful to the practitioner in a variety of ways, and are, indeed, indispensable. In the first place, he can easily follow with this instrument, the diminishing strength of the liquid flowing from the ash-tubs, and form a just estimate of its value, when, at the same time, a test with acid proves the absence of carbonic acid. But even in the process of soap boiling itself, the test of the lye afforded by the hydrometer, combined with the personal experience of the workman, is a clue by which he is enabled to judge whether the proper strength has been attained, knowing, as he does, what degree the hydrometer ought to indicate from any particular soda or potash-lye, for any particular purpose. The buoyant power of the lye was the old-fashioned and erroneous test: in applying this, it was ascertained whether an egg, or a piece of hard soap, would swim on the surface of the lye and not sink, for which a certain density was of course necessary. Thus the respective densities of different lyes could never be ascertained, but only whether a certain lye had attained that particular density. In other words, weak lyes could never be examined upon this principle.

Theory of the formation of Soap.—A clear idea of the formation of soap, and a correct explanation of this remarkable process, can only be obtained from a thorough knowledge of the constituents of the fats, as well as of their mode of combination. The question respecting the theory of soap formation, and the question concerning the constitution of the fats, have reference, therefore, to one and the same thing. All that we know concerning these bodies at present, has been furnished by the extensive and exemplary researches of Chevreul, dating from the year 1813 to 1823, the results of which were published by the Author in his "*Recherches Chimiques sur les corps gras, etc., Paris,* 1823." More recent researches upon this subject have seldom found anything to correct, but have adduced new facts, and given rise to explanations of those already known, which are more in accordance with the advanced state of science. These researches, conjointly, have proved that the fats, such as tallow, lard, olive oil, &c., are mixtures of two kinds of matters, which, taken singly, possesses all the properties of the fats themselves. They are chiefly distinguished from each other, by their state of aggregation at ordinary temperatures. Those which appear solid and hard have been called *stearine* by Chevreul; the fluid kinds he termed *oleine.* The consistence of a fat, therefore, depends upon the predominance of one or other of these constituents; so that the fluidity of the oils is due to a preponderance of oleine, the solidity of the varieties of tallow, to that of stearine or margarine. Pelouze and Boudet have observed, that the oleine from olive oil, hazel-nut oil, human and swine fat, is very different in solubility, and in its action with nitrous acid, to the oleine from linseed oil, nut, poppy, hemp-seed oil, and cocoa-butter. There are, consequently, several distinct substances included under the collective name of oleine, which, in the above-mentioned fats, hold margarine and stearine in solution. The same chemists have shown that those substances which were supposed to be different varieties of margarine and stearine, are rather combinations in definite proportions of oleine with margarine and stearine, as in the butter of cocoa and in olive oil. With reference to the recently examined fats of the cocoa-nut and the palm, it has already been stated, that the varieties of stearine which they contain in consequence of a difference in their chemical constitution, have been called cocine and palmitine respectively.

These proximate principles, stearine, margarine, and oleine, which, either merely commingled, or in chemical combination, constitute the fats, are considered as true salts, or as combinations of a base with an acid, and this view has been arrived at by the appearances observed during their decomposition, and the similarity of their behavior to other well-known combinations. The base is the same in the greater number of the fats; it is the oxide of a compound radical, glyceryle ($C_6H_{14}O_5$ or $2\ C_3H_4O+3\ H_2O$), the acids in combination with it, however, are of various kinds. Oxide of glyceryle is a substance soluble in water; it is colorless, and has a sweet taste, (sweet principle of oils,) and possesses none of the properties of the fats, which are, on the contrary, retained by the so-called fatty acids. These bodies are fluid at common temperatures, when derived from a fluid constituent, (for instance, oleine,) but are solid, when obtained from a solid ingredient, (as stearine.) Thus oxide of glyceryle, in combination with stearic acid, forms stearine; with margaric acid, margarine; with oleic acid, the oleine of olive oil; with palmitic acid, palmitine; with coco-stearic acid, cocine, &c., combinations, which have always the characters of a fat, but not those of oxide of glyceryle. The basic metallic oxides, the earths, &c., speedily decompose these compounds in the presence of water, uniting with the acid, whilst the oxide of glyceryle dissolves in the water. The salt produced by the union of the fatty acid with the metallic oxide, is a soap in the extended scientific signification of the word. When a natural fat is treated in the same manner, the same decomposition of its constituents occurs as if they had been taken separately; the same number of salts of the metallic oxide are produced, as there are fatty acids present, and these together form a mixture. A mixture of this kind is obtained on a large scale, when fats are treated with potash or soda (or lime), and this is then called *soap* in a limited practical sense of the word. The process concerned in the saponification of a fat is, therefore, the following:



When, therefore, olive oil is boiled sufficiently long with water and oxide of lead, a lead-soap is obtained, *lead-plaster*, which is insoluble in water, and swims upon the surface of a solution of glycerine in water. Indeed, the existence of glycerine was first observed in preparing this plaster, as no other substance soluble in water occurs in the process to mask its presence. Some of the fatty acids are volatile, as was observed by Chevreul in the case of butter and train oil. Such acids are the cause of smell in some kinds of soap, for, during the gradual decomposition of the salts, the acids are volatilized. The same chemist has proved, that the formation of soap is entirely independent of the access of air, and that the weight of the products of saponification always slightly exceeds that of the fat employed. Thus, he obtained from 100 parts:

	Stearine.	Oleine.
Margaric acid	78.0	20.08
Oleic acid	18.4	75.92
Glycerine	8.5	9.80
	104.9	105.80

This increase of 4.9 and 5.8 per cent. traced back to the elementary constituents of the products of saponification, is found to be oxygen and hydrogen in the same proportions as those in which they combine to form water. In fact, the fatty acids and oxide of glyceryle which are anhydrous in the fats, are obtained after decomposition in the state of hydrates. In palm oil and cocoa-butter, the fatty acids have separated in great part from the oxide of glyceryle during the process of spontaneous decomposition (in becoming rancid); the saponification has, therefore, in this case obtained a start, and the alkalies are not obliged, in the first instance, to decompose a combination of oxide of glyceryle, but have simply to enter into combination with the existing free acids to form soap. The small proportion of undecomposed palmitine and cocine is all that remains to be decomposed by the alkali. Thus, it is easily explained why the saponification of palm and cocoa fat is so much more rapid than is the case with the greater number of the other fats. Resin (colophony), on the contrary, is very differently affected, inasmuch as its constitution is very different to that of the fats. Commercial colophony is a mixture of a large quantity of pinic acid with a little sylvic and colophonic acids, (compare p. 129,) a mixture, which, from the nature of its ingredients, possesses the properties of a weak acid. In this case, therefore, no real saponification ensues, but the alkali is simply saturated with the resinous acids, and a substance obtained, which, in a commercial point of view, is equivalent to soap. The production of this substance is still simpler and easier than the saponification of the acid vegetable fats.

Thus far in speaking of alkalies, reference has been made only to caustic soda and potash. It is, however, well known, that soap can be prepared with the carbonates, and even with the bicarbonates of the alkalies; but the process is then so tedious and imperfect, that it is never practised on a large scale. A solution of carbonate of potash, when boiled with fat, parts with one-half of its potash to form soap, whilst the other half becomes bicarbonate. The decomposition of this latter continues, with the evolution of carbonic acid, as long as the boiling lasts, provided sufficient fat is present; but the process is so tardy, that a perfect soap is hardly attainable in this manner. For saponifying (saturating) resins upon a large scale, the carbonate of the alkali is quite as applicable as caustic lye.

An excess of alkali is requisite for saponification, and is so much the more willingly employed, as it can be removed again without difficulty. It must not be supposed, that the production of soap is a momentary process, or that it can be done with the same exactness and rapidity as the decomposition of an ordinary salt. On the contrary, the production of soap passed through a number of stages, and these occupy a considerable length of time, from the first mixing of the fat with the alkali—when a milky turbid mixture (emulsion) is produced—to the formation of soap ready for use, or to that point when the whole of the alkali is saturated with fatty acid. Acid salts are first produced with the fatty acids, and these hold the remainder of the fat in a state of solution and division, until it also is enabled to combine with alkali, and transform the acid into neutral salts, or into soap ready for use. This reaction may easily be observed if the fat is boiled with one-half the requisite quantity of alkali; the whole of the oil is at length dissolved, but the solution becomes troubled on cooling, and when diluted with water and boiled, unsaponified fat separates, and this had only been retained in the fluid by the stearate (margarate) of the alkali that had been formed.

From what has been stated, it appears that ordinary soap is a mixture of the compounds of the fatty and resinous acids with potash or soda. The choice of the base is, however, by no means a matter of indifference. The potash soaps are of that nature, which in ordinary salts is termed deliquescent, *i. e.*, they do not dry up when exposed in solution to the air, but retain so much water as will form with them a soft slimy jelly. On the other hand, artificially dried potash soaps absorb a large quantity of moisture, and become converted into a soft jelly. This kind of soap is called "*soft soap*" by the soap boiler, in contradistinction to the soda soap, or "*hard soap.*" The latter neither holds back so much water, nor does it absorb so much as to render it soft, but hardens when exposed to the air, and with a certain amount of water forms a perfectly solid mass, in which it is difficult to make impressions with the finger. The deliquescence of the former kind of soap is derived from the stearate, margarate and oleate of potash, whilst the properties of the latter are due to the corresponding salts of soda.[*] Resin, in combination with either soda or potash, forms by itself a soft soap. Soft soap is made from train oil and the drying vegetable oils; hard soap from the vegetable fats and oils which do not dry, or from tallow. Every kind of soap found in commerce contains a variable quantity of water depending upon the state of humidity of the air; part of this is in chemical combination, but by far the greater portion is only imbibed from the atmosphere. Hard soap becomes harder by drying, so that at last it can be pulverized. Potash-soap decomposes the salts of soda, *e. g.* common salt or sulphate of soda; the potash, or the stronger base, unites with the more powerful (mineral) acid, and the fatty acid combines with the soda. There result, therefore, chloride of potassium, or sulphate of potash, and a soda-soap. It is, indeed, in this indirect manner, that hard (soda) soap is fabricated in Germany. The action of sol-

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[*] 100 parts of dry oleate of potash absorb from the air 162 parts of water.
100 " " margarate " " " 55 " "
100 " " stearate " " " 10 " "
100 " " stearate of soda " " 7½ " "

vents upon soap is particularly interesting, and of the greatest importance in the different purposes for which it is employed. In alcohol and hot water, soap is perfectly soluble. The aqueous solution is more thickly fluid and slimy than the alcoholic solution, but both solidify to a jelly at a certain stage of concentration; opodeldoc is soap mixed with alcohol in this state of concentration. It has constantly been found that potash-soap is more readily soluble in water than soda-soap. This can be better seen with the salts of the pure fatty acids than with soap. Stearate of soda undergoes hardly any change when brought together with 10 parts of water, whilst stearate of potash is converted by it into a thick jelly. Oleate of soda is soluble in 10 parts of water, oleate of potash in 4 parts, and forms a jelly even with 2 parts of water; margarate of potash is converted by 10 parts of water into a transparent stiff jelly. From this, it will also be seen that the salts of oleic acid are more soluble than those of stearic (or margaric) acid with the same base, so that the softness or hardness of soap is not solely dependent upon the base that is used, but also upon the relative quantities of oleic and stearic acid which it contains. The fats mentioned as serving for the production of soft soap, are remarkable for the large proportion of oleic acid (oleine) which they contain.

Cold water never dissolves the oleate, margarate, or stearate of an alkali—the soap of commerce, therefore—without *decomposition*. The neutral salts are resolved into alkali which dissolves, and into an acid salt that is precipitated. The same decomposition occurs, when hot solutions of soap—particularly weak solutions—are cooled. Chevreul investigated this decomposition, in the case of stearate of potash, with the greatest accuracy, and the results of his examination are well suited to illustrate the action of soaps in general. When a solution of neutral stearate of potash ($\overline{St} + 2\ KaO$) is cooled, ¼th of its potash remains in solution, and a mixture of neutral with acid stearate of potash is separated. If the same salt is allowed to dissolve in 5000 parts of cold water, the acid stearate ($\overline{St}$, KaO) is alone precipitated, in the form of scales, possessing the lustre of mother-of-pearl, and the half of the potash remains in solution, for—

From		We obtain	
1 eq. neutral stearate of potash	1 eq. stearic acid	1 eq. acid stearate of potash* . .	1 eq. stearic acid.
	1 eq. potash . .		1 eq. potash.
and	1 eq. potash . .	and	1 eq. water.
2 eq. water . .	1 eq. water . .	1 eq. hydrate of potash . . .	1 eq. potash.
	1 eq. water . .		1 eq. water.

This behavior is common to the neutral margarates and oleates of potash and soda, and it explains why, in using soap, even with the

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* The acid salt = $\overline{St}$, KaO, Aq, when separated from the liquid, is again decomposed by a large quantity (1000 parts) of hot, but not of cold water, when

1 eq. neutral stearate of potash = $\overline{St} + 2KaO$.

and 1 eq. of a still more acid salt = $2\overline{St} + KaO + 3\ Aq$.

are produced from every 3 eq. of the acid salt = $3\overline{St} + 3\ KaO$ and water purest water, a whitish turbidness—*soap-suds*—is always obtained; the alkaline property of soap-suds, is solely due to the liberation of a portion of caustic potash or soda, and this it is that affords the possibility of removing fatty impurities in water, which is the sole object of washing with soap.

Every kind of soap, when it leaves the pan, and is afterwards sold, is a more or less concentrated solution of soap in water, which, when it has cooled, and become firm, should be subject to the same phenomena of decomposition. In fact, common soap shows a number of extremely slender crystaline fibres, but slightly transparent, and having a silky lustre, which are surrounded by a more translucent matrix.

The physical reaction of soaps with different saline solutions, as that of common salt, carbonate of soda, the corresponding potash compounds, sal ammoniac, &c., is of the utmost importance to the soap-boiler, because, although it may not be instrumental in the formation, it is very much concerned in the separation of the foreign matters that render hard soap impure, and is also influential in imparting to it the proper amount of water. In practice, a *solution of common salt* is always employed for this purpose.

When soap, cut up into small pieces, is placed in a solution of common salt, saturated at the ordinary temperature, no action whatever takes place. The pieces of soap, far from being dissolved or softened, swim on the surface of the solution without even being wetted by it; the solution of salt flows from their surface as oil from ice. Even after long immersion, no other result ensues than would occur if the soap were plunged into mercury; instead of softening, its hardness is rather increased. If the solution of salt is boiled, the soap is softened by the heat, and assumes the form of a gelatinous, or, rather, thick and doughy mass, which is equally insoluble in the saline solution, keeping perfectly distinct from it, or, at most, separating into flocks that swim upon the surface. These flocks harden when taken out, and cool down to hard soap. If the solution of salt is not saturated, but diluted to a certain extent, the soap and salt contend for the water after such a fashion, that neither positively gets possession of it. The water is partly imbibed by the soap, but a part remains with the salt, so that a solution of soap is seen swimming upon the saline solution, which is now saturated, without mixing with it or dissolving, but still forming a distinct layer. It is only when the salt in solution is below the $\frac{1}{400}$ of the liquid, that the soap is not prevented by it from dissolving. If a solution of this kind is boiled for a length of time, the following appearances will be observed as the water gradually evaporates:

The fluid, when steadily boiled, assumes, in the beginning, a thin, frothy character. The mass of soap and the froth become gradually thicker, until, on allowing a sample to run down the stirring rod, it is observed, by the manner of its descent, that the solution of soap, although still very soft and liquid, is nevertheless separated from the saline solution. At this period of the process, the solution of salt is so far concentrated, that the soap cannot remain any longer dissolved. It can easily be observed in what manner the stirring rod is wetted by a liquid (solution of salt), above, or on the surface of which, the solution of soap slides down in flat lumps or flocks, without attaching itself, or partially sticking to the rod. From this time, the solution of soap becomes constantly thicker, for the solution of salt takes water from it, in proportion as its own water is diminished by evaporation. The solution of salt collects more and more in the lower part of the vessel; the soap swimming on the top boils, and throws up larger and larger froth-bubbles, until it becomes, at length, so tough and thick, as to obstruct the passage of the vapors arising from below. The surface now splits up into several fields, separated from each other by deep furrows; these have not the fresh and soft appearance of the froth in the furrows, but present the appearance of dry slabs, which, being forced from side to side by the escaping vapor, slowly arrange themselves one above the other. The escape of the vapor soon becomes so retarded by the thick mass, that it forces its way, as it were, through craters, and gives rise (particularly in covered boilers) to a peculiar sound (*Pfeifen*). At length, the period arrives when the attraction of the soap to the remainder of the water is so great, that it completely resists every endeavor of the salt to remove it. Soap and salt, therefore, balance each other with reference to their affinity for water. This state is attained when the soap, which, previous to this, was always covered with froth and bubbles, suddenly sinks, and the froth breaks up into roundish massive grains, distinctly separated from each other, and from the saline solution. In this state, the mass no longer rises, even when a greater amount of heat is applied; but the saline solution is thrown up from time to time with much force from below, breaking through the granular mass (*curd*) on the surface, and then sinking down again. If soap is taken out during the boiling process, and allowed to cool, it solidifies to a more or less firm mass, depending upon the quantity of water it has retained; when it is removed in the granular state, it has the consistence and hardness of commercial soap.

Soap that contains a larger amount of water than curd soap, is called "*watered*"* when water or weak lye is added, and mixed with the curd in the boiler itself, or when the curd is treated subsequently with water whilst still in contact with the brine. It is called, on the contrary, "*filled*" when the water is added and stirred into the curd after its removal from the boiler, and immediately before it solidifies.

All varieties of soap are not separated with the same ease from their solutions by means of salt. Thus, soap made from cocoa-nut oil requires a much larger quantity of salt to separate it from solution than soap made from tallow; the former being soluble in saline solutions, in which the latter is perfectly insoluble. Resin soap is affected by common salt, in the same manner as the soaps from fat.

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* These terms, *watered* and *filled*, as applied to soap, will, perhaps, appear strange to the English soap-boiler, but it is obvious that they both apply to soap *watered* in a particular manner, and for which there are no corresponding technical terms in our language.

The same results as those obtained by the use of common salt are also produced, although in a less energetic manner, by chloride of potassium (which acts but slightly), carbonates of the alkalies, sulphate of soda (also very weak in its action), acetate of potash, and sal ammoniac. In weak caustic lye, soap is perfectly soluble; in strong lye, on the contrary, or when the concentration of the lye is increased by boiling, the soap separates in the same manner as from a solution of common salt. For this reason, the soap-boilers are in the habit of using weak lye, particularly in the beginning of their operations, as stronger lye, in separating the soap, would prevent the necessary amount of contact amongst the ingredients, and very much retard the process of saponification.

As glycerine has no kind of resemblance to soap, as regards its reaction with saline solutions and caustic lye, but dissolves in them all with perfect ease, the use of common salt affords a ready means of separating this and other foreign matters from the soap.

It is perfectly impossible, during the preparation of soap, to avoid entirely the presence of the earths and metallic oxides. These, consequently, always decompose a small portion of the soap, combining with the fatty acid which they take from the alkali. Portions of lime and magnesia constantly accompany the caustic lye, and are brought with it into the boiling pan, and the sides of this vessel are always sufficiently acted upon to impart a visible trace of iron or copper to the soap. The soaps formed with lime, magnesia, iron, and copper, are not soluble, and they are much less rapidly softened by heat than the corresponding alkaline compounds. They are disseminated, however, in such a minute state of division throughout the mass of hot soap, as amounts almost to solution. As the soaps of iron and copper possess the colors peculiar to the salts of those metals, the whole mass of soap acquires by their presence a uniform greenish or blue color. This color is partly caused by the sulphur contained in the lye, (particularly in soda lye,) forming sulphuret of iron or copper. When a soap of this kind is allowed to cool rapidly, the cut surface presents a uniformly colored appearance, something like wet slate. If the mass, however, cools slowly, the soaps of the earths and metallic oxides separate from the great bulk, and collect into larger or smaller groups in different parts with a certain degree of regularity, giving a *marbled* or *mottled* appearance to the cut surface. Colored veins are then seen disseminated over a white ground; these are numerous and small when the soap is quickly cooled, and larger and farther apart when the cooling is less rapid. The soap assumes the appearance of granite when it has been very rapidly cooled. Sulphuret of iron is the chief coloring matter of the veins; and when this is present, the speedy disappearance of the blue color, on exposure to the air, is explained by the oxidation of the sulphuret of iron, and nothing is left but the reddish yellow color of the real iron soap. It is obvious, that the substances which impart the mottled appearance to soap, are only held in suspension in consequence of its thick state of fluidity. If the mottled appearance is to be entirely removed, and white soap produced, it is necessary to add a quantity of water, that those substances may be enabled to subside whilst the soap is still in a perfectly liquid state in the boiling-pan. This additional quantity of water is not again separated, but is sold with the soap. This is the reason why so much importance is attached in commerce to the mottled appearance of the soap; as it is a sure indication to the consumer, that the amount of water in the soap cannot extend beyond a certain limit, which is very much exceeded in white soap. It must, however, be borne in mind, that methods have lately been discovered of imparting any kind of mottled appearance to soap containing much more water than ordinary curd soap, by mixing mineral colors with it when it has attained a certain stage of hardening.

It is self-evident, that mottling can only be applicable to hard, and never to soft soap.

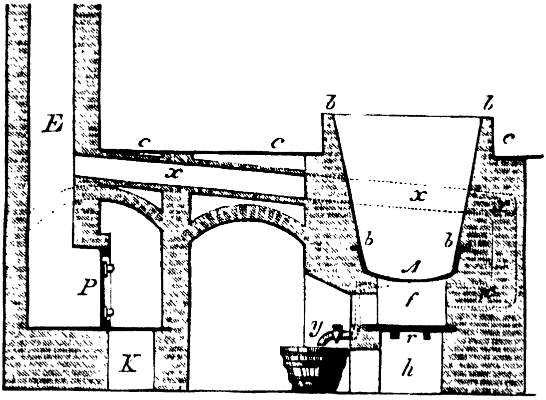
Process of Soap Boiling.—The use which has been practically made of the foregoing principles in the manufacture of the most important kinds of soap will now be seen from a series of examples.

Marseilles, (Venetian,) or Olive Oil Soap.—The saponification of olive oil by means of caustic soda, forms an extensive and flourishing branch of industry in the southern countries of Europe (in the south of France, north Italy), and on the northern coasts of Africa; in those parts, therefore, where the olive-tree is a native of the soil. With reference to the oil itself, the relative value of the different kinds depends upon their amount of color, and of the fatty substance recognized by Pelouze and Boudet, as a combination of oleine and stearine. The value of the oil increases with its want of color, and with the quantity of stearine which it contains; it is in proportion, therefore, to the facility with which it becomes solid in the cold. The oils of Provence rank first for excellence. The finest salad oil is too costly for the manufacture of soap, but the oil obtained by the second pressing is peculiarly adapted for this purpose, on account of its cheapness and larger amount of stearine. Sometimes a small quantity of seed oil is added to it, that the soap may acquire a somewhat softer consistence. The lyes prepared by lime from soda are of three different strengths; the strongest lye is indicated by 20° to 25°, the lye of middle strength by 10° to 15°, and the weakest by 4° to 5° of the hydrometer. All three are preserved separately in walled cisterns. Formerly, when saponification was carried on only with natural soda ash, the chloride of sodium contained in the ash was also dissolved in the lye; but as the presence of this salt is very objectionable in the first stage of the boiling process, and is only necessary in the subsequent additions of lye, an evil is incurred by employing it, which is not the case when artificial soda is used. Pure soda is, therefore, taken for the first lye, and, afterwards, soda containing chloride of sodium, which is especially prepared for this purpose (see p. 273).

The quantity of soap which is made at once, is technically termed a "*boil*," and the operation is commenced in two boilers, and finished in one only. The plan of the apparatus may be seen in Fig. 154.

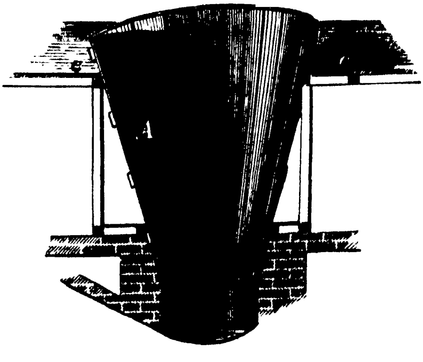
The bottom and lower part of the boiling-pan *A* is of cast iron or copper. The sides are composed of brick-work erected and lined with cement (mortar resisting the action of water). This upper part *b b b b*, which never comes into contact with the fire, and is intended to afford space for the soap to rise, expands in the form of a cone. The fire-place *f* is separated from the ash-pit *h* by the grate *a*. The fire, after having heated the bottom of the pan, passes by the flue *x x x*, half round the side of the pan into the chimney *E*. This is accessible for the purpose of cleaning by the door *P*; the soot is thrown into the pit *k*. A tube with a cock leads from the lowest part of the pan, for the removal of the (under) lye. The whole of the pan is sunk into the floor of the boiling-house, which is made of planks, stone, or iron plate, in such a manner that the brick-work of the upper part projects to about 3 feet above the floor.

Fig. 154.



The pans or boilers are calculated to contain 240 cwts. of soap. The upper part is frequently constructed of mere staves, without any bottom, and these are fixed, water-tight, into the rim of the boiler, Fig. 155. This arrangement is quite as convenient, and much cheaper. Sometimes a syphon is introduced between the bottom and the upper part, instead of the cock and tube *y*. The plan of surrounding the pan with an external casing, and using the intermediate space for the purpose of applying steam heat, has been abandoned, as it is preferred to run some risk of burning rather than forego the advantage of tur-

Fig. 155.



bulent ebullition. This latter is valuable from its mechanical agency, and answers the purpose of a stirring apparatus; it can only be effected by an open fire.

A boil, which comprises generally 120, 140 to 160 cwts. of oil, passes through three stages: the preliminary boiling (*empatage*), the cutting up the pan (*i. e.*, the addition of saline lye, *relargage*), and the clear boiling (*coction*), to which, for mottled soap, the marbling or mottling process (*madrage*) must be added.

For the preliminary boiling, a lye of from 8° to 11° is used, and this is prepared in the boiler by mixing together weaker and stronger lye, free from common salt. As soon as it has attained the boiling point, the whole of the oil is admitted at once, and combination is accelerated by stirring. A dirty whitish mass, like an emulsion, is produced; if this appear too thin, which results from an excess of lye, more oil is added; if, on the contrary, oil is seen floating on the surface, there is then need of more lye. In a short time, the temperature, which had been lowered by the addition of cold oil, again rises, and the mass begins to boil steadily, becoming thicker and thicker as the water gradually evaporates. This first action of the oil and alkali can only take place rapidly and completely, when the soap remains dissolved in the lye. An excess of lye of 8° to 11° may, however, produce a contrary effect; it then becomes necessary to add an extra quantity of weak lye, and stir until no further separation is visible. During this preliminary boiling, the mass of soap, inasmuch as it is dissolved in the lye, comes into immediate contact with the sides and bottom of the metallic vessel. Hence, when the whole has acquired a thicker consistence, a portion frequently attaches itself to the bottom of the vessel, becomes overheated and burns. This burning is indicated by a black smoke (called by the Provençales, *tabaco*), which passes off here and there with the vapor, and is a sign to reduce the fire as quickly as possible, and prevent the evil from increasing by adding some gallons of the strongest lye. By this means a slight separation of the soap from the lye is occasioned, and the contact between the former and the metallic surface destroyed. In the ordinary process, when such interruptions do not occur, the soap boils steadily, throwing up froth as high as the breast of the boiling-pan. Towards the end, the proper quantity (6 to 8 lbs.) of green vitriol is added, for the purpose of mottling, this is immediately precipitated by the lye, partly as sulphuret of iron, and partly as iron-soap. As soon as the mass of soap has become perfectly uniform, and has acquired the proper consistence, *i. e.* is no longer like an emulsion, but has acquired more completely, though not entirely, the nature of soap, the fire is extinguished, and the salting process begins.

The lye which has been added up to this period relinquishes the whole of its alkali to the oil, and remains merely as water, of which a small portion only is evaporated in the pan. If the stronger lye were added at once, it would become instantly diluted by the excess of water, and the object which it is intended to serve would be defeated. This water must, therefore, be got rid of, not, however, by boiling, but by means of common salt, or rather by the lye containing common salt already spoken of. Whilst one workman pours this gradually into the boiler, another is occupied in stirring the two thoroughly together, until the soap—having become insoluble in the solution of salt—begins to congeal, and separate in flocks. In the course of three hours, the soap has so far separated that the lye below it (*under-lye*) may be drawn off. The quantity drawn off must amount to double that of the saline lye employed. The soap is now all scooped into *one* pan to undergo the clarifying process, and soap and lye are allowed to boil with only just sufficient common salt to keep the soap perfectly distinct, as, if this were not done, the thick mass would certainly attach itself to the vessel. When the fire has again burnt up, about 220 gallons of a mixture of pure and saline lye of from 18° to 20° are added, and the boiling is continued. The workmen keep the boil constantly stirred, particularly the surface, partly to hasten the combination of the caustic soda, and partly to prevent the liquid from boiling over. During the preliminary boiling, the caustic soda combines rapidly with the fat, (the soap is then said to "eat well,") and this is also the case in the first period of the clarifying process, but the nearer the process approaches to a close, the more difficult it becomes to incorporate the last deficient portions of soda with the soap. The further assumption of soda is now chiefly dependent upon the state of concentration of the lye (solution of salt) in the pan; if this is too concentrated, the soap becomes too dense and dry. To establish the proper relationship between the water in the soap and that of the lye, it is necessary that the amount of salt in the boiler should not exceed a certain limit. When, therefore, the caustic soda of the lye has been incorporated with the soap, or when the lye appears no longer caustic, and produces no burning sensation on the tongue, that which is in the lower part of the pan is drawn off, and is replaced by a fresh portion, about 275 gallons—of the same mixture of lye. The future stages of the process consist in four, five, or six repetitions of the same operation,* during which the soap acquires greater consistence, and the alkalinity of the lye is each time less easily destroyed. At length, the lye retains its entire alkalinity, and the soap, now near its completion and highest consistence, begins to boil in jerks, and not smoothly and steadily as before. The frothy mass begins to form itself into granules, the soap takes the form of curd, and the clarifying process is finished. The curd, when pressed against the flat part of the hand, should form a firm, granular, crumbly mass. The smell of oil is now no longer perceptible. According to the nature of the oil, and the state of the weather, the fire is kept up 10, 12, or 18 hours after the addition of the last portion of lye, and is then extinguished.

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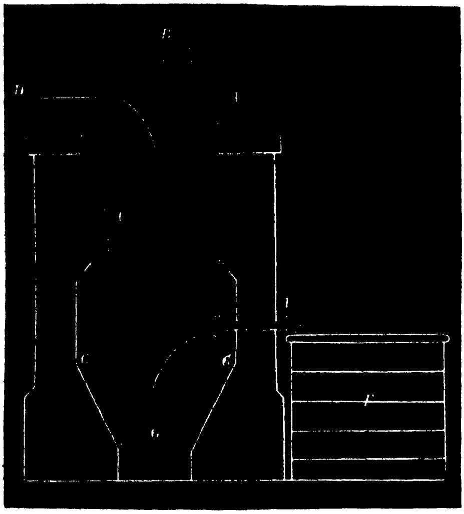
* If lye could be procured quite free from common salt, which is never the case, there would be no need of drawing it off, and the boiling might be completed with one and the same quantity of common salt. The lye as it is actually employed, however, would soon raise the amount of common salt to an injurious extent.

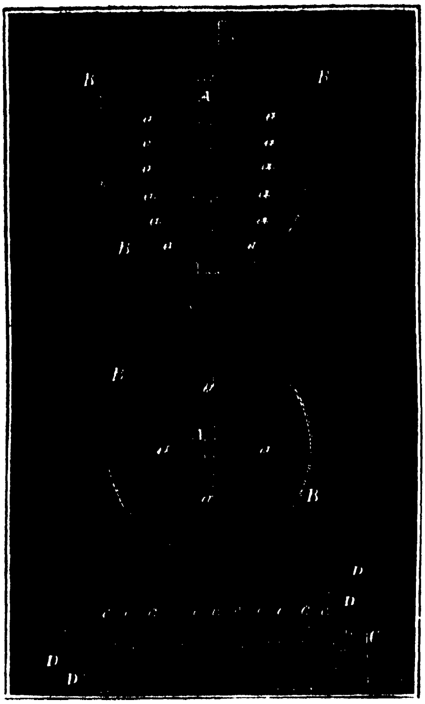
Instead of boiling the lye and tallow, or oils, in an open vessel, which is attended with much waste, in consequence of the difficulty of combining the whole of the ingredients with each other, Davis has patented a process for performing this operation in a close boiler under pressure. The boiler is furnished with a man-hole door *A* (Fig. 156), safety-valve *B*, and all the ordinary appendages of such an apparatus, with a thermometer plunged in a mercury chamber *C*. *D* is the feed-pipe, *E* the discharge-pipe, and *F* the pan, or frame, for the reception of the soap; *G G G* shows the fire-place and flues for heating the boiler. The valve is pressed until the temperature in the boiler rises to 310° F., and the boiling is complete in about an hour after the heat has attained the above degree.

Fig. 156.



On the other hand, Mr. Hawes, the great soap-manufacturer of London, has patented a process for effecting the saponification by mechanical means, without boiling, whereby he saves fuel, and obtains a more beneficial result than by the usual method of boiling. The process consists in melting a certain quantity of tallow, mixing with it sufficient alkaline lye by mechanical means, so as to saturate completely the tallow. He employs about 20 gallons of a lye of 1.125 sp. gr., for every 100 pounds of tallow. The apparatus (Fig. 157) consists of an upright shaft *A*, from which the arms *a a a a* radiate to the sides of the kettle *B*, or a cylinder may be employed with a shaft *C* passing through it horizontally, from which arms *c c c c* radiate in the same manner. An oscillating, or rotary motion is communicated to these shafts in the ordinary manner. A cylinder, 6 ft. diameter and 12 ft. long, is adapted for working 2¼ tons of tallow. Convenient doors, *D D*, are attached for changing and emptying the cylinder. The container is charged with the tallow first, and the lye is afterwards gradually added, while the agitation is continued for about three hours, and the whole is then allowed to stand for some time, varying according to the quantity of materials employed.

Fig. 157.

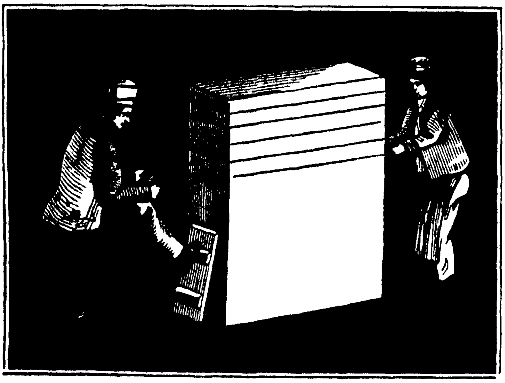


As the benefit of the process arises mainly from the saponification of the materials in a comparatively cold state, the contents of the kettle, or cylinder, as soon as they have thickened, are removed into an ordinary boiler, preparatory to their being finished, and converted into yellow or white soaps, as the case may be.

In consequence of the iron and sulphur in the soda, and the green vitriol which was added, the curd has a uniform slate-color, produced by the sulphuret of iron and iron soap. These substances must not, however, remain uniformly disseminated through the mass, but must be diffused as veins, in order to give the mottled appearance to the soap. But the proper consistence, which has been somewhat exceeded, must first be imparted to the curd, and this is dependent upon the strength of the under lye. With this object in view, the contents of the pan are left at rest for ½ an hour, until the under-lye has collected, and this is then drawn off. A tedious operation now begins: some workmen mount upon boards laid across the pans, and work the mass about with rakes, whilst others, at measured intervals, sprinkle the surface with weak lye. The motion of the stirrers must be carried on in such a manner as to bring the lower parts of the curd to the top, partly, that all portions may be equally impregnated with lye, and partly to mingle the colored parts, which have chiefly collected at the bottom during standing, with the rest of the mass. During this operation the roundish grains open, and unite to form a uniform, connected, tough mass. As soon as the boiler perceives that the proper consistence has been obtained, which very much depends upon the strength of the lye worked in, he has the mass scooped into the *moulds,* where, in eight or ten days, (with the above quantity,) it cools down to mottled soap. Exposed to the air, the color of the mottling changes, becomes clearer, so that the reddish tint, called *manteau Isabelle,* is diffused over the bluish mottled mass.

A layer of lye is always found at the bottom of the mould when the soap has cooled. These moulds consist of wooden boxes with movable sides, which can be wedged together or separated at pleasure. The cold soap is cut into square bars before it is sold. According to Poutet, 100 parts of olive oil produce on an average 155 to 158 parts of soap. The process of cutting soap is shown in Fig. 158.

Fig. 158.



In the preparation of *white soap* the same process is followed in the beginning, with the exception of the addition of green vitriol, which is of course omitted. Towards the end, however, certain deviations are necessary, with the view of separating by subsidence the iron compounds which may have been formed, and the impurities. This is done by softening and liquefying the finished soap, by the addition of lye and heat to such an extent, that the superior gravity of the iron compounds may enable them to sink below the lighter mass of soap. After standing for a sufficient length of time, the soap is pure, and of the ordinary yellowish white color; the precaution is, however, taken of pouring it through sieves into the mould, to keep back any casual impurities. After the removal of the white soap, there is always a residue of dark colored soap left behind. This amounts to $\frac{1}{8}$th of the whole mass, and it may be used for the purpose of mottling.

It is evident, that the French oil-soap belongs to that class of soaps which are always brought into the mould with a greater portion of water than is necessarily present in the curd. In mottled oil-soap, this excess of water is reduced within certain limits, which cannot be exceeded without causing the separation of the mottling. In white oil soap, on the contrary, the quantity of water is left entirely to the option of the boiler; he can incorporate as much water with the soap as it will bear without impairing its firmness.

Curd Soap from Tallow, German, upon the old Plan.—The original German process, of preparing hard (soda) soap from tallow is interesting and remarkable, because, by the use of certain ingenious contrivances—derived from very ancient experience, which have been confirmed, approved, and explained by modern theory—it enables us to obtain an exceedingly pure and perfectly hard curd soap from a very impure material, viz.: from crude tallow, and the lye of ashes, or from potash lye.

An imperfect potash-soap is first prepared, which, in the subsequent boiling, is converted into soda-soap; this is supplied at the same time with an excess of alkali, and the neutral soda-soap produced, is then boiled down to curd.

The indications of progressing saponification, through all the grades of the process, are so distinct, that nobody ever entertained a thought in the first instance of working with weighed quantities. All that was necessary was to add more lye or more fat, according to the appearance of a specimen, until the proper state had been attained.

The ashes are treated with lime exactly in the manner stated above, and as much tallow is added as the saponifying tub is thought capable of converting into soap; the boiling is begun with lye of 20°. The melted tallow immediately forms a kind of milk with the lye, in which the constituents, although not by any means in complete chemical union, are, nevertheless, in such a state of combination, that they cannot be distinguished from each other. On continued boiling, this mass becomes more and more translucent, clearer, and more thickly fluid, and the fire must consequently be regulated with care to avoid burning. When finished, the result is a very uniform, slightly colored, clear transparent solution of potash-soap in the water of the lye (or in weak lye, when the whole of the potash is not in combination), and has altogether the appearance of a thick syrup. It is obvious, that this transparency cannot be brought about, as long as there is unsaponified fat present; this it is which, swimming about in small globules, gives the mixture the appearance of milk. This turbid appearance is a sure indication that more lye is requisite, and that the boiling must be continued, but it is always better to dissolve a few drops of the mixture in pure rain-water, that no deception may occur. It is just possible, that the turbid appearance might arise from an excess of lye, or, as it is technically termed, from the soap being *overdone.* The water dilutes the lye, and the real nature of the soap then becomes apparent. If the lye contains free lime, the turbid appearance may arise from that cause, but it should then disappear on the addition of a little carbonated alkali. When, therefore, the milky nature of the solution continues after this addition, there is certainly a want of alkali, and the boiling must be continued. The lye employed for this purpose is much weaker than that used at first.

When the solution has become sufficiently clear, and flows from the spatula in a thick continuous stream, (not in drops,) which can be wound round it like treacle, and solidifies to a thick jelly when thrown upon a cold stone, the *salting process* begins, *i. e.*, salt is thrown into the pan (previous solution being unnecessary,) and is allowed to boil with the solution of soap until it is dissolved, and begins to act upon it.

The soap having become insoluble in the solution of salt, coagulates into a whitish mass consisting of small flocks, and on being removed from the pan, allows the mother liquor to run off from the interstices. After remaining at rest for some time, the under-lye subsides, and can be drawn off from the pan. If the pan has no exit tube and stop-cock, as is the case in the German soap works, the soap is scooped in the meantime into the *cooling cistern*, and the under-lye can then be removed.

The process of salting answers several purposes. In the first place, it effects a chemical decomposition of the soap, for potash-soap and chloride of sodium mutually decompose each other, and produce soda-soap and chloride of potassium. This, together with the excess of common salt, causes the separation of the soda-soap, and the formation of the under-lye. In this separation, the excess of lye, the foreign salts in the ash, and the impurities—chiefly those produced by the action of the lye upon the membranous parts of the crude tallow—are all taken up by the under-lye. The salting process is, as it were, a means of washing the soap, and enables us to obtain it quite clean, although the crude materials used in its production were not so.

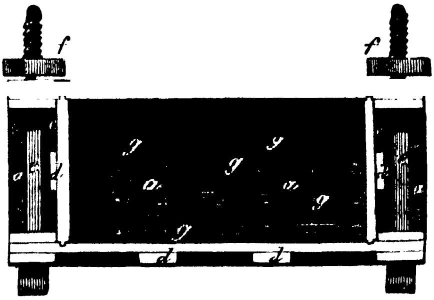
Attention has already been called to the fact, that ashes—in consequence of the foreign salts which they contain—do not afford strong lye; indeed, the lye obtained from them is so dilute, that hardly any pan would be large enough to contain the whole quantity of fluid necessary to supply the amount of potash required to saponify an ordinary charge of fat. Another important function, therefore, devolves upon the salting process, that of separating from the soap the excess of water, which would otherwise render the later additions of lye inefficient, (as was the case in the preparation of oil-soap.) It is also worthy of notice, that many soap-boilers make the addition of salt long before the potash-soap is completely formed. Although the soap is not spoilt by this mode of proceeding, inasmuch as it must always be subsequently boiled with alkali, and therefore has an opportunity of making up the deficient quantity; yet, it is not advantageous, for this reason, that an imperfect soap is not completely decomposed by the addition of salt, but remains viscid, and retains the under-lye in great part, which is quite opposed to the object in view.

When the under-lye has subsided sufficiently, the coagulated soap is again brought into the clean pan, and boiled with an addition of weak lye. After some time, it re-dissolves completely in this weak lye, forming a solution as at first, with this difference only, that it now chiefly consists of soda soap. At the same time, more potash enters into combination, assisted by the viscid nature of the mixture, and this is promoted by an addition of lye from time to time. Lye is constantly added in this manner, until the soap is gradually saturated with alkali. Before this point is attained, the process must be often repeated; and, indeed, the number of repetitions must increase with the impurity of the ingredients, and the dilute nature of the lye. Formerly, when crude tallow was commonly used, five repetitions of the process were hardly sufficient; under other circumstances, it may be finished in two. The boilings subsequent to the first, are performed precisely in the same manner, only less salt is required at each repetition, as there is naturally less potash-soap to be decomposed at the end than at the beginning.

When the last portion of water has been added, which may be the second or sixth portion, according to circumstances, or when the soap has become sufficiently firm and pure, it is then boiled clear, *i. e.* boiled until it has acquired the proper proportion of water. The same phenomena then occur as those already described, the solution of salt becomes more and more concentrated by boiling, and extracts the water from the soap. This first boils softly, throws up froth to a considerable height in small bubbles, until, at length, the frothy surface forms large brilliant bubbles, and the peculiar sound is produced under the boarded covering of the pan. Lastly, when the froth sinks down, and the curd itself boils in jerks, when, on applying the thumb-test, a connected, flexible, shining thread is produced, which is neither brittle nor slimy, when the lye has entirely lost its burning, alkaline taste, or nearly so, the fire is then extinguished, and the soap is skimmed off from the under-lye into the coolers.* From thence the liquid mass is transferred to the mould, over the bottom of which a linen cloth is spread, that the lye may more easily drain away. To enable the curd to form a connected mass of soap, and promote the separation of the lye, it is necessary to stir the soap with an iron rod before it completely solidifies. By performing this operation with a certain degree of regularity, the mottling, which ensues spontaneously in the German soap without any additional help, assumes the desired appearance.

The moulds should be so constructed as to afford, at the same time, a space sufficiently closed from which no soap can escape, and yet be easily taken to pieces, as is the case with the moulds commonly used in Germany, Figs. 159, 160, 161 and 162. The bottom *a a*, seen at full breadth in Fig. 161, and in longitudinal section in Fig. 162, is constructed of two layers of planks. In the upper one there are four grooves *b b*, into which the projections in the sides fit. The two narrow sides are also supported on the inside by the cross pieces *c c*. All the sides

Fig. 159.



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* In the German soap-works, the pan has seldom an exit-pipe for drawing off the lye; when this has to be removed, the soap is scooped from the pan into a vessel by the side of it—the cooler—until the pan is emptied. This cooler is placed in such a manner near the pan, that any soap which may boil over shall fall into it, and not upon the ground.

are strengthened by the supports *d d*. When all the parts are put together, the bolts *e e*, having screws at the other end, have only to be inserted through the projecting parts of the longer sides, and made fast by the nuts *f f* at the ends, to form the whole into a solid box. A cloth spread over the bottoms, prevents any soap from passing the holes *g g*, through which the lye drains off.

g. 160.

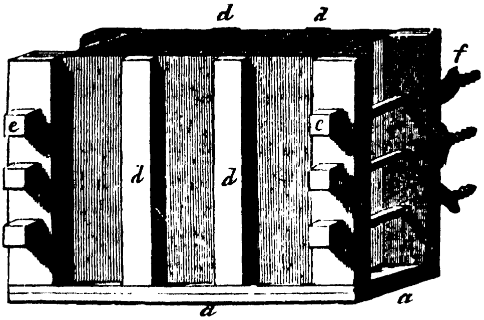


Fig. 161.

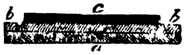
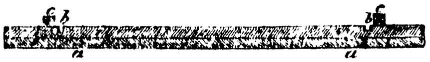


Fig. 162.



The German soap-boilers also, call the crystaline matter, which separates in the mottling process from the amorphous matrix, *curd* and *flux*, terms which are often confounded with each other, the one calling curd what the other calls flux, and *vice versâ*.

The process which has here been described for preparing tallow-curd-soap, is technically called, *boiling for lime*, inasmuch as the mass is always completely dissolved before the salt is added. There is one advantage in this plan, that the action of the lye is very much facilitated, but it is also attended by a great evil, *i. e.*, the soap easily burns, and becomes discolored by the impurities in boiling, and acquires also a disagreeable odor. This is obviated by many soap-boilers, who introduce a little salt with the lye, "*boiling for curd*," in which case the soap never forms a viscid solution, but is always somewhat separated from the lye, (which should be thoroughly caustic,) and consequently does not burn or mix with the impurities. When the soap boils too quietly, salt is added; when it boils in jerks, an addition of weak lye is made, that the proper mean may be preserved between the state of solution and complete separation by an excess of salt.

The unmottled *clear-white soap*, which is more generally used in some parts than mottled soap, is prepared upon the same general principles; instead of removing the colored portion (the flux) by subsidence, as in France, white soap is fabricated in Germany by preventing the separation of the colored portions in veins and groups by a quick process of cooling. This then remains disseminated throughout the mass of the soap, and gives it a gray tint. All additional matter, which is used to increase artificially the natural mottled appearance, is here, of course, omitted.

According to direct experiment, 100 lbs. of tallow will produce 150 to 155 lbs. of perfect curd-soap, weighed as soon as it is cut; and the reason why some soap-boilers obtain more, (sometimes as much as 200 lbs.,) is only because they are forced to add water in order to compete with soap of an inferior quality. Real curd-soap is now seldom to be met with, and what is sold as such, is always more or less mixed with water. At present, the use of crude tallow is abandoned, as a useless retardation of the boiling process, and rendered, or purified tallow only is used.

The membranous portions, which are converted into glue during boiling, are decomposed by a portion of potash, and this portion is saved by the present plan. In the best manufactories, the nauseous odor is unknown which before infested the boiling-house and its vicinity, and was derived from the impurities of the tallow. Since the want of wood has become more perceptible, and pure wood ashes consequently more scarce, and since the manufacture of soda from common salt has been so extensively carried on, and the foreign fats, palm and cocoa-nut oil, have been introduced at prices often below that of tallow, the original plan of preparing soap from tallow and the lye of ashes has fallen into disuse, and threatens to become entirely forgotten.

It will easily be understood, that it is a much safer process, and more rapidly completed, when the tallow is boiled with a lye prepared from potash, because there is then no necessity for making so weak a lye, and we are able to ascertain accurately the amount of alkali present, which, in the case of ashes, it is difficult to do, in consequence of the large amount of foreign salts. Notwithstanding the price of pure potash is too high to admit of its being used alone, yet the addition of potash to a lye prepared from ash enables the soap-boiler to work larger quantities of tallow at a time. The boiling is conducted precisely in the same manner as was the case with lye from ashes, only that it is unnecessary to add so many consecutive portions of salt.

The boiling is conducted with still greater ease and rapidity when *caustic lye from soda-ash* is employed; from 8 to 10 cwts. of tallow can easily be converted by its means into soap upon the same water. Less common salt is likewise necessary in this case, partly because calcined soda generally contains some of this salt, and partly because the portion previously required for the decomposition of the potash-soap is now no longer needful. Another saving, not altogether inconsiderable, is effected in consequence of the equivalent of soda being smaller than that of potash, 2 parts of hydrate of soda combining with the same amount of fatty acid as 3 parts of hydrate of potash. All soap prepared directly from soda lye (but not all that contains soda) is called in Germany *soda-soap.* The celebrated white or Windsor soap of England belongs to this class, and is not unfrequently made from soda obtained from the ashes of marine plants.

Cocoa-nut Oil Soap.—The consumption of cocoa-nut oil has increased enormously since its first introduction into Germany in the year 1829 or 1830. Differing in origin and constitution from the other oils and from tallow, its reaction with saponifying agents is also quite peculiar. It has been found by experience, that the soap prepared from this oil can only be separated from solution by very strong solutions of common salt. Weaker brine acts very imperfectly upon it, in fact, the soap is soluble in dilute brine.* As this kind of soap can only be obtained by the use of a very large quantity of common salt, and then contains so very little water, or is so exceedingly hard that it cannot be cut with a knife, this mode of proceeding cannot be had recourse to upon a large scale. For the same reasons, a clarifying process or boiling down to curd would be equally objectionable, and very difficult. Whilst tallow, for instance, when treated with very strong lye, comes to the surface and is but slightly acted upon, exactly the opposite occurs with cocoa-nut oil. It does not form that kind of milky mixture which generally indicates the commencement of saponification, but swims as a clear fat upon the surface; when, by continued boiling, the lye has attained a certain degree of concentration, saponification suddenly begins, and proceeds with extraordinary rapidity. For this reason the soap-boilers only employ the strongest soda lye, of at least 20°, and are able to dispense with the use of salt in purifying the soap, by employing pure and perfectly caustic lye, and avoiding any excess as much as possible. Pure cocoa-nut oil soap hardens much too quickly to exhibit any distinct formation of curd, and is consequently incapable of marbling of itself; it is very white, translucent like alabaster, exceedingly light, and forms a good lather, but always possesses a disagreeable savor. No means have as yet been made known to remove this smell, although, it appears, that several manufacturers are possessed of the secret. An important property of cocoa-nut oil soap, is its power of combining with more water than can ever be communicated to tallow soap, and this property of the soap frequently gives rise to, or encourages dishonest traffic. Cocoa-nut oil actually produces no greater quantity of soap than an equal weight of tallow; but the soap from the former can easily be made to absorb ⅓rd more water or lye. Ordinary soap treated in the same manner, or containing the same quantity of water, would be so soft, that it would yield easily to the pressure of the thumb; whilst cocoa-nut oil soap, on the contrary, neither exhibits any want of consistence or softness, nor does its appearance in any way indicate the fraudulent practice which has been adopted in its manufacture.

It has been observed by soap-boilers, and the remarkable fact is by no means satisfactorily explained, that cocoa-nut oil is saponified with so much the more difficulty the more rancid it has become.

In general, cocoa-nut oil is not saponified alone, but is employed as an addition (to tallow, &c.) for the purpose of producing quickly solidifying soaps containing a large proportion of water, which could

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* It is highly probable that marine soap is prepared from this fat. It is a kind of soap to be used in washing with sea water, which will not dissolve ordinary soap.

not be obtained from tallow alone. It is even possible to prepare soap on a large scale in a few hours, without salt and almost without fire, by the use of cocoa-nut oil and tallow, which are merely warmed together with strong lye sufficiently to melt the fat, and kept in a constant state of agitation. Soap prepared in this manner has a fair appearance, and sets in the mould, so that it can be cut; it contains, however, nearly all the water of the lye (there being hardly any evaporation in the pan) with the entire amount of foreign salts, and in the fresh state has less resemblance to soap than to stiff dough, which takes deep impressions of the thumb, and when squeezed between the fingers has a slimy consistence. When dried for a length of time, during which there is a copious efflorescence of foreign salts, it acquires at last the consistence of ordinary soap.

The less cocoa-nut oil is used in the manufacture of soap, the more imperceptible its smell becomes in the lather, but the boiling of the cheap soaps, which harden quickly, and which combine an excessive amount of water with the appearance of ordinary tallow soap, is exceedingly difficult. When equal parts of cocoa-nut oil and tallow are used, the soap has the smell of common tallow soap. The boiling is continued until a specimen exhibits the proper consistence under the thumb. It would be impossible to saponify tallow under the same conditions, but the saponification begins with the cocoa-nut oil, which induces the action, and the saponification of the tallow is then effected by means of the presence of the cocoa-nut soap.

The different kinds of cocoa-nut soap, which all belong to that class of soaps that contain a considerable quantity of water, are marbled artificially. Marbling or mottling of this kind is not dependent upon the production of *Curd* and *Flux*, but is simply a mechanical effect carried out in the following manner. The blue or red color (bolus, &c.) is rubbed up with a residue of the soap, or better, with a separate portion of good cocoa-nut soap, until the whole acquires a uniform red or blue color. This is now scooped into the form in alternate layers with the colorless soap, and by stirring the mass together, streaks and veins are produced in all directions. It is evident, that this kind of mottling has nothing whatever to do with the natural mottling that occurs in the other kinds of soap.

Palm oil Soap.—This soap is boiled almost precisely in the same manner with caustic soda as tallow soap. It has an agreeable but powerful smell, and a yellow color when the oil was used in an unbleached state, but is white, with a very slight odor, when the oil has been bleached. Palm oil is most frequently used as an addition to the following kind of soap.

Rosin Soap.—Colophony combines at the boiling temperature, when it is perfectly fluid, much more rapidly and with greater ease with the alkalies than the fats themselves. This kind of combination, which can scarcely be called saponification, ensues equally well with carbonated as with caustic alkali, and no particular precautions are necessary in conducting the process. The soap separates on the surface when an excess of carbonate is used, or in the presence of common salt, as a thick slimy brown mass, smelling strongly of rosin, and containing 15.8 per cent of dry soda. The amount of water in this soap, although not exceeding 27—30 per cent. is, nevertheless, sufficient to communicate to the soap a smeary, viscid consistence, which is not altered by long exposure to the air. The attraction of the soap for water is so great, that it not only does not lose its water, but becomes liquid on exposure after having previously been dried artificially. A portion of the rosin, however, appears to remain dissolved in a modified state in the under-lye, judging from the deep brown color of the latter. Although rosin soap by itself is thus unfitted for use, an excellent and perfectly firm product is obtained by its combination in certain proportions with tallow and palm oil soap. The amount of rosin in this mixture should not exceed ⅓d of the fat; if equal parts are used, the properties of the rosin soap become too prominent, and a soft bad soap results. The best plan of preparing this soap, is to saponify the rosin and tallow separately, and to mix the two soaps in the boiler, where they are retained in a state of ebullition for some time until a uniform mixture has been effected; salt is then added, and the soap brought into the moulds. It is not advisable to mix the separate soaps in the moulds, which is a plan sometimes adopted. In England and America, where rosin soap was first manufactured, it is usual to add the rosin in the form of coarse powder, with the last quantity of lye to the fatty (palm oil) soap; consequently, before the boiling is finished: and to boil the mixture with the necessary addition of lye for completing the formation of the resinous compound. This point is attained when a cooled specimen presents the proper consistence, and leaves no film of rosin when used for washing the hands. The boiling finishes with the addition of some weak lye to the soap which has already separated from the under-lye; this addition is made in order to facilitate the deposition of the impurities with which commercial colophony is always mixed; the soap is then carefully filled into the moulds. Rosin soap has a brownish color, which passes into that of yellow wax (yellow soap) when palm oil is used, and this of course requires no previous bleaching. It is very firm, somewhat rough to the touch, and very translucent; it produces an excellent lather, but always retains the smell of rosin. The low price of rosin renders this soap cheap, and for common washing purposes, where the smell is not an objection to it, it is a highly useful product.*

Soft Soap.—The substance commonly called soft soap is a more or less impure solution of potash oil soap in caustic lye, and not an actual soap; it forms at ordinary temperatures a transparent smeary jelly. If an attempt were made to separate this soap from the lye by means of salt, the potash soap would be converted into hard soda soap by the chloride of sodium, and the object in view thus frustrated. Recourse cannot consequently be had to a method of purification of this kind,

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* Instead of rosin, raw turpentine, when sufficiently cheap, is said to be sometimes used, with the advantage of yielding a soap of lighter tint, but otherwise of very similar characters to many rosin soaps.—Am. Ed.

and to render all purification less necessary, pure potash lye is employed instead of the crude lye from ashes; this is kept ready, of different strengths in separate cisterns. The weaker lye must be perfectly caustic, but this is neither necessary nor desirable in the stronger lye, which is prepared in the cold. Soap-boilers have found by experience, that the boiling is easier when these lyes are slightly carbonated. Amongst the oils employed are hemp, linseed, camelina oil, and poppy oil, which belong to the class of drying oils, and do not become solid at 0° (32° F.); also the different varieties of rapeseed and train oils, which do not dry up, and become partially solid at 0° (32° F.). The former produce a softer kind of soap; the latter soap of firmer consistence; it is hence usual to mix the oils in different proportions, according to the season of the year, choosing the drying oils in the winter, and the others for the summer, when the market price admits of this selection being made.

In boiling soft soap, the weaker lyes from 9° to 11° are first used, and a moderate heat is applied and kept up until complete combination is effected, *i. e.*, until a thick sticky fluid falls in streaks from the stirrers; this ought to possess a shining appearance, and although it may be somewhat turbid, should not resemble soap separated by means of salt.

As soon as it clearly evinces these properties, the clarification commences with the gradual addition of the stronger lye. This is kept up at equal intervals, until the soap passes from the state of a turbid imperfect mixture to that of a clear transparent slime. When this state of things is too tardy in making its appearance, in consequence of too great dilution, the operation is assisted by an addition of very strong lye. The clarification completes the chemical combination of the constituents, which is indicated by a peculiar test; but the soap still requires the proper proportion of water to render it saleable. The tests employed for ascertaining these points are very empirical in their nature, but, nevertheless, they are distinctly marked, and of quite a peculiar character. The soap-boiler is enabled to ascertain, by the presence and extent of turbidity in a cooled drop, whether chemical combination has been effected, or what is the cause of failure. When a specimen free from scum is taken with a spoon from the middle of the soap-pan, and a drop of the size of a sixpenny-piece is allowed to fall and cool upon a piece of clean colorless glass, several cases may occur: the drop either remains perfectly clear, in which case the soap has attained the proper state of mixture; or it exhibits on the margin only a gray rim, which indicates a want of lye, and this in proportion to the breadth of the rim. If this deficiency is very great, the rim is not only exceedingly broad, but the specimen itself is fluid and slimy. The opposite must, of course, occur when the proper quantity of lye has been exceeded, and the soap is overdone. This is easily recognized by the consistence, and by a gray skin, which spreads itself over the whole drop instead of forming a ring or rim only. The soap is then granular without lustre, and is easily detached in the wet state from the glass, (it is technically said to be *vitreous*?) It is advisable to follow the process closely, by constantly trying specimens from the period when the soap begins to boil clearly until the end of the process. The lamination is the removal of the excess of water by evaporation, for in this process, as has been stated already, the use of salt for that purpose is inadmissible. The soap is kept in a frothy state by increasing the fire, and the evaporation of the vapor is accelerated by beating the froth constantly with the stirrers; a means of causing a rapid exchange of the humid air over the surface of the pan, for dry air from without, is seldom found in use in the boiling-houses, although some plan for that purpose might easily be devised, and would effect a considerable saving of fuel.

The soap becomes naturally thicker as evaporation proceeds, its color becomes darker, and less froth is produced. At last the froth is so much diminished, that the soap sinks, and the bubbles are so far larger, that they resemble films or lamellæ, which overlap and cover each other upon the surface. This is what the soap-boilers term the *lamination;* and the noise occasioned by the process gives rise to the saying, "the soap talks." The soap is now really finished, but another specimen or test is taken before it is scooped out into the moulds. When this no longer shows any opaque zone, after having cooled for some time, or only in a very slight degree, it may then be safely concluded, that the proportions in the pan have been properly attained. A certain amount of experience is necessary, in order to form a correct judgment from these indications, for, when the specimen is left too long exposed to the air, the action of the moisture upon the small quantity of soap in the test, brings about changes in its appearance, which interfere with the discriminating characters stated above. Thus, for instance, the opaque zone or rim spreads gradually over the whole surface of the specimen, until at length it entirely disappears. The mass, when completely cold, must never be fluid, but always of a thick consistence.

As soon as the tests prove satisfactory, the fire is extinguished, the soap is left for some time longer in the pan to cool, and is then packed in small casks for sale.

Soft soap, intended for winter use, which is then liable to become thick or lumpy, should be clarified with stronger lye, or with such as contains a portion of carbonate of potash.

In Russia, soft soap is prepared from beginning to end, according to Kurrer, with one and the same species of lye, containing ¾th caustic, and ¼th carbonate of potash. The half of this lye, which is brought up to 10° B., is added to the linseed, rape, or hemp-seed oil in the boiler. The other half is placed in a cistern by the side of the boiler, and is allowed to flow uninterruptedly from a cock in such a very thin stream throughout the process into the boiler, that the soap is kept constantly in a state of ebullition. When the soap flows from the stirrer as a clear slime, and can be drawn out in threads between the fingers, having thus attained a certain consistence, the process is considered finished. This mode of procedure, which is very uncertain, and never affords a very uniform product, can only be recommended in countries like Russia, where there is a great want of able hands.

Some kinds of oil, for instance, hemp-seed oil, naturally communicate a green color to the soap, which is much prized, and has, consequently, become a necessary property of soft soap. Other varieties of soap, therefore, which have a yellow color, are rendered green by the addition of a little indigo. Indigo, however, is not soluble either in soap or in caustic lye, it is therefore necessary to pulverize it very finely, and even then it is difficult to diffuse it uniformly through the mass of soap, nor is it easy to moisten the powdered indigo, and it easily subsides to the bottom of the vessels. The usual mode of applying it, consists in boiling the finely powdered indigo with a little water for some time, until it is uniformly moistened, and then adding it to the soap; or in precipitating a solution of indigo in oil of vitriol with lime, and using the precipitate as the coloring matter. Soft soap is often colored black by the addition of inky fluids, which are prepared by making an infusion of gall nuts, and mixing with it a solution of green vitriol.

A so-called corn or grain is sometimes produced in soft soap by the addition of tallow. The soap then retains its ordinary character, but fine granular particles of a crystaline structure are observed in it, consisting probably of salts of stearic and margaric acids. The formation of this grain requires a certain degree of heat, and can only be effected in the colder seasons of the year, at temperatures between 9° and 15° (48° and 59° F.); it is practised merely from habit, and no useful object is gained by it. Attempts have been made to imitate this useless appearance, in a manner calculated to injure the quality of the soap. Thus, for instance, slaked lime has been used with the production of a lime soap, and even starch has sometimes been mixed up with the soap.

All kinds of soft soap exhibit a strong alkaline reaction, and are characterized by a penetrating disagreeable odor, which, however, does not necessarily resemble that of the fats employed. The smell is most perceptible in soaps prepared from train oil, and is due to the presence of delphinate* and phocenate of potash, produced by saponification, as has been explained at page 117.

Soft soap is used to some extent for washing coarse linen, but it is of far greater importance as an indispensable and powerful detergent in the linen bleaching works.

The important distinction between soft soap and the ordinary soaps is very marked, the latter being easily and completely separated by means of salt from all the impurities and the excess of lye, which necessarily remain attached to the former. Soft soap is consequently contaminated with all these substances, when they are not removed in the beginning by the care of the boiler; nor is there any guarantee, as is the case in curd soap, that a certain amount of water is not ex-

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* These two acids, the phocenic and delphinic, have been found identical with valerianic acid by Dumas.

ceeded, and indeed this sort of soap is more hygroscopic, or is more subject to change with the amount of moisture in the atmosphere. Soft soap never dries completely to a solid mass, even after long exposure to the air.

The contest which straightforward honest industry has constantly to maintain against the specious inventions which, sometimes as the result of ignorance, and at others of fraudulent intention, constantly depress its exertions, has given rise, with reference to the soap manufacture, to several new products, which must here be noticed, not so much as examples of useful progress, as instances of the errors to which this important branch of manufacture is liable.

Bone Soap.—Amongst these must be classed the so-called *bone soap,* which is nothing more than ordinary soap from tallow, resin or palm oil mixed with animal gelatine or bones disintegrated, dissolved, or partially decomposed by potash. Two methods have been published for the preparation of bone soap, (which contains on an average 56 to 60 per cent. earthy matter, and 40 to 44 per cent. animal matter). By the one method, bones are treated with concentrated hydrochloric acid, which dissolves the phosphate and carbonate of lime, leaving the animal gelatine as a translucent mass in the form of the original bone. This is freed from all adhering acid by repeated washing with water, and is then added during saponification to one of the fats named above. The other method is more generally practised, and affords a substance of much less value than the former kind of soap. It is now extensively sold under the name of *Liverpool poor man's soap.* The whole mass of bone is disseminated throughout soap of this kind, and not the gelatine only, as was the case in the variety above. The previously broken bones are softened by immersion in strong potash lye in an iron vessel. The action is here precisely the converse of that in the former case. The lye dissolves the gelatine, leaving the earthy particles as a powder behind, so that at the expiration of from fourteen days to three weeks, and in warm weather in still less time, the bones become quite soft and pulverable. The finely powdered mixture is allowed to boil for an hour in the pan, and the fat, for instance, cocoa-nut oil, is then added just in the same manner as if ordinary lye had been used. During boiling, the gelatine partly dissolves as glue, and is partly decomposed with the evolution of ammonia. This decomposition is a matter of perfect indifference in the preparation of this soap, as the only object of manufacture is to mix as much of a cheap substitute, such as bones or glue, (no matter how much decomposed,) with the real soap, as will not prevent it from becoming solid, or from frothing when used.

Bone soap of this kind has none of the appearance of curd, and exhibits a dark-brown color on the cut surfare, but is not translucent like rosin soap. It possesses a very disagreeable penetrating odor of glue, dissolves easily in hot water (with the exception of the earthy particles), and forms a good lather. When a solution of the soap, however, is treated with a sufficient quantity of common salt, only the fatty soap separates with its ordinary color, whilst the glue remains in the dark brown under-lye, partly in a state of solution, and partly as a flocculent precipitate. It appears, therefore, that soap of this kind cannot be prepared by salting, and the reason is obvious why it is most readily produced from cocoa-nut oil.

The English patentees are in the habit of crushing and softening the bones in the lye, by the aid of friction-rollers.

Similar patents have been obtained, for the so-called saponification of the intestines of animals, and refuse of a like character, for instance, skins, sinews, hoofs, &c. Cheap fish of various kinds have also been recommended as material for the manufacture of similar kinds of soap; and with these the natural amount of fat of course adds to the quality of the soap. These varieties of soap, however, have been known for a much longer period than the patents which have recently brought them again into notice; for Hermbstädt mentions a soap made with fish, and a similar one from refuse wool.

Later processes for employing naphtha, hair, fish, and dextrine, have been patented in England by Caldecott, Chauvier, Poole, and Snell.

Another class of these inventions, are the soaps which contain admixtures of certain detergent mineral substances, as, for instance, silica, alumina, or fuller's-earth, &c. The solidity or firmness of the soap is not diminished by the addition of substances of this nature, which exert, however, a purely mechanical action, and are contained in no kind of chemical combination. The value or price of the soap is very much lowered, as a great portion of the real soap is replaced by a substance of similar but less efficacious action, the price of which bears no comparison with that of the fats. Two products of this kind, known in commerce by the appellations *sand-soap* and *savon-ponce* (pumice-soap), the former of English, the latter of French origin, have been examined by Karmarsh. Sand-soap, when treated with alcohol, left 74.4 per cent. of sand, similar in grain to that used for covering floors. Three kinds of savon-ponce, treated in the same manner, left respectively, 19.7, 22.9, and 26.2 per cent. of a white, or reddish-white angular powder, which consisted either of ground pumice-stone, or perhaps of ground quartz or flint.

The mode of incorporating silica with soap, practised by Sheridan, and at a later period by Dunn, is somewhat different. A solution of silica (a kind of soluble glass) is obtained by boiling ordinary flints—which are first reduced to powder by being heated to redness, and then thrown into water, and afterwards ground—with a lye of caustic potash or soda. This mass is then disseminated, by mechanical stirring, throughout soap previously prepared in the ordinary manner, and brought into the proper state for solidifying; the whole mixture is then placed in the moulds. It must not be forgotten in practising this method, that powdered quartz is only dissolved with the greatest difficulty, and very slowly, in a boiling solution of potash, and that a red-heat is the proper temperature at which the combination of silica with potash is effected. An exception to this rule has been pointed out by Fuchs, who finds that the amorphous varieties of quartz, for example, powdered opal, dissolves easily in solutions of caustic alkali. Neglect of these facts, involves the production of soap containing a large quantity of water, instead of silicious soap; for the fluid thus obtained holds but little silica in solution, and consists for the greater part of caustic lye. Girardin has examined a soap of this sort, which is called silica-soap. It contained resin and palm oil, saponified with soda, and was easily dissolved by water with the production of a copious lather; a deposit of silicious matter subsided, however, from the solution, the ash of which, when treated with muriatic acid, left 19 per cent. of residue. That the silica may be thoroughly incorporated with the soap in a state of solution, it is necessary to prepare the silicious fluid, or soluble glass, in the ordinary manner (as will be described under *Glass*). In Sheridan's soap, the insoluble and soluble portions are mixed with the soap in equal quantities, so that the greater part is evidently only in a state of mechanical admixture.

With the same object in view, and in a much more appropriate manner, powdered soap-stone and porcelain earth are used by Howitt, and Davis proposes that pipe-clay, or, still better, fullers'-earth should be mixed with the soap. If the assertion prove true, that these soaps can be used at sea with salt-water, the invention will be truly valuable.

Chlorine-soap.—Lastly, a product of English manufacture called *chlorine-soap*, deserves notice, which has also been introduced into France under the name of *savon chloruré.* This substance is intended to realize the idea of the union of the cleansing properties of soap with the bleaching effects of certain compounds of chlorine. The method of preparing it proposed by the inventor is, however, so much at variance with all the laws of chemical combination, that the product must necessarily be anything but that desired. It is proposed to saponify the oils, or fats, with chloride of lime, or with the corresponding potash, or soda compound (*lye of Javelle*); or the ready-prepared soap may be softened by immersion in a solution of that nature. With reference to chloride of lime, it is obvious that the greater part of the valuable alkaline soap will be converted by its agency, into a useless lime-soap. With regard to the other bleaching compounds, soap may possibly be obtained which is mixed with a greater or less proportion of the bleaching salt, but this cannot certainly exert any appreciable amount of action, when the soap is used for washing. An attempt has also been made to saturate the fats themselves with chlorine before saponification, but it is well known that these bodies are decomposed by the continued action of chlorine with the formation of hydrochloric acid, and if the action of chlorine is modified, the oils will be bleached; but soap can never absorb such an amount of chlorine as will communicate bleaching properties to it. In short, these chlorine soaps are nothing more than foolish novelties.

Toilet Soap.—Toilet soap is essentially ordinary soap mixed with different aromatic oils, and diversified, as to form, to suit the fashion of the day. The fundamental material used in this branch of industry, in which the French so very much excel all other nations, is either one of the varieties of soap already mentioned, or a soap prepared specially for this purpose, in a manner far too costly for any other. The following kinds are usually employed: olive oil soap, tallow soap, palm oil soap, and soap prepared from lard and almond oil. The saponification of lard, which yields a very white soap, is not effected by boiling, but by agitation of the materials; the lye possessing a density of 36 B., a temperature of 65° (149° F.) being employed without any salt.

Transparent Soap.—It has been stated on a former occasion, that soap is more perfectly and readily soluble in alcohol than in water. A concentrated solution of soap in water becomes partially opaque on cooling, by the formation of crystals; this, however, is not the case with a similarly concentrated alcoholic solution. This fact is applied to the manufacture of transparent soaps, the preparation of which was formerly kept a profound secret. In preparing soap of this description, ordinary soap is thoroughly dried in a stove, and dissolved in hot alcohol. All foreign matters not consisting of soap will remain undissolved, and must be removed in this case, with so much the more care, because they cannot remain concealed by an opaque mass, as in ordinary soap. They are removed by deposition, or by a filter supported by a funnel, surrounded on the outside with hot water. The alcohol is then separated from the solution by distillation, until the residue is capable of forming a solid mass, when cooled in the metallic moulds. Transparent soap of this kind is generally too hard, and affords a lather with great difficulty.

Light Soap.—Soap bearing this name, is merely ordinary toilet soap in a different form, and any of the kinds mentioned above, with the exception of that from hog's-lard, can be used in its preparation. It is obtained by threshing or agitating a solution of soap, to which $\frac{1}{6}$ or $\frac{1}{8}$ of water has been added with a rouser, or paddle-wheel, until the lather which is thus produced, has risen to twice the height of the soap solution, and this is then transferred to the moulds.

It is a remarkable fact, which is rendered obvious by a mere glance at the novel processes introduced into the soap manufacture, that these must be regarded as speculations (often not very profitable) with the mixture of ingredients in the soap, and not as real steps in advance or improvements in the operation of boiling; nevertheless, it is highly probable that this operation in particular, is capable of much simplification and improvement. The improvements here adverted to, may be of two kinds: they may either be of a chemical nature, for instance, the use of very concentrated lye, or they may be founded upon physical principles; and with reference to this latter point, experiments upon a large scale have been instituted in England, which are worthy of the greatest attention.* Indeed, it is very probable that saponification might be effected very much more rapidly at a temperature considerably above the boiling-point of ordinary lyes, without actually attaining that point at which the fatty acids or

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* Compare page 413. [In relation to the various subjects here treated, reference may be made to a recent publication, entitled "Chemistry applied to the manufacture of Soap and Candles," by Campbell Morfitt. Philadelphia. Carey & Hart. 1847.]—AM. ED.

the soaps are decomposed. These conditions might be easily complied with in an ordinary steam-boiler, admitting of the application of high pressure; but then every soap-boiler by profession would doubtless raise as an objection to such a proposal, the impossibility of observing the soap during the boiling process. Nevertheless, experiments of this kind, according to Schonbein, have not only been crowned with success in England, the centre of all operations with steam, but the exclusive use of them has been secured by patent, and large manufactories have been erected for carrying them out upon an extensive scale. By boiling in this manner, under high-pressure, the time required, which upon the old plan was several days, is reduced to two or three hours. In what manner the patentees have been able to dispense with the close observation and frequent process of testing, so indispensable under ordinary circumstances, and how the proper amount of water is incorporated with the soap, has not been made public up to the present time, (compare p. 412.)

With reference to the former point, viz., the use of very strong lye, in which case the production of soap is more a melting together of the materials, than a boiling process for combining fatty matters with the lye, the experiments, if such have been made, are not generally known, unless the soaps prepared from cocoa-nut oil can rank with this class of products, which are produced by digesting the oil with strong lye at a high temperature, and afford a product of no great value.

Value of Soap.—There are few things which are so ill understood in practical life as the *real value*, or what is the same thing, the proper price of soap. The value of soap is mainly dependent upon the amount of dry soap, (the dry combination of alkali with the fatty acid), which it contains, and this is very easily ascertained. To establish this point, a weighed specimen in the form of thin shavings is exposed to the heat of a drying stove, until its weight is no longer diminished. The loss of weight is hygroscopic water, and what remains is dry soap. The latter invariably retains the water that is in chemical combination, or water of hydration, but this quantity is so small in proportion to the equivalent of the soap compound, that it is practically of no moment.*

Greater sources of deception are naturally traceable to an excess of alkali, salt, &c., which are peculiar to soap not in the form of curd, and particularly to such as contains much water, or has been prepared without boiling. These admixtures are indicated by the general appearance of the soap, but can only be accurately estimated by a careful chemical analysis. Indeed, a ready test, which should indicate with sufficient accuracy the amount of the soda or potash compounds with the fatty acids contained in the soap, and which could be executed without requiring much manual dexterity, is very much needed. The real analysis of soap is, however, an easy process. The amount

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* It is, perhaps, not superfluous to remark, that the soap-boilers are in the habit of erroneously considering the whole of the water retained after cooling by curd soap, properly prepared, as water of hydration.

of water is ascertained by drying; that of the fatty acids by separating them with the aid of sulphuric or hydrochloric acid, washing, melting, and weighing; and lastly the alkali is estimated by incineration. This is the main principle of the process which led to the following analytical results. The great discrepancies in the value of different kinds of soap are clearly pointed out in the following table; yet it must be noticed, that the portion of alkali in combination with the fatty acids was not separated in the analyses from that portion contained in a free state, for instance, as lye.

Kind of soap.	Fatty acids.	Dry potash.	Dry soda.	Water.	Common salt.	Name of the analyst.
Castile soap, sp. gr. =1.0705	76.5	—	9	14.5		Ure.
Ditto sp. gr. =0.9669	75.2	—	10.5	14.3		"
Fine white toilet soap	75	—	9	16		"
Ordinary white soap from Glasgow	60.0	—	6.4	33.6		"
Mottled tallow soap of good quality prepared by an able soap-boiler from pot-ashes, after having been kept for several years	81.25	1.77	8.55	8.43		Heeren.
Brown resin soap from Glasgow	70.0		6.5	23.5		Ure.
London cocoa-nut soap*	22.0	—	4.5	73.5		"
Hard poppy-oil soap	76	—	7	17		"
French soap—*savon en tables blanc*	50.2	—	4.6	45.2		Thénard.
Marseilles soap—*savon marbré*	64	—	6	30		"
Ditto	60	—	6	34		D'Arcet.
White Marseilles soap	68.4	—	10.24	21.36		Braconnot.
White tallow soap, Leipzig, prepared by a company	76.3	8.8		14.7		Abendroth.
Ditto, Leipzig, privileged manufactory	50	9.4		29.8		"
Marbled soap from the same manufactory	45	9.8		38		"
Soap from hazelnut oil	64	7	—	28	1	—
Soft soap	44.0	9.5	—	46.5		Thénard.
London soft soap	45.0	8.5	—	46.5		Ure.
Belgian soft, or green soap	36	7	—	57		"
Scotch soft soap	47	8	—	45		"
Another kind of good green soap	34	9	—	57		"
Scotch, soft rape-oil soap	51.66	10	—	38.33		"
Scotch, soft olive-oil soap	48	10	—	42		"
Semi-hard soap for fulling	62	11.5	—	26.5		Verviers.
Ordinary soft soap, 1st sample	44	9.5	—	46.5		Chevreul.
Ditto 2d "	42.8	9.1	—	48		"
Ditto 3d "	39.2	8.8	—	52		"

Dumas recommends the following plan for the analysis of soap. The water is first determined in the manner stated above: a portion should then be treated with alcohol, when, if pure, white soap should

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[*] This soap, consisting of nearly ¾ water, was tolerably hard, but dissolved very easily in boiling water. It is called *marine soap*, and is said to be applicable to washing with sea water.

leave a very small quantity, and mottled soap not more than 1 per cent. of insoluble matter. If more insoluble matter is obtained, silica, alumina, gelatine, &c., must be looked for. The amount of alkali is determined by the alkalimeter with sulphuric acid, from a solution of the soap in boiling water, and the fatty matters by adding a weighed portion of pure white wax to the boiling liquid, after the completion of the alkalimetrical test. The wax then combines with the fats, and its increase of weight on cooling, indicates the quantity present in the soap. The solution of the sulphates may then be tested for potash and soda by crystalization, or by chloride of platinum. The nature of the fatty substances may be examined by decomposing the soap with tartaric acid, and taking the fusing point of the mixed fats. If tallow, or oil have been used, it will then be apparent; and the smell evolved during fusion, may also assist in forming an opinion as to which kind is present in the largest quantity. Neutral fatty bodies may be discovered by decomposing the soap with hydrochloric acid, producing a barytic soap, and treating the latter with alcohol, which will then dissolve any admixture of unsaponified fat, and this may be further tested with litmus paper.

Composition of Soap.—It must not be overlooked in analyses of this kind, that the fatty acids and the alkali are obtained in the state of hydrates, and that the water of hydration must consequently be deducted in both cases. The consumer should not be satisfied with a soap in which the amount of the dry fatty alkaline compound accords with the price, unless the soap fulfils another condition of equal importance. The problem to be solved by the soap-boiler is the production of an article, from which no more is dissolved or washed away, when it is employed for washing linen or the hands for instance, than is absolutely necessary for cleansing purposes. When this is not the case, much soap is uselessly wasted. This property of soap is carefully watched by the laundress, and for purposes of domestic economy the quantity of soap employed is much more materially affected by it, than by the state of the materials to be cleansed. If the soap contain too much water, or its consistence be rendered too loose by reason of an excess of lye or salt disseminated through it, as is the case with many of the varieties of soap described, the waste from this cause will be proportionally great. On the contrary, if the soap is over dry, much laborious exertion will be required to detach a sufficient quantity for the purposes required. Curd soap is the only kind which maintains the proper mean between these two opposing characters, and this is due to the quantity of water which it contains, and its state of solidity. Soap that has become too dry is improved by being kept in a moist place, and an opposite treatment improves soap that contains too much water. But soaps of the latter kind are not altered or improved by keeping, as regards the foreign salts which they contain. Curd soap is therefore the proper form in which soap should be sold; no deception need be practised, however, when soap containing a larger amount of water, as that from cocoa-nut oil, is manufactured, provided a corresponding reduction be made in the price. The same applies to soap prepared with bones, fullers' earth, silica, &c., which cannot be positively called adulterations, but which are very much calculated, like the former, to promote dishonest traffic. The production of these articles will find very little encouragement where the soap-boilers understand their own interests and responsibilities.

The statements made above, with reference to the too rapid solution of the soap, are of course not applicable in cases where the substances to be cleansed are boiled with the soap, as in bleaching and dyeing; they must not, consequently, be extended to soft soap.

OIL VARNISH.

The vegetable oils are by no means unaffected by exposure to the air, and the changes which they undergo by the agency of atmospheric oxygen have given rise to the distinction of the *drying* from the *persistent oils.* The latter remain viscid on exposure, but become acid and ill-savored, in short, become rancid, whilst the former dry up to an inodorous, clear, slightly-colored varnish, as is witnessed in linseed, hempseed, walnut, and poppy oils. This drying action of the air requires time, during which hydrogen and carbonic acid are incessantly evolved from the oils, but at certain intervals with greater energy than at other times. Saussure has observed these changes with the greatest attention in some of the oils, and he found that of the whole time during which oxygen was absorbed, and this often lasted several months, and even years, a certain period was attained at the expiration of from five to seven months, when the absorption was very much more rapid than had previously been the case. Thus, for instance, walnut oil had absorbed thirteen times its own volume of oxygen at the end of eight months, when, during the next ten days, the absorption increased to sixty times the volume, and then again diminished throughout the three subsequent months. The important and extensive application of these oils, particularly of linseed oil, in decorative and artistic painting, is founded mainly upon this drying property. The rapidity with which linseed oil dries, is dependent upon its age, &c., but this property can be considerably increased, when the oil is raised to the boiling point, or is kept for some hours at a temperature approaching that of ebullition, either by itself, or as is more usually practised, with the addition of $\frac{1}{18}$ or $\frac{1}{20}$ of oxide of lead. In this state, when it has cooled, the oil is termed *linseed-oil varnish;* it is much less colored, more thickly fluid than before, and dries, at longest, in twenty-four hours; spread, for instance, upon a plate of glass, it forms a clear brilliant surface, which retains none of its first adhesiveness.

The general opinion has been, that the oxide of lead served as the purveyer of a great portion of the oxygen to the oil which it otherwise absorbed from the air after a considerable length of time, and that the oxide was partially reduced; the boiling process would then be reduced to the speedy execution of a part of those changes which are gradually produced by exposure to the atmosphere. Liebig, however, has recently shown that this opinion is erroneous. Another view of the subject, which supposed the conversion of the oil into varnish to be the effect of saponification by the aid of oxide of lead, or the destruction of glycerine by the agency of heat, is equally fallacious. Although a portion of oxide of lead is taken up in boiling, this has rather an injurious tendency than the reverse; for Liebig has shown, that when linseed-oil is boiled for a length of time with water and oxide of lead, a thickly fluid mass is obtained, which dries with difficulty and remains smeary for some length of time.

Even by saponifying linseed oil in the ordinary manner, and subsequently decomposing the soap with muriatic acid, so as to separate the whole of the glycerine, and then dissolving as much oxide of lead in the fatty acid, as will not influence the fluidity of the mass on cooling, no varnish can be obtained. Thus we have positive evidence that the separation of the glycerine is not the object in the manufacture of varnish. When it is borne in mind, that linseed oil absorbs oxygen from the air with much greater rapidity at a later period than when first exposed, it then appears probable, that one or other of the foreign matters which it contains, encloses the oil, as it were, and retards the absorption of oxygen, until, after a long resistance, it is at length dissipated, and the oil comes into free contact with oxygen. The formation of varnish is rendered much more intelligible by adopting this highly probable assumption; it is then reduced to a simple purification of the oil, by removing all those substances which prevent the immediate contact of the oil with oxygen. The very same supposition led Liebig to the idea, that those foreign (mucilaginous substances) might be removed by precipitation at the ordinary temperature, with the same effect as is produced by oxide of lead at a high temperature, and for this purpose he proposed the use of basic acetate of lead, a substance frequently applied in practical chemical operations to similar purposes.

In carrying out this method, which is both better and more easy of execution, the basic acetate of lead is first prepared in the following manner: 1 lb. of sugar of lead (neutral acetate) is dissolved in 5 lbs. of rain water, and 1 lb. of litharge (oxide of lead), in fine powder, is added to the solution, and this is then allowed to stand until the red color of the litharge has been replaced by a white color. The clear fluid above the sediment is then basic acetate of lead, and is in sufficient quantity to convert 20 lbs. of linseed oil into varnish. The basic acetate of lead is mixed with an equal quantity of water, and added to the linseed oil, which has been previously rubbed up with 1 lb. of litharge in fine powder. The mixture now only requires shaking from time to time, and is, lastly, allowed to stand at rest for some hours. The linseed oil is then observed swimming on the surface of the aqueous fluid in the form of a wine-yellow colored varnish, which, however, is not quite clear. By filtration it can be separated from the fine white powder which remains suspended in it, and obtained perfectly clear, like water. Varnish prepared in this manner is readily bleached by exposure to the sun. It contains 4 to 5 per cent.

of oxide of lead chemically combined in solution; this also can be easily removed by agitation with weak sulphuric acid and subsidence, should it in any way interfere with the uses to which the varnish is destined.

For a repetition of the process, it is unnecessary to prepare a fresh solution of sugar of lead, as the whole of that salt is contained in the water below the stratum of varnish. Litharge may, therefore, be again added to this, and will produce with it the basic acetate of lead, as before.

The simplicity of execution which forms the chief value of this process, is further enhanced by the precipitation of coloring matter with the oxide of lead, in addition to the mucilaginous substances which obstruct the formation of varnish, so that the linseed oil is partially bleached at the same time that it is converted into varnish.

Oxide of zinc (or white vitriol) was sometimes used with oxide of lead, or instead of it, upon the old plan, and in England, magnesia has been substituted for either.

The conversion of linseed oil into *printers' varnish*, or *printers' ink*, is a process founded upon very different principles. In this case, the object is a thick fluid, which shall impress the outline of the type upon the paper without running, and yet dry rapidly ; it can only be obtained by an incipient dry distillation, to which the oil is submitted by heating in a copper still.

Only aqueous vapor passes over at first, but as the temperature rises, and the color of the oil becomes darker, (which is here naturally unimportant,) combustible gases and carbonic acid are generated. At a still higher temperature, these are accompanied by inflammable condensible vapors, which ascend as smoke when the oil is in a state of ebullition, and may be ignited. The boiling is continued until a sample is sufficiently sticky on cooling, and exhibits the proper state of consistence.

The temperature at which the varnish is boiled destroys the oxide of glyceryle, and produces a change in the composition of the fatty acids, which has not yet been carefully investigated.

APPENDIX TO THE FIRST GROUP.

Soot, Lampblack, &c.—The luminosity of every flame, as we have repeatedly shown, depends upon the separation of a portion of charcoal which is burned subsequently to its separation, this process being repeated every instant; now this subsequent combustion may be very readily impeded, by cooling the flame or diminishing the draught of air. In this case, in addition to the true products of combustion, empyreumatic vapors and gases also escape in conjunction with carbon liberated by their partial combustion (soot), all of which result from mere decomposition by heat (dry distillation)—and form ***smoke.*** Thus, a strong current of air causes the flame of a candle to smoke, and a porcelain plate, or a plate of metal held in it, becomes coated with soot; both these phenomena are the result of cooling. In all fires, the combustion is imperfect in consequence of the burning substances being too much cooled, and from the defective supply of air. The internal walls of chimneys and flues become coated with various kinds of soot or black; near the fire, this assumes the form of a blackish-brown, shining, varnish-like layer, ***glance-black***, consisting of dried tar with a little charcoal (3.8 per cent., Braconnot), which, after undergoing preparation, is used as a pigment (bistre), and also to preserve meat from putrefaction. The soot deposited in the more distant parts, contains much more carbon, and forms a brown, flocculent mass, *flake-black.* These are the only two kinds of soot yielded by wood; whilst substances containing little oxygen, but abundance of carbon—those, therefore, which burn with a powerfully luminous flame—as resin, fats, and oil of turpentine, deposit a kind of soot, which consists principally of charcoal, mixed with but little tarry matter; the quantity of the latter being less in proportion to the time which has elapsed before the soot is deposited, or in proportion to its distance from the fire. This product, called ***pine-wood black***, is dark, pitch-black, and from the chemical indestructibility of the charcoal (except by combustion) is one of the most important (opaque) colors; its production consequently gives rise to a peculiar process of manufacture. It is extensively used in ordinary printing, lithography, and copper-plate printing, the manufacture of blacking, &c., and hence arises the necessity for preparing it at one time in the most minute state of division and purity, whilst at others it may be used in its ordinary condition. Braconnot found in 100 parts of pine-wood black:

Carbon		79.1
Empyreumatic resin	soluble in alcohol	5.3
	insoluble in alcohol	1.7
Humin		0.5
Sulphate of ammonia		3.3
" lime		0.8
" potash		0.4
Phosphate of lime		0.3
Water		8.0
Sand (accidental)		0.6
Chloride of potassium		a trace.

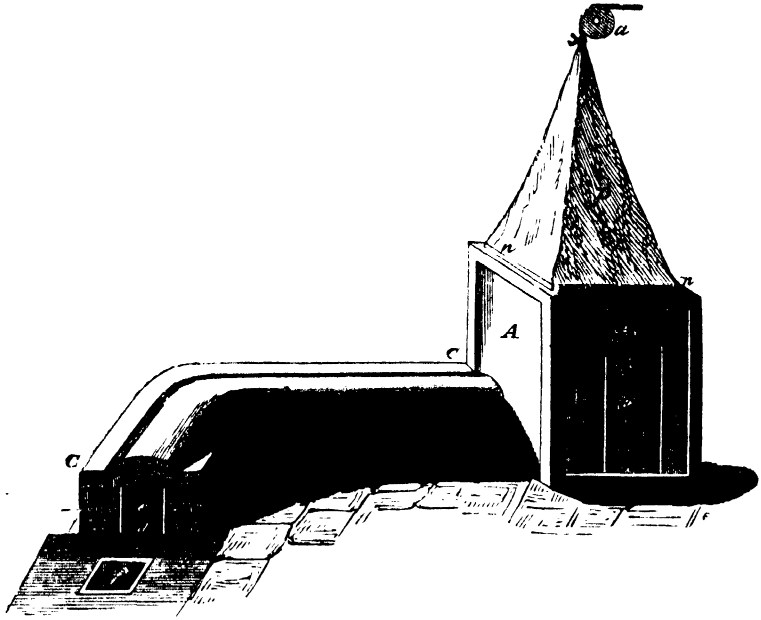
Reichenbach found napthaline also. The fixed salts present were really constituents of the ash carried over with it.

For making the common qualities of black, refuse resinous matter of all kinds are used. Those parts of fir-wood, for instance, which abound in resin, and remain after the resin or colophony has been strained off, fir-leaves, chips, rubbish, &c., covered with resin; lastly bark, leaves, &c., upon which resin has dropped, these are collected when the fir-trees, from which the resin is obtained, are cut down. The peculiar manufacture of the black from these substances consists in burning them with a very limited access of air, just sufficient to consume the hydrogen and a part of the carbon, leaving another portion of the latter unburned, which is then deposited as pine-black. Fig. 163 represents the simple furnace used in this process.

A canal of brick-work *C C*, 2½ feet wide, connects the fire *d*, with the soot chamber *A*; the length of the canal is at least 14 feet, this extent being requisite, that the inferior tarry-black may deposit before the purer portion. The aperture in the fire-chamber, which also forms the anterior part of the canal *C*, can be either opened or closed for the proper regulation of the draughts, by means of a movable iron plate *e*. The plate *o* forms the margin of the pit *f*, in which the workman remains; it also serves to receive the coals when withdrawn, and the fresh matter to be burnt. On commencing the process, no regard is paid to the collection of the black, but the fire is at once lighted to warm the smoke-channel first. Without this precaution, a large portion of the black would be deposited in it, and be very liable to take fire. Two kinds of soot are thus obtained, one of which is brown, sometimes of the kind called flake-soot, sometimes glance-black, which is derived from the woody portions, and black, or true pine-wood black, from the resin. The object of the process is to separate the two, causing the former to be deposited in the canal *C*, and the latter alone in *A*, this being practicable only when *C* has been sufficiently heated. As soon as this is effected, a fresh charge of the wood (¼ cwt.) is introduced, and the manufacture commenced by lowering the plate *e*. The light soot collects at the back part, partly on the walls of the chamber *A*, which has a capacity of from

2 to 3000 cubic feet, but mostly in the hood *D*. The latter is a kind of roof composed of loose woolen cloth, which may be extended at

Fig. 163.



the apex by the pulley *a*; and at the base by the heavy frame *n n*, it can also be lowered into the chamber. When the manufacture proceeds favorably, a day's work of 10 hours should yield about 3 cwt. of the material. In a properly conducted process, the temperature of *A* should always be somewhat lower than that of the smoke; but in time, this relation becomes reversed, which renders it advisable to work only every other day, that the furnace may cool in the meantime. Another precaution is made requisite by the black itself, which by its deposition, gradually impedes the draught; for, it is evident, that this must traverse the tissue, which as it were, strains the soot from the various gases. The workman is consequently obliged to shake off the soot from time to time into the chamber by gently tapping the hood. The extremely fine state of division of the fresh soot, gives it, especially when warm, a dangerous tendency to inflame on exposure to the air. For the sake of caution, therefore, the chamber must always be allowed to cool, before anything is removed from the door *E*.

The loose uppermost soot, which has fallen from the hood, is separated as a finer article for making printers' ink, from that which coats the walls of *A*, and forms ordinary lamp-black. Sometimes, instead of a single chamber with a hood, the soot is deposited in several successive ones; in this case, the last will contain the finer kinds.

In the coal districts, the caking-coal forms a useful material for this manufacture, which is then either separately, or incidentally carried on, the coke-ovens being combined with an arrangement for collecting the lamp-black. In England, for instance, the method practised is somewhat different from that which has been described, and which is the common practice in Germany, the chamber with its hood being replaced by a series of tall bags, about 3 feet in diameter, and stretched perpendicularly. The canal conveying the smoke, opens into the first bag at the lower and lateral part, this and the second being joined by a connecting tube above, the second with the third by a similar one at the lower and lateral part, and so on. The lateral connection is made below, so that the (tin) mouth-pieces of the bags with their capsular lids remain free, and can be occasionally emptied of the lamp-black. The last bag finally opens into a chimney. In this arrangement, the lamp-black is much better sorted, according to the fineness of its quality.

The presence of empyreumatic resins in lamp-black, a small number of which belong to the acid, but the greater part to the neutral class, seriously deteriorates its quality, causing it to burn with flame, and yield empyreumatic oil, when heated with exclusion of air. They interfere with its application by imparting a brown tinge instead of the pure black to the lamp-black, and by preventing its being moistened with water. It is consequently necessary previously to mix the impure lamp-black with brandy, whenever it is required as an addition to water colors. The removal of the empyreumatic resins by solvents cannot be carried out on a large scale; for they are usually only imperfectly soluble in alcohol, or in caustic alkali, and Braconnot only succeeded in removing the entire amonnt present (7 per cent.) by means of ether and oil of turpentine. One of these solvents, the ether, is too expensive, and the turpentine requires a second operation to re-obtain it. In cases, therefore, where they are prejudicial, as, for instance, in lamp-black for lithographic ink, &c., it is preferable to destroy the resins by a red heat.

The ordinary method of proceeding is rather crude, and consists in burning the lamp-black with a very limited access of air. A tub filled with the soot is buried in the earth, the lid being level with the surface; by means of a thick pole, which must be carefully withdrawn, a perpendicular hole is bored through the middle of the mass, and into this, a roll of tow, saturated with oil of turpentine, is pressed and then ignited. When the lid is put on, the slow and smouldering fire spreads, until at last the whole of the soot is heated to redness throughout. During this process, the tarry ingredients burn at the expense of a portion of the soot, about $\frac{1}{10}$th to $\frac{1}{8}$th, which is consumed by the air. A better plan is to press the soot into a large tin case, placed within a cast-iron vessel (like a gas-retort). The latter is bricked in over a fire, and the vapors of the decomposed tar conveyed by a conducting tube into the fire, where they serve as fuel.

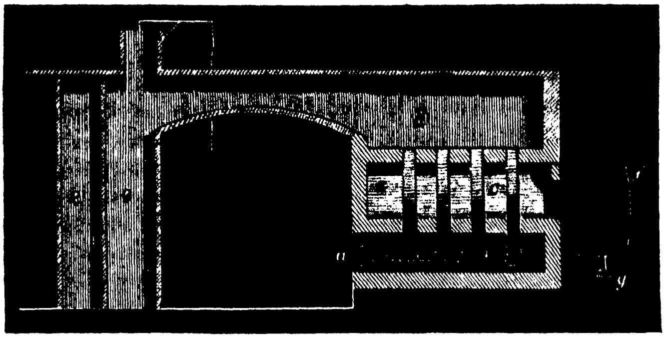
Black of greater purity, and in a much finer state of sub-division, is obtained from fixed-oils—oil of turpentine, or oil from rosin gas, when these substances are burnt in lamps; but it is difficult to prepare this, which is properly called lamp-black, in large quantities. The lamp is placed under a tin hood, which carries off the smoke by a lateral tube into chambers, or is closed, and receives the soot on its inner walls. The most profitable method of cooling, is that of holding metallic plates in the flame, provided they are not allowed to become too hot. For this purpose, Prechtl proposed a roller of tin, which revolves in the flame, and laterally rubs against a brush, so that the soot is constantly brushed off, and fresh cool parts of the metallic surface are constantly brought into the flame.

Inaccurate reports have diffused many fabulous accounts concerning the nature of Indian-ink; it is principally composed, however, of lamp-black of inconceivable fineness, and Prechtl, in accordance with the best accounts, has rendered it more than probable that it is prepared from camphor, by the same process as lamp-black; the cementing matter is some kind of animal gelatine.

In manufacturing lamp-black according to the German method, about $\frac{1}{8}$th of lamp-black is obtained from the residue of strained pitch; but the produce from fir-wood is of course much less, because the woody portions tend more to the formation of tar. The quantity which theoretically ought to be obtained from a given quantity of material, cannot well be determined, because the process is not definite and constant, but is entirely dependent upon the contingent management of the draught of air, and at the same time upon the nature of the material in the fire. At all events, it is certain that the lamp-black originates from that portion only of the carbon which, during the process of decomposition, is carried away by the hydrogen. Common coal, $\frac{6}{9}$ to $\frac{8}{9}$ths of which, on an average, take no part in the decomposition (remaining in the form of coke), and the hydrogen of which amounts to only 5 or 6 per cent., yields consequently considerably less than oils, resins, or camphor, which leave no residue of charcoal, and contain 2 or 3 times as much hydrogen. In all these cases, a portion of the carbon is removed from the process of the formation of lamp-black by the oxygen present; this is not the case, however, with oil of turpentine, &c., in which oxygen is entirely absent, and the oil contains almost 18 per cent. more carbon than is required to form olefiant gas with its hydrogen.

Production of Lamp-black with and without Tar.—The preparation of common lamp-black from the refuse small coals, is intimately allied to the process of coke burning. In some cases it is combined with the manufacture of coal tar, and consists of the following arrangements. Fig. 164 shows *a* the furnace in which small coal is consumed with the admission of as little air as possible, the heat and smoke pass through the openings *b b b*, round an iron or clay retort *c c*, into a flue *d*, which is about 500 feet long, with many bends *e e*. The lamp-black is deposited in these flues or caves *e e*, and the retort *c c*, which is filled with coal, is heated from the furnace *a*, so as to distil the coal tar, which passes through the cask *f* into a larger cistern communicating with the underground flue *g*. The inflammable gases pass off from the cistern, and are burnt in the open air. The details of working this arrangement are so simple as not to require any notice. A similar arrangement for making lamp-black without tar resembles Fig. 164, with the omission of the retort c c.

Fig. 164.



Matches.—Many barbarous nations, unacquainted with the methods in use amongst civilized people for procuring fire, usually effect this object by violently rubbing dry pieces of hard against pieces of soft wood. Although flint, steel, and tinder have appeared irreplaceable for centuries past, both in simplicity and certainty, yet, modern art, keeping pace with the progress of science, has turned many chemical observations and discoveries to surprising advantage, with reference to the production of fire. Some of the inventions which have been brought forward deserve more particular notice, on account of their rapid and extensive diffusion.

The contrivances, in which sulphur-matches were inflamed by immersion in phosphorus (*phosphorous matches*), were first superseded by the so-called *chemical-matches*, which consisted of sulphur matches, with a coating of chlorate of potash. This salt (KO, Cl_2O_5), when brought into contact with concentrated sulphuric acid in the cold, is decomposed with explosion and the production of fire, into bisulphate of potash, perchlorate of potash, and chlorous acid, and by the two latter (one of which is resolved into chlorine and oxygen, and the other into chloride of potassium and oxygen) inflammable matters of all kinds, as sulphur, metallic sulphurets, rosin, gum, &c., are inflamed when within the immediate reach of its action. The sulphur ends of the matches are covered with a composition of chlorate of potash, flowers of sulphur, colophony, gum, and cinnabar (as a coloring matter): on dipping this into a bottle containing asbestus, previously moistened with sulphuric acid, it quickly becomes inflamed. These matches are now superseded by the more simple lucifer matches, which inflame without the aid of acid, or anything of the kind, by mere friction: an invention, the history of which, notwithstanding its novelty, is already lost, as has been the case in many similar instances, partly on account of its simplicity, and from the rapid introduction of similar processes.

Lucifer-matches.—These, like the last, are sulphur matches, to which a separate inflammable compound has been added. The primary coating of sulphur cannot be dispensed with, because the inflammable composition burns much too rapidly to set fire to the wood. The flame produced by the combustible mixture is, therefore, first communicated to the sulphur, and from it to the wood. The mixture at first contained chlorate of potash as an essential ingredient, and the production of fire depended upon the power of this substance of inflaming the sulphur, phosphorus, &c., with explosion, the effect being produced even by shaking or friction. Thus phosphorus was mixed with mucilage, at a temperature of 104° F., so as to form an emulsion, to which the chlorate of potash was then added. The phosphorus was sometimes replaced by sulphuret of antimony. The operation of mixing the ingredients in the dry state is at all times dangerous. The unpleasant noise which occurred whenever a match was inflamed, and a certain amount of danger from fire, rendered it desirable to replace the detonating action of the mixture by a slow combustion, and this has been accomplished in the *noiseless lucifer-matches*. None of those compositions which inflame *without* explosion contain chlorate of potash, but nitre and phosphorus instead; the latter of which burns at the expense of the oxygen of the former. The general principle concerned in the action of these matches is, that substances (as phosphorus) having a great affinity for oxygen are mixed with a large amount of it, condensed into a small space (in the nitre), so that the slightest cause is sufficient to effect their combination. The peroxides of lead and manganese, which abound in oxygen, are often mixed with the nitre; they act in the same way when they have once attained a red heat.

As the thickness of the match and the quantity of the composition upon it must always bear a certain proportion, both because the latter is expensive, and burns with a disagreeable odor, the matches require to be cut by machinery, or planes constructed for the purpose; they are thus obtained thin, sufficiently strong, perfectly uniform, and of an elegant appearance. Moist poplar wood is best suited for this purpose. The round or angular matches are dipped in bundles into melted sulphur, and then coated with the inflammable composition. According to Böttger, 16 parts of gum-Arabic, 9 parts of phosphorus, 14 parts of nitre, and 16 of finely divided peroxide of manganese, form a good composition, which must be worked up with water, to avoid danger. The mixture then forms a thick paste, into which the matches are separately dipped and then dried. Occasionally, smalt and similar matters are added to produce certain colors, or to increase the effects of friction. After repeated trials, the inflammability of the composition has been gradually diminished to such an extent, that it only inflames when strongly rubbed against rough surfaces, but not readily by pressure or shaking, especially when the matches are preserved in closed boxes; hence they are much less dangerous than might be anticipated. The slow combustion of the sulphur, with the emission of sulphurous acid, forms a great objection to these matches, as this gas is injurious to respiration. Matches have consequently been introduced into commerce which have been first dipped into fused stearine, instead of sulphur; these however, frequently miss fire.

Platinum Lamp, or Instantaneous Light.—In those cases where the apparatus is not required to be carried in the pocket, but is rather intended for use in the house, the action of spongy platinum upon hydrogen, discovered by Döbereiner, affords an excellent, although certainly not a very cheap, means of procuring a light. To prepare this, a solution of platinum in aqua regia (chloride of platinum) is precipitated with muriate of ammonia, and the platino-chloride of ammonium thus obtained, is stirred with a little pure ammonia into a thick paste, a drop of which is placed upon one end of a thin platinum wire, which is made into a loop. By drying, and the subsequent application of a white heat in a spirit-lamp, the double salt is completely decomposed, the platinum remaining as a metallic, porous mass, resembling a sponge. Like several other metals, but in a greater degree, platinum possesses the property, by some peculiar and inexplicable action of its surface, of inducing the combination of hydrogen and oxygen to form water, at temperatures at which this does not spontaneously ensue. This power increasing with the extent of surface, is greater in thin coiled wire than in foil, and is greatest in spongy platinum in consequence of its porosity; or the very extensive surface which it presents in a small bulk.* A current of hydrogen mixed with air, or oxygen, and brought into contact with the platinum sponge, begins to burn, forming water; this immediately raises the sponge to a white heat, and the gas then takes fire from the incandescent metal. This is also the process by which light is obtained in the "*Döbereiner's platinum lamp,*" Fig. 165.

Beneath a cap of brass plate *d*, fastened to the wire *n*, the spongy platinum is placed, exactly opposite the aperture *c*, from which, when the lamp is in use, a current of hydrogen issues. The latter is produced in the lower vessel *B B* from a mass of zinc *b*, and sulphuric acid (diluted with 6 parts of water), and is accumulated ready for use in the upper movable vessel *A A*. As often as any of the hydrogen is consumed, a fresh supply is produced at the same time, because the zinc only comes into contact with the acid when the apparatus is engaged in yielding light; at other times, it remains above the surface as in the figure. To allow of this, *A A* slides in the lid *g* like the piston of a pump, and when at rest, is kept up by the spring *f f f*; in that position, the only outlet for the accumu-

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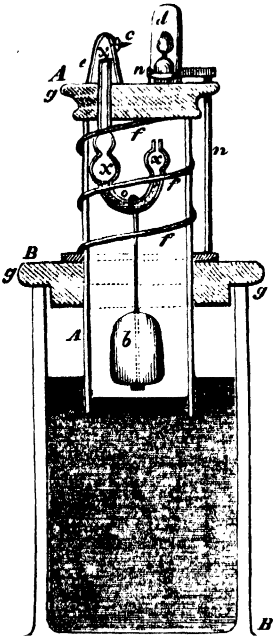
* Supposing the pores in a cubic line of spongy platinum to be $\frac{1}{100}$ of a line in diameter—which is far too much—and that these spaces were also cubical, there would be (independently of the thickness of the walls) a million of cells in the entire cube, each containing $\frac{6}{10000}$; hence altogether $\frac{6000000}{10000} = 600$ square lines; *i. e.*, a surface 100 times larger than that of the solid cube; thus an idea of the increase of surface produced by porosity may be readily obtained.

165.



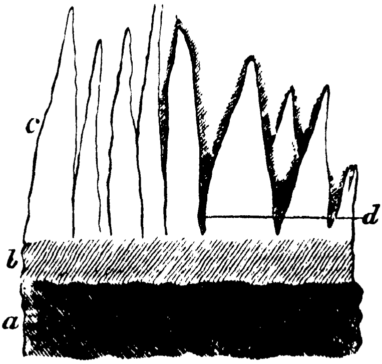
lated gas, through the glass tube *x x x*, is closed by a few drops of dilute sulphuric acid *o*. If, however, *A A* be depressed by the hand, the gas contained in it is subjected to sufficient pressure to drive back the resisting fluid *o* into the bulbs, and to open an outlet for it, first into the cap *e*, which is firmly fixed to the lid of *A*, and from thence to *c*, where it raises the spongy platinum *d* to a red heat, and then inflames. On the escape of the gas, however, the acid simultaneously rises in *A*, and coming into contact with the zinc, replaces, by a further evolution of gas, that which has escaped. This process continues uninterruptedly as long as the quantities of zinc and acid are not exhausted. Besides the apparatus figured above, which is of more recent invention, and was first proposed by Eisenlohr, there is another more generally used, which is, however, expensive, in which *A A* is fixed immovably into *g*, and supports above a brass cock, which carries a cap fixed to an arm to preserve the sponge from dust, as in Fig. 165. An advantage is gained by this arrangement, for the dust which burns on the sponge leaving an impure coating upon it, together with the sulphate of zinc, which is carried off by the gas in the form of very finely-divided drops, greatly impairs its inflaming powers. To understand the extreme injury produced by such trifling quantities of foreign matter, we must recollect that the action of platinum-foil in electrical experiments may be destroyed by merely wiping it with the cleanest cloth. According to Mohr, the sponge when spoiled may be restored by treating it with concentrated sulphuric acid, and washing with distilled water. This is more readily and easily effected by first immersing the sponge in a solution of chloride of platinum, then in a solution of muriate of ammonia, and subsequently heating it to redness; in this way an entirely new surface is produced.

IMPROVED PROCESS OF COKING.

The preparation of coke has become a very extensive trade within the last few years, in consequence of the increased demand for railways and smelting operations.

The small coal from many districts, which was formerly of comparatively little value, has now become a most important source of profit, and in some cases it has even been proposed to grind the large coal for the purpose of making coke. Indeed, coke made from large coal has never the same density and strength as that made from small. There is some difference as respects the management of different qualities of coal in converting it into coke. The great object of the coke-burner, is to produce a dense, compact coke, in such large masses, that in cases of long carriage, either by sea or land, these lumps of coke may arrive without being broken up into such small pieces as to be unfit for smelting or locomotive purposes. This object is most effectually accomplished by burning large quantities of coal of sufficient depth to ensure long upright masses of coke in the oven at the end of the operation. But some coals, which contain a large per centage of ash, form a coke which melts easily, and the consequence is, that when the ovens are charged with too deep a load of coal, the coke has melted, and covered the upper layers in such a manner that the air cannot penetrate to the unburnt coal at the bottom of the oven, and the produce is a mixture of charred coal and coke. On the other hand, when a coal contains a large proportion of ash, but does not melt in coking, the same result is observed, which arises, however, in a different way. The mass of coke at the top which is first formed, of course, continues to burn, leaving its ash on the surface, and this accumulating, at length falls down into the crevices, and chokes the fire before it has time to reach the bottom layer of coal; thus, in Fig. 166, *a* is the unburnt coal, *b* that partially coked, *c* the coke already formed, and *d* the ashes which have fallen down, and prevented the access of air to support the combustion. In such cases, the difficulty of coking such coals is obviated by building smaller ovens, and loading them lightly.

Fig. 166.



When suitable coal exists, the advantages of heavy loading are very obvious. The whole mass of coke is longer exposed to the hardening effect of the fire, and the heavy products of distillation, ascending from the bottom layers of coal, deposit large portions of their carbon on the side of the already formed coke, thus increasing the produce from a given quantity of coal. The ovens about to be described are charged with from 10 to 15 tons of coal, and produce a very excellent coke, both as respects quality and quantity.

After the oven has ceased to burn, the whole is made perfectly close, and the coke kept in the heated state, contracts in bulk, and becomes much harder and more compact. In coke intended for iron and other smelting operations, where it is exposed to the action of a blast, long before it really does any efficient duty, the above qualities are most valuable.

Figs. 167, 168 and 169 are figures of the same ovens, showing

Fig. 167.

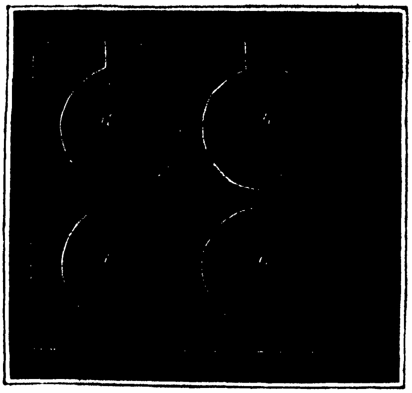


Fig. 168.

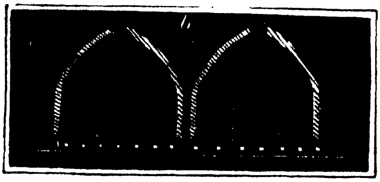
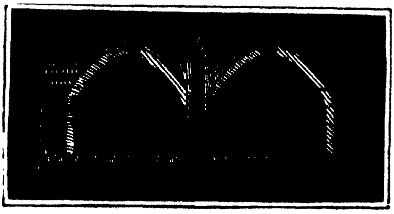


Fig. 169.



them in different positions, about ten feet in diameter, and 4 feet from the floor to the springing of the dome, and in favorable localities each oven will cost about £25 ($125). *a*, Fig. 167, indicates a series of flues under the floor of the ovens, ending in a chimney *b*, the object of which is to assist in cooling the floor as rapidly as possible after the coke has been drawn out, so that there may be no distillation of the coal of the next charge, which would tend to produce an inferior coke at the bottom. It may also be noticed here, that the dome ought to be made as flat as possible, consistent with durability, in order to reflect the heat as much as possible down upon the coal, and preserve the heat of the oven generally.

Figs. 170, 171 and 172, show a similar form of oven, in which the smoke is, however, carried along the flues *a* to a high chimney, thus avoiding the inconvenience of the large volumes of smoke which are poured forth by a range of coke ovens; *b*, Fig. 170, is a cast iron pillar supporting a railway for conveying the coal wagons to any particular oven, so as to be charged in front, it having been found that when the coal is more equally spread in the ovens by manual labor, the charge is burnt off in less time, than when the wagon discharges the coal into the oven all at once through the opening in the dome, independent of saving in the wear and tear of the dome occasioned by the passage of heavy coal wagons.

A patent has been secured for drawing the whole of the coke at once from the oven, so as to save labor and time, but it has not come into general use. Indeed, the great point to which attention ought to be directed is, especially to increase the yield and the rapidity of the coking process*, so as to save the great waste from the escaping gases

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* The rapidity of coking diminishes the yield of coke, but gives more compactness to at which is produced. See "Report on American Coals," p. 278.—Am. Ed.

Fig. 170.

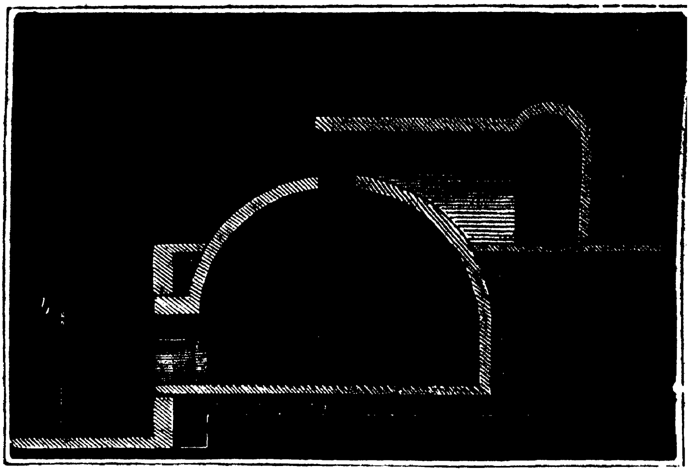


Fig. 171.

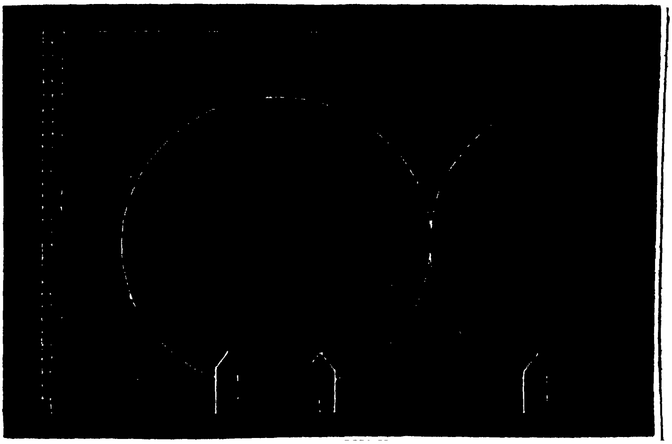
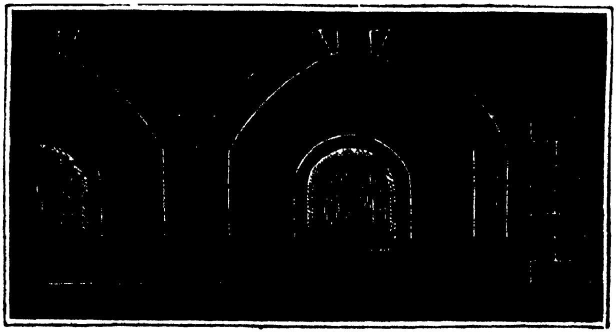


Fig. 172.



and small residual coke, technically called *brees*. The large ovens have, in some measure, remedied this latter point, and an attempt to convey the waste heat between the lining of the ovens and the outer wall to facilitate the coking operation, did not answer in an economical point of view, the first and subsequent expenses amounting to more than the gain.

Another patent for separating the sulphur of the coal by electricity, has met with no better success.

The cost of making coke is so small, as will be seen from the following statement, that the truth of the above remarks will

	s.	*d.*	
and burning coke, with all attend- required, including filling wagons .	0	10	per ton
Filling ovens with coal	0	2	" "
Wear and tear of ovens	0	2	" "
Total cost	1	2	" " "

= 28 cents.*

MANUFACTURE OF PATENT FUEL.

The great object in the production of this species of combustible has been to convert those natural fuels, which are in such a form as to be unfit for use, into an article possessing all the advantages of the more esteemed steam-coal, with this important additional recommendation, that it occupies less space.

Peat and small coals have accordingly attracted the attention of inventors, but in many instances, the parties have recommended the mixing of materials, such as clay, &c., which can in no way add to the value of the fuel, except perhaps as a retainer of the heat. We have, therefore, overlooked those processes, with the view of noticing two more fully, which have strong claims for support, from the really valuable nature of the inventions.

The first is that of Mr. Hill, who distills dry peat, and collects the pyroligneous spirit and tar. The tar is converted into pitch, which he mixes, while hot, with peat charcoal, and thus renders a very bulky, and, for many purposes, valueless article, one of great importance.

The other is much more extensive, and is being carried out into practice on a large scale by Mr. Wylam. This manufacture consists, however, of several distinct branches, which it will be better to pursue in their order. We have first the separation of coal tar by distillation into naphtha, dead oil, and pitch. The pitch is subsequently mixed with small coals, and moulded, by pressure, into bricks. The naphtha is rectified and sold as such, while the dead oil is converted into ivory-black. The tar is mixed with about an equal quantity of

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* The price of labor in the United States will probably considerably increase this estimate.—Am. Ed.

water, which appears to facilitate the separation of the naphtha. The process of distillation is conducted by exposing the tar and water to the heat of a common fire in a large iron retort *A*, Fig. 173. Two pipes, *B* and *C*, uniting at *E*, convey the volatile products from the retort. During the first stage of the distillation, the pipe *C* is closed by a valve at *d*, and the naphtha and water escape through the swan-neck shaped pipe *B*, which is carried about 3 feet above the retort, to prevent any dead oil passing off at the same time, during any sudden ebullition of the contents of the retort. The pipe then passes through a condenser *F*, kept cool by a stream of water, and discharges the naphtha and water into the vessel *G*. The naphtha floats on the top, and flows off in a continuous stream at *g*, while the water syphons itself off by the syphon *H*, Fig. 174, as it accumulates. As soon as all the naphtha has passed over, the pipe *c* is opened, and more heat applied, until the distillation of the *dead oil* is complete. The pitch which remains behind, is ultimately drawn out by an opening at the

Fig. 173.

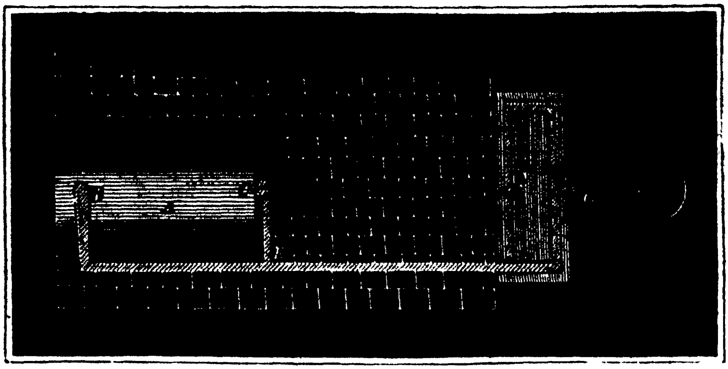


Fig. 174.

lower end of the retort, into shallow stone coolers. *I* shows the fireplaces, and *K K* the flues for heating the retort. Fig. 175 shows an end view of the swan neck of the retort.

Fig. 175.

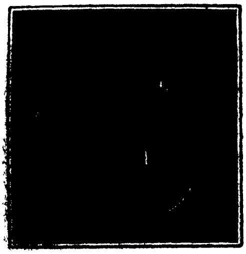
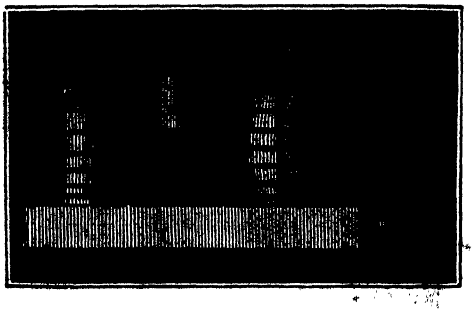


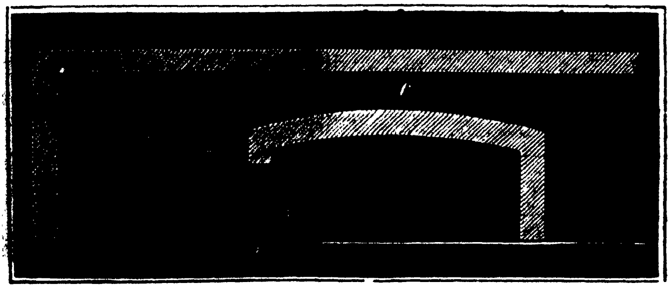
Fig. 176.



The naphtha is re-distilled from a vessel *I*, after being mixed with a small quantity of water. Instead of the heat of a common fire, steam, in this case, is applied by the pipe *K*, as shown in Fig. 176. An intermediate vessel *L* is placed between the still and the condenser, to retain the products of any sudden ebullition. The condensation and separation of the naphtha and water are conducted in the same manner as has already been described. The letter *l* shows how the cold water passes to the condenser, and *m* the exit pipe of the heated water, after serving the purpose of condensation. The naphtha from this second distillation, is then mixed with chloride of calcium, or quick-lime, and subjected to a third distillation in a similar apparatus, when it is obtained perfectly colorless and fit for sale.

The *dead oil* obtained as the second product of the distillation of the coal tar, is sold for the purpose of illumination on the quays of manufactories, railway-works, &c., as a solvent for pitch, in which case it makes a valuable varnish, for coating wood and iron-work exposed to the weather, and lastly, for the manufacture of a very superior *ivory-black*. The arrangements for making the ivory-black are very simple. The dead oil, which is kept in a large reservoir, is heated by means of steam, to render it more fluid, so that it may flow through the pipe *A* (Fig. 177) more easily, and makes its exit at *D*.

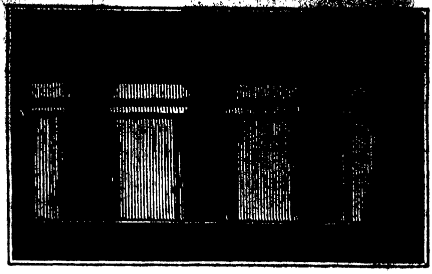
Fig. 177.



It is ignited at this point, and the lamp-black which results is deposited in long galleries, into which it passes through the flue *C*. The large chamber *B* is constructed with the view of preventing occasional explosions extending into the galleries. Fig. 178 shows the end view of the burners *E E*.

Fig. 178.

Fig. 179.



The pitch, after having become hard, is ground under edge-stones, and mixed with small coal in the proportion of 1 to 4. The mixture of coal and pitch is carried up into a large hopper, from which it gradually passes into the receivers *M M M*, Fig. 179. At the bottom of these receivers, a pair of plain rollers *O*, Fig. 180, are kept in motion by the shaft *N*, Fig. 179, and by this simple contrivance, a regular supply is thrown into the retort *R*. An Archimedean screw *Q*, Fig. 180, inside of the retort, is also made to revolve by the above shaft *N*. The retort is maintained at a dull red heat by the hot air in the flue *T*, and the fuel passes through the whole length of the retort in about three minutes. The retort is about 15 feet long. The mass of coal and pitch is discharged at the opposite end of the retort in a pasty state, and carried by an endless chain into the receiver *S*, Fig. 181, where it is kept in motion by the arms *r r*, so as to prevent it hardening into lumps. From this cylinder or receiver it runs into large moulds, where it is subjected to a heavy pressure in the following manner. *A* represents a movable oval table, upon which the moulds *B B* are fixed. *S* the vessel which re-

Fig. 180.

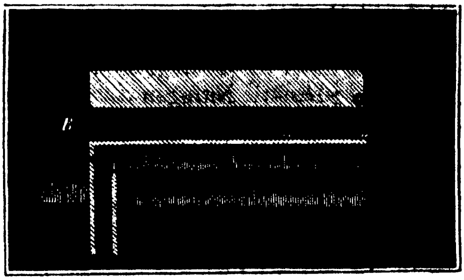
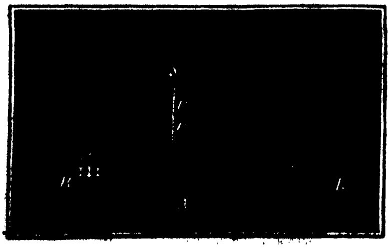


Fig. 181.



ceives the fuel paste, *u* and *x* two cylinders similar to the cylinders of a steam engine, but worked by water, *v y* the pistons to which two rams are attached, each having six arms that fit accurately the moulds *B B*, and *z* is a lever worked by means of the motion of the piston *y*. The moulds are filled from the vessel *S*, as the table is made to revolve by the movement of the lever *z*. As the moulds approach the cylinder *u*, the piston descends and compresses the fuel with an enormous pressure, and after the piston rises, another set of moulds take their places, while the piston *y* of the cylinder *x* having descended at the other end of the table, the six bricks are forced out of the moulds, and are received below ready to be stamped with the maker's name. The machinery and the whole arrangements are exceedingly beautiful, and the accompanying sketch is only intended to convey an idea how the process is effected, without showing all the details of the mechanism.

One of the manufactured bricks was reduced to powder, and furnished the following results.

1. 4.56 grs. burnt with chromate of lead yielded

CO_2 . . 12.81 grs. = Carbon . . 3.493
H_2O . . 2.13 grs. = Hydrogen . .235

2. 25.93 grs. in Will and Varrentrap's apparatus yielded 6.41 grs. platina salt = .4 grs. nitrogen.

3. 123.27 grs. left 8.72 grs. ashes. Hence the composition in 100 parts will be as follows:

Carbon	76.60
Hydrogen . . .	5.15
Nitrogen . . .	1.54
Oxygen	9.63
Ashes	7.08
	100.00

A metallurgical assay furnished the following result, 123.27 grs. in small pieces left 84.74 grs. coke. Hence the composition in 100 parts:

Coke	Carbon . . .	61.67
	Ashes . . .	7.08
Gaseous matter . .		31.25
		100.00

The pitch employed in the manufacture of the patent fuel possesses a specific gravity of 1.01016, and the analytical results were as follows:

1. 4.265 grs. burnt with chromate of lead furnished

CO_2 . . 11.54 grs. = Carbon . . 3.147
H_2O . . 3.11 grs. = Hydrogen . .345

2. 163.10 grs. left 93 grs. ashes. Hence

Carbon .	. 73.56
Hydrogen	. 8.08
Oxygen .	. 17.79
Ashes . .	. .57
	100.00

The pitch contained no hygrometric moisture, and this patent fuel only 0.86 per cent.

A glance at the above composition of the pitch proves how valuable the substance must be in the manufacture of a fuel destined for raising steam on board steam-vessels. The large proportion of hydrogen and oxygen, add materially to the amount of heat it will evolve, and the facility of its combustion. And it must be obvious to all, that a fuel manufactured from this substance in proper proportion, and a suitable small coal, will far surpass any natural coal for steam purposes.*

APPLICATION OF HEAT.

Heating and Ventilation of Dwellings.—The advantages of an open fire-place are so numerous and so highly prized by the inhabitants of the country, whose ideas of comfort and sociability are directly connected with the fireside, that it is not likely or desirable that other modes of heating rooms or dwellings will or should ever entirely supersede this old established plan of obtaining the necessary amount of warmth. The open fire-place and chimney afford the simplest possible means of creating a thorough circulation of air throughout the inhabited room, a condition which can never be dispensed with without injury to health, and which is entirely absent in those arrangements on the continent of Europe, where the fuel is introduced into the stove on the outside of the room, and is supplied with the requisite amount of air from without also. The change of air in rooms under such circumstances is dependent entirely upon crevices in windows and doors, and as these are avoided as much as possible in the construction of the houses, double windows and double doors being frequently employed, the air becomes vitiated where many persons are breathing in the interior in a very short time, and the sallow complexions and stove-dried appearance of persons habitually occupying such dwelling-rooms are visible proofs of the injurious tendency which it must exert upon bodily health generally.

The ordinary arrangement of the fire-places in our dwelling-houses at present, however, is connected with several inconveniences. There is always a very considerable loss of heat, and a very unequal temperature is diffused in the different parts of all rooms, which are heated solely by one fire-place. The supply of air to the fuel is fur-

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* The above incidental products of the distillation of coal to produce illuminating gas, prove how important are those results of the manufacture which have hitherto been almost wholly neglected in the United States.—Am. Ed.

nished by the crevices in doors, or other parts of the room only, and wherever this air is admitted, a draught must be occasioned, and, consequently, persons sitting by the fire, are constantly exposed to the unpleasant sensation of having one side heated excessively by the radiated heat from the fire, whilst the other side is cooled by the cold air rushing in to maintain the combustion of the fuel. Draughts of this kind are exceedingly objectionable, and can only be remedied by some plan similar to those described below. Another objection to the open fires and chimneys, is the downward draught frequently occasioned in neighboring chimneys not in use, by large powerful fires in other rooms of the same building, and which are not supplied from other sources with sufficient air for the consumption of fuel going on in them. Foul air, carrying with it particles of soot, is thus disseminated throughout the rooms, to the detriment of health and cleanliness.*

In order to moderate as much as possible, the inevitable loss of heat which the use of open hearths involves, and yet retain all the advantages of the open fire, numerous contrivances have been devised at different times, and amongst the most successful of these are Sylvester's stoves, which are now becoming very general in the best arranged houses in London; the fuel is placed upon a grate, the bars of which are even with the floor of the room, and air is supplied to the ash pit below by a series of passages which pass under a hearth composed of separate bars of iron, arranged in a radiating or otherwise ornamental manner in front of the grate. The radiant and conducted heat from the fire is thus made to warm the hearth and the air passing below it, which is consequently warmed before reaching the fuel, and in an economical point of view this is of course advantageous. The warm hearth and the low position of the fire are also means of disseminating the heat much more effectually than is done by the ordinary arrangement of the fire-place. The sides and top of these stoves are constructed of double casings of iron, and in the sides a series of vertical plates, parallel with the front facing, are included in the interior, which collect, by conduction, a great portion of the heat generated from the fire, the mass of metal of which these are composed being so proportioned to the fuel consumed, that the whole can never rise above the temperature of 212° F. under any circumstances. The sides and top of the stove are thus converted into a hot chamber, offering an extensive surface of heated metal; at the bottom, by an opening in the ornamental part, the air is allowed to enter, and rises as it becomes warmed, traversing in its ascent the different compartments formed by the hot parallel plates, and is allowed to escape at the top by some similar opening into the room. A current of air is thus constantly traversing the hollow sides and top of the stove, collecting the heat communicated to the metallic mass, and disseminating it through the room. If allowed to enter the room

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* On the heating by flues from anthracite furnaces, and the reflections which led to that mode of employing the fuel, see above pp. 98, 99.—Am. Ed.

by the top aperture, the air would now be in the rarefied, dry state which is considered very unwholesome; a basin of water is consequently introduced into the top of the arrangement, and evaporates rapidly by exposure to the air, communicating to it the proper amount of moisture. Figs. 182 and 183 represent two modifications of these stoves: the one, Fig. 183, is intended to stand forward in the room; the other, Fig. 182, to fit into the recess of an ordinary chimney. At the back is a series of louvres or flat bars like those of a Venetian window blind, by opening or closing which, a greater or less draught can be created, according to the amount of combustion required. The whole opening into the flue behind can be closed when the fire is not in use, by one of Mr. Sylvester's patent adjusted sliding-doors, Fig. 184, which form a valuable addition to every chimney, and from their important applications to other technical purposes connected with the econo-

Fig. 182.

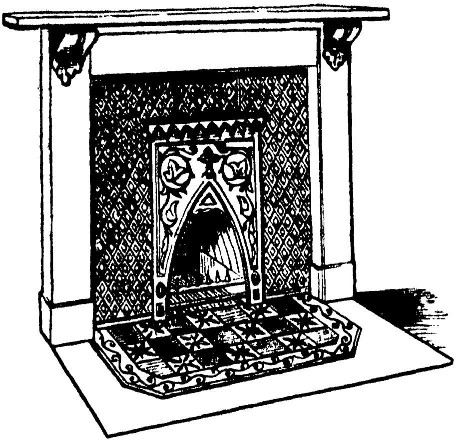


Fig. 183.

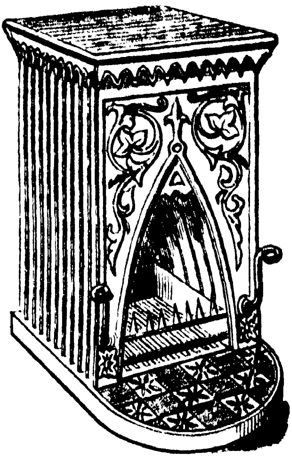
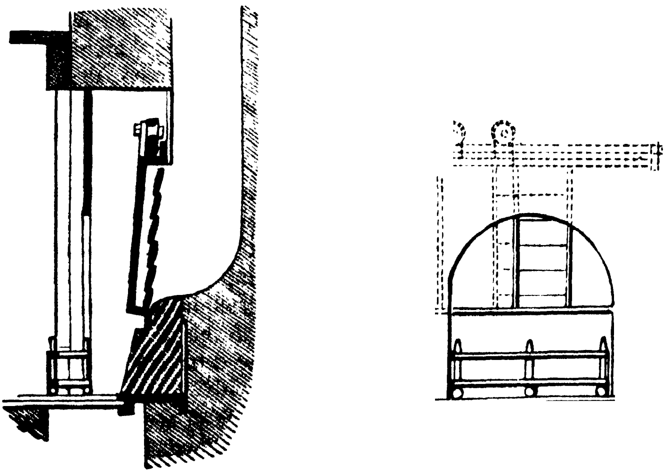


Fig. 184.



mical use of fuel, deserve more particular notice. These doors are constructed in such a manner that they slide in contact with the planed surfaces, a portion of their weight being distributed against the sliding surface, for the purpose of preserving contact; they are provided also with friction rollers to support them on their bearing bar, and in order that they may be easily moved. Chimneys not in use can be completely closed by this contrivance, and the disagreeable downward currents, mentioned above, are most effectually stopped by closing the door. These doors will also be found of much service in the case of a chimney taking fire, for by closing the door all air is prevented access to the burning soot, and the fire speedily extinguished.

Applied to furnace or boiler fires and ash-pits, in the manner represented at Fig. 185, they afford a means of regulating the draught to a great nicety, and thus supply one of the most important conditions for moderating the combustion of fuel. For these purposes they may be lined with fire-brick or clay.

Fig. 185.

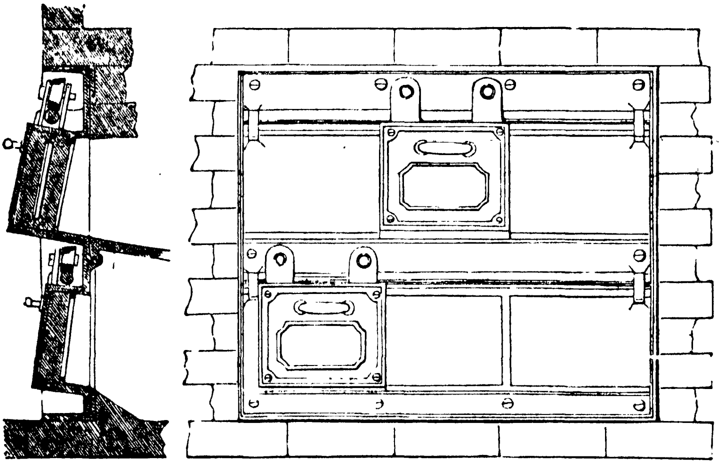
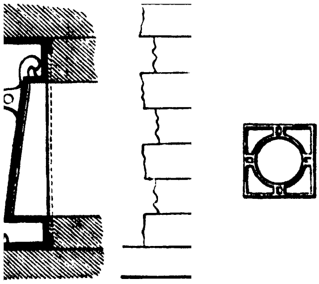


Fig. 186.



The same contrivance is applied to soot or flue doors, Fig. 186, introduced into chimneys for the purposes of cleansing, which can thus be accurately closed, and will prevent any interruption to the draught from side currents.

The economy of heat and fuel is very great in the kinds of stoves or fire-grates which have just been described, but the air which supports the combustion is supplied in the ordinary manner from adventitious sources, and the only mode of remedying this, with proper attention to ventilation at the same time, is by affording a distinct entrance to pure air from without the building by some passage made expressly for that purpose. Mr. Sylvester recommends that a subterranean passage be made from the basement of every house to the garden, that the entrance to this passage be furnished with a kind of revolving hood which shall turn easily and present an opening to the wind, that the air which enters this passage be caused to traverse the heated sides of a large stove, constructed upon the same principle as that described, and be conveyed from thence to the different passages and rooms of the whole house. The extraneous entrance of air is thus rendered unnecessary, the air which is supplied may be heated in cold weather to the proper temperature by the stove in the basement, and being supplied in this state to the dwelling-rooms, no unpleasant or injurious cold current will be felt, a small fire in the grate of each inhabited room will cause quite sufficient draught to afford a constant renewal of fresh air, and the small quantity of fuel which will then be requisite in each room, will fully compensate for the consumption in the large general fire below for supplying the constant current of warm air. In summer, the same arrangement will be a source of pure cold air, which in winter supplies warm air, and thus perfect ventilation will be established independent of windows, doors, &c. For large buildings, churches, theatres and rooms where great numbers of persons are constantly congregated together, a thorough supply of pure fresh, but at the same time genial air, becomes an object of the greatest consequence, although, until lately, it has attracted but little attention. Our churches are, for the most part, filled with roasted and over-heated air, and the upper parts of our theatres cannot be endured by persons of delicate constitution. The inconveniences attending the want of proper ventilation are, however, beginning to make themselves felt, and numerous plans and experiments have been undertaken to effect this in the most complete and economical manner. The plans proposed and carried out in some of the large buildings, are so various and in many cases so new, that they must all be considered in the light of experiments, the respective values of which can only be ascertained after a more lengthened trial has been vouchsafed them. The main object is, however, the same in all, and involves the supply of a certain portion of fresh air to a certain locality, either warm or cold, within a certain space of time. The amount of air constituting this supply varies, of course, with each individual case. Indeed, it does not appear that philosophers are agreed as to the mean quantity of air required by a number of individuals during a given time, and until this point has been definitively settled, the calculations which must obviously be based upon it, will necessarily differ according to the standard assumed by each observer. There can be no doubt, however, that it is preferable in the meantime, until that question shall receive a definite answer, to supply an excess of fresh air rather than a deficiency, which has as yet been the prevalent error in practice.

In the British House of Commons, which has been ventilated under the superintendence and according to the plans of Dr. Reid, the air is supplied to the basement of the building, passing first through a fibrous veil 42 ft. long by 18 ft. 6 in. deep for the exclusion of visible soot, it arrives at the heating apparatus, consisting of large chambers intersected by steam pipes, and proceeds from thence to other chambers, where it can be mixed with cold air and brought to any required temperature. The floor of the house is double, and the space below the floor can be connected by means of valves with the hot-air chamber. The floor is perforated by a great number of apertures, and these are covered with hair-cloth, so that the hot air in escaping from the floor into the body of the house is infinitely divided, and no perceptible current is experienced. Having performed its functions, the vitiated air ascends to the ceiling, which is also double and perforated, in the same manner as the floor, whence it is carried off by the draught created by a powerful fire under a chimney shaft erected in another part of the building.

The plan adopted by Mr. Barry for warming and ventilating the House of Peers, the royal ante-chamber and the public lobby, differs from that just described both as respects the admission of the air and its removal. The floors of the rooms are impervious, and are heated in the first instance simply by the passage of hot air below them, the hot air then escapes by passages along the external sides of the rooms to the ceiling, which is divided into two compartments; the one for the admission of the warm air, entering at the sides from below the floor, and the other for the exit of the vitiated air. The warm air after passing below the floor to the roof becomes somewhat cooled, so that its temperature on entering the ceiling is a few degrees lower than that actually present in the room; it consequently descends to the level at which it is at once heated again, and, deteriorated by combustion, respiration, &c., rises through the centre of the room, passing through the ceiling to a foul-air chamber above, whence it is conducted to a chimney and carried off by the peculiar motive power first applied by Mr. Bell to the production of draught. This power consists of a jet of steam, which, when produced under pressure of 32 lbs. to the square inch, is capable of setting 217 times its bulk of air in motion; 10,000 cubic feet of air are thus gradually diffused through the three apartments per minute, no draught of any kind is perceptible and no inconvenience is experienced from dust or other solid particles being carried mechanically forward by the air, as is said to be the case when the air enters from below.

In other cases in England, as at the prison in Milbank, warm air is admitted at the ceiling and carried off by the draught of a chimney in connection with the sides or lower part of the rooms. At the form Club House, and at the new Hospital for Consumptive at Brompton, warm or cold air is forced forward, or pumped in nels conveying it over the whole building by a steam engine basement, and is allowed to find its own escape through chimneys and other apertures.

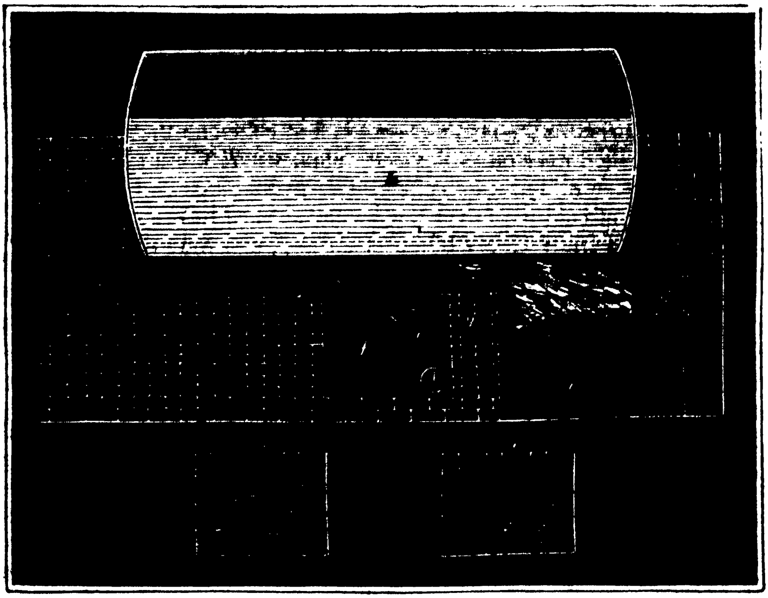
CONSUMPTION OF SMOKE.

The prevention and consumption of smoke have of late attracted great attention. A committee of the British House of Commons has collected evidence with the view to legislation, while the Health of Towns Commissioners have drawn increased attention to the whole subject by an attempt to estimate the many damages the public sustain from unconsumed smoke. There have also been nearly forty patents secured in England, independent of many other plans which have been suggested, as capable of removing or modifying this evil.

The previous section on heat and light, contains all that is necessary in the way of general remark on this subject, from which we readily infer that *smoke*, (by which is meant the black carbonaceous particles,) is either the result of a deficient supply of air, or of too great a supply at too low a temperature. In countries where bituminous coal is the chief fuel, it is extremely difficult to employ a plan which shall be applicable at once to the volatile portion of the coal and the coke which remains on the grates. Where anthracite is employed this nuisance is wholly avoided. It would be impossible to notice all the plans which have been proposed to accomplish this object; we can only revert to two which appear to have been the most successful.

Mr. Williams' plan consists essentially in admitting a current of air behind, or through the fire-bridge, in several small jets or streams,

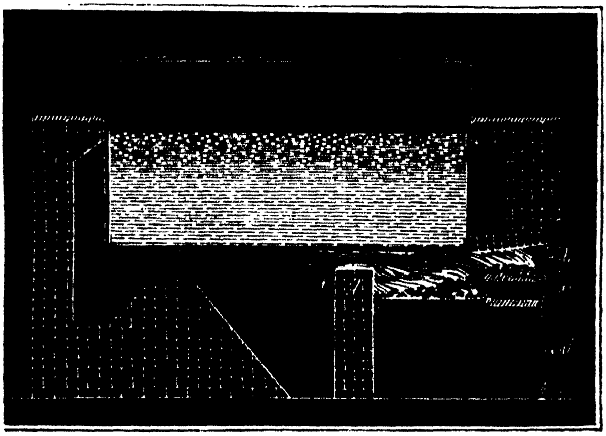
Fig. 187.



as readily to mix with the mass of heated hydro-carburets in their escape from the fuel on the grate bars, as shown in Fig. 187. *h* represents the boiler; *d* the fire-door lined with fire-clay; *a* the ash-pit, whence the coke on the fire-grate obtains its supply of air; *g* the fire-bridge, behind which is found an iron box *e* pierced with a number of small holes, through which the air streams from a tube *b* communicating with the outside. The space *f* is intended to act as a diffusion chamber for the more perfect mixture of the air and gases.

The other plan is that of Messrs. Howard and Co.'s. Fig. 188

Fig. 188.



represents a front view of the boiler and fire arrangements, where *a* is the boiler, *b* the feeding door, *c* door for removing the cinders, &c., *d* the ash-pit door, through which the admission of air is regulated by slides, *e* another door for the regulated admission of air to the posterior part *f* of the fire-bridge *g*, Fig. 188. The cooking plate *h* must be built of fire-brick or stone. The coal is first coked on the above plate, and then pushed over on to the grate bars, where there always exists a bright surface of burning coke. The gases generated in coking a fresh portion of coal pass over this heated surface before they come in contact with a fresh supply of warm air at *f*, and thus an almost perfect combustion of smoke is the result.

The saving in fuel produced by these plans varies form ¼ to ½ of the whole, and was, therefore, well worthy the attention of manufacturers; and where there exists a prejudice against patents, a very beneficial result would follow the previous coking of the coal on a broad plate made of stone in front of the fire, and the admission of a fresh supply of air at the back of the fire-bridge.*

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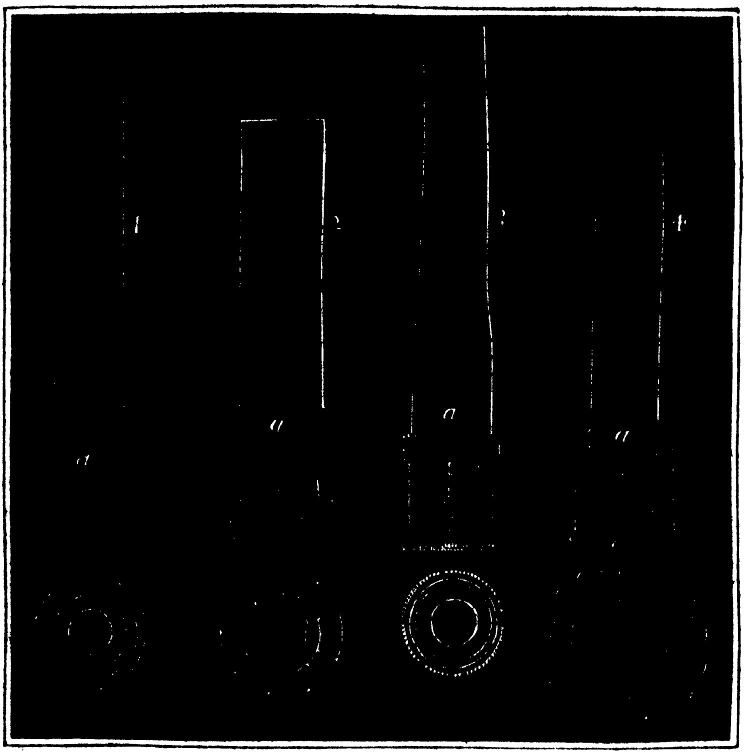
* Baker's improvement in steam boiler furnaces resembles the above, and consists essentially of a *succession of bridges* sometimes five or more in number, distributed at equal distances along the fire-flue from front to rear of the boiler. Each bridge is concave towards the grate intended to reverberate upwards the hot gases, and one or two of them nearest the grate are furnished with chambers and perforated plates for the

LAMPS.

Oil Lamps.—The principle of the lamps constructed by Benkler and Rühl, and described in the text at p. 200, has also been carried out in England in the lamps first introduced by Mr. Smith, of Birmingham, under the name of Solar Lamps. The main point in the peculiar construction of these lamps, is the manner in which the air is caused to impinge upon the flame by the adaptation of a metallic or glass cone, represented at *a* in the figures below.* The introduction of air at this particular part of the flame, or at this certain angle, admits of crude cheap oil being consumed in the lamps, which would produce smoke if burnt in lamps of the ordinary construction. The combustion of this oil in the ordinary manner being attended by

Fig. 189.



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admission of air to burn any combustible gases. Like Howard & Co.'s, Baker's furnace also admits the hot gas to play against the rear end of the boiler. Several manufacturers and others have testified to the advantage of this arrangement of furnaces, proving that the gain in evaporative power of fuel over the old defective plan of arranging cylindrical steam boilers, amounts in some cases to nearly 100 per cent. The patent to Henry T. Baker of Boston, bears date May 30, 1846.—Am. Ed

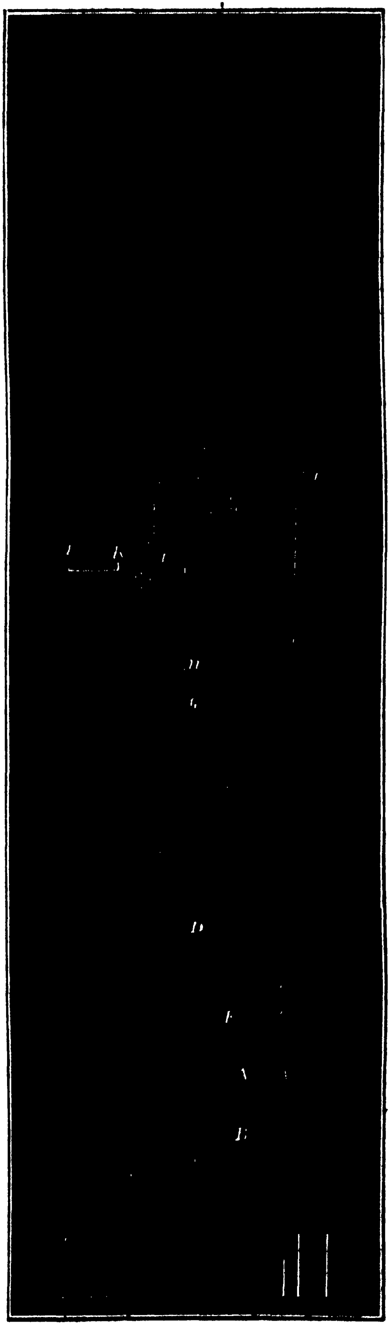
* For description of Cornelius' solar lard lamp, see above, p. 210.—Am. Ed.

an evolution of smoke and smell, indicating an imperfect consumption of the constituents of the oil, gives rise to the necessity for an increased supply of oxygen or air to that particular part of the flame where these unconsumed portions are evolved, to produce the inodorous and invisible products which alone should result from perfect combustion. The oil in the solar lamp is contained in an annular vessel, similar to that described at page 141, and the lamps are constructed in precisely the same manner, with the exception only of the burner. The first form in which the new burner was introduced, is represented in section at 1, Fig. 189, and consists of a solid metallic box fixed upon the circular wick-holder of ordinary construction, so that the cone or contracted aperture *a*, shall be barely $\frac{5}{8}$ths of an inch above the top of the wick-holder; this relative position is observed in all the burners. This form of cone box was found very inconvenient by becoming exceedingly hot and throwing a considerable shadow; it was consequently soon superseded by that represented at 2, Fig. 189, in which the metallic box is very much diminished in size, and the cone is composed of glass, with a smaller ring of metal round the mouth *a*. This ring of metal is essential; it is necessary that the aperture should be always of the same diameter, and glass cones can never be made with sufficient nicety to present at all times an exactly similar mouth. Messrs. Whitfield and Hughes subsequently replaced the solid box, by the open skeleton cone holder represented at 3, Fig. 189, called the screw cone glass-holder, in consequence of the tall thin chimney being screwed on to the top of the holder. The last improvement is the plate cone glass-holder of Mr. Smethurst, represented at 4, Fig. 189, in which the metallic cone is replaced by a flat metallic ring fixed upon a skeleton support, the external edge of which fits closely to the glass chimney.

In the last form of burner, little or no external current impinges upon the flame from the outer sides of the cone or its substitute; but the flame is only forced inwards so as to come more completely in contact with the current of air passing through the interior of the burner. The solar lamp has been extensively used in consequence of the low price of the oil which it consumes; it requires, however, a good deal of care and cleanliness in trimming, the wick must be freshly cut every time the lamp is used, and the reservoir should be refilled with oil.

A form of pressure lamp, called the Elliptic lamp, in which the constant flow of oil to the wick is regulated in an ingenious manner, has been patented by Mr. Meyer, and is found to answer perfectly, even when crude vegetable oils are consumed in it. Fig. 190 represents an entire section of the lamp, the foot of the lamp forms at the same time the oil cistern, it is of a cylindrical shape, and a leather piston or valve *B*, is worked up and down in it by rack and pinion seen at *L*, *F* is a spiral spring of strong iron wire fixed at the top to the solid stem of the lamp, and exerting a constant pressure on the piston, so long as it is in any position above the bottom of the oil cistern. The tube *D*, which opens at the bottom in the shape of an inverted funnel, and ends in a disc pierced with holes, supplies the oil to the burner, and passes in an air-tight manner through a stuffing box in the piston *B*, and can thus be moved with ease, the piston remaining stationary. This tube *D* is widened above on approaching the burner, and receives a fine silver tube several inches long, and $\frac{1}{30}$th of an inch internal diameter, which is surrounded by a cap of gauze, made of copper wire tinned, to prevent corrosion. This gauze has very small meshes, that no solid particles mechanically mixed with the oil may be carried up into the silver tube, and thus impede or altogether stop the passage of the oil. The whole of the oil must pass through the silver tube before reaching the burner, and the friction thus exerted against the sides of the narrow tube is the only resistance offered to the oil, which would otherwise be forced up all at once to the burner by the pressure of the spiral spring. This, therefore, is the regulator for the supply of oil, and must be so proportioned in length and bore to the force of the spring, as to admit of a constant excess of oil flowing to the wick and over the sides of the burner, where it is caught in a receptacle, and carried back into the oil vessel at the foot of the lamp. The lamp is filled with oil by slightly raising the whole interior portion from *L*, and pouring oil through the stem to the cistern below; the oil then rests in the first instance on the top of the piston. The whole interior portion of the lamp is then wound up by the key *I K* and the rack-work *L*, until

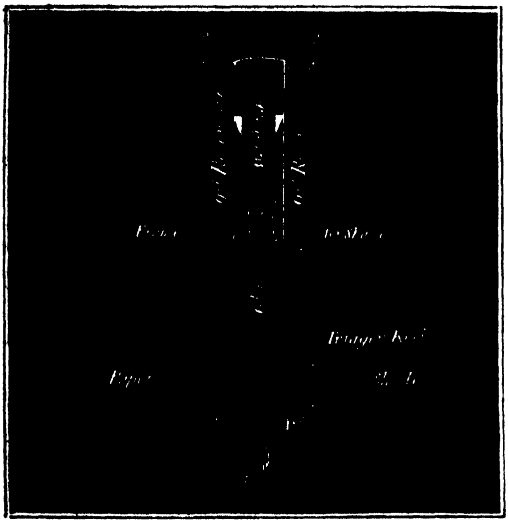
Fig. 190.



the top of the cistern prevents the piston *B* from ascending higher. The tube *D* and the burner, &c., attached to it, is then pushed down by the hand through the stuffing box until it attains its original position. The oil which was previously above, having passed during the ascent of the piston between it and the sides of the cylinder, is now below the piston, and the spring in forcing the latter down will tend to force the oil out through the tube *D* to the burner. The force of the spring and the resistance offered by the silver tube are so proportioned that the supply of oil shall last 8 or 10 hours.

The thick consistence of crude whale oil offers such powerful resistance to the action of capillarity at the ordinary temperature of the air, that the oil cannot be burned in common lamps, unless it is previously rendered more fluid by the aid of heat. To effect this a very ingenious form of lamp has been introduced by Mr. Parker, called the Economic, or hot-oil lamp. The oil reservoir of this lamp, Fig. 191, is composed of a double cylinder surrounding the upper part of the chimney, which is constructed of metal and slightly curved outwards, so as to reverberate the heat upon the oil vessel, and heat the oil to a considerable extent. The hot oil then descends by the arm to the burner, as shown in the figure. The lower part of the arm, which is attached to the oil vessel, is furnished with a slide valve worked by the trigger, so that the supply of oil can be cut off by raising the trigger, and the oil vessel entirely removed from the lamp for the purpose of filling, &c. The oil is introduced by this valve, the oil cistern being inverted, and this should be refilled each time the lamp is used, care being taken that no air remains in the vessel, as this would be expanded very much by the heat, and cause the oil to overflow.

Fig. 191.



The flame is regulated by raising or lowering the bell-mouthed glass chimney, which rests upon three points below and is moved by rack and pinion; the wick is not movable, as is the case in ordinary lamps, and a fresh wick, which is accurately cut by machinery expressly for this lamp, must be inserted every time the lamp is used. A paper or glass shade surrounds the whole of the upper part of the lamp, according as the light is required to be thrown downwards or uniformly diffused through the apartment. Dr. Ure has reported the illuminating power of this lamp to be superior to that of Carcel's mechanical lamp, and when consuming southern whale oil, it would appear from his statements to deserve the appellation of the "Economic" to the full extent of the word.

Camphine Lamps.—It is only within the last few years that oil of turpentine or camphine has been successfully introduced into general use as a source of illumination, and it is by applying the principle of the solar cone in an extended manner that this highly carbonaceous substance can be completely and conveniently consumed. The method of procuring oil of turpentine by distillation from the crude turpentine has already been noticed at page 129, but the oil obtained from the first distillation must be repeatedly rectified over chloride of calcium or some similarly active substance in order to free it from all water. The pure oil is clear, colorless and very mobile, it has a peculiar smell and a burning taste. Its specific gravity is 0.86 to 0.87; the commercial oil is frequently adulterated with resin, which raises the specific gravity, and which increases in quantity when the oil is exposed, in consequence of the absorption of oxygen from the air. When pure, the oil boils at 312°, and contains no oxygen, but consists of:

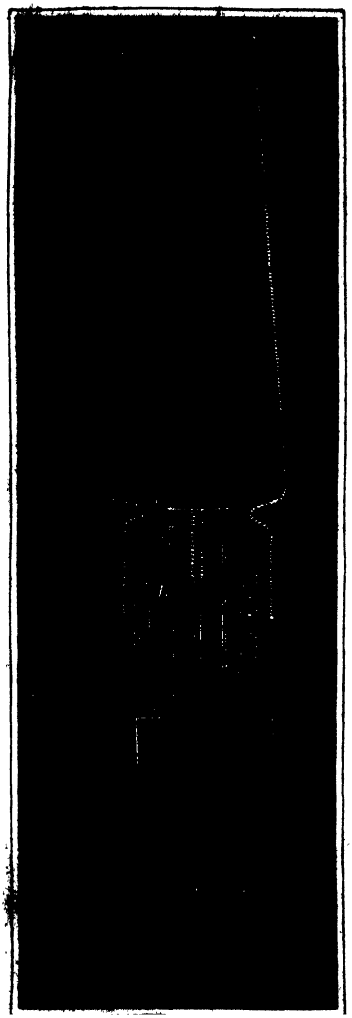
88.46 carbon
11.54 hydrogen

100.

which corresponds to the formula $C_{10}H_8$. A glance at the composition of this substance, containing so large an amount of carbon, shows that it must be a powerfully illuminating body, if proper modes can be adopted of supplying a sufficient quantity of oxygen or air for the entire consumption of the two combustible constituents, and at the same time so regulating the order of combustion that the full amount of light shall be obtained from it.

Mr. Young was the first who applied the increased draught of air produced by a cone to the flame of oil of turpentine. The burner of Young's Vesta lamp is shown in Fig. 192. It is an ordinary Argand burner with a Liverpool button *a*, for deflecting the internal current of air, which enters by a space left open near the pinion handle and passes through *a*, against the inner side of the flame; *b* is the wick tube and *c* the space between the latter and the cone, which only rises in this case to the same level as the burner. Through *c* a current of air impinges upon the flame at that part where it is expanded by the button *a* and the internal current of air, and again the air in passing up the inner sides of the chimney is deflected inwards upon the flame by the contracted portion at *e*. *f* is the pinion-handle for raising or lowering the wick. The whole of the burner is screwed upon the glass vessel containing the oil of turpentine, and completely insulated by a ring of wood or other non-conducting material; no metallic tube passes through the spirit to supply air to the interior of the flame, as it was supposed that this would become too strongly heated and give rise to acrid and offensive fumes from the volatile spirit. Fig. 192 shows a plan of Young's burner. This lamp, when properly managed and supplied with pure camphine, gives an excellent light, much superior to that produced by any oil lamp; but if attention is not paid to the management, or the camphine is not pure, it frequently evolves a strong smell of turpentine, producing head-ache and other disagreeable sensations, or large flakes of soot escape unconsumed and cover everything in the vicinity. The evolution of smell or soot is always the result of imperfect combustion, and the lamp has been modified in different ways to avoid the possibility of unconsumed products being evolved.

Fig. 192.



The lamp which fulfils the conditions for the perfect combustion of camphine in the most successful manner, is the Gem lamp, patented by Mr. Roberts, a section of which is shown in Fig. 193. It differs from Young's lamp, in the mode of deflecting the currents of air, and in allowing the Argand tube supplying the internal current of air to pass through the reservoir containing the oil of turpentine. In Fig. 193, *a* is the tube supplying the internal current of air which passes through the reservoir *b* to the burner *d*, with which it is in metallic connection, and it is not found that the turpentine is heated by this tube to more than 1 or 2 degrees above the temperature which it attains in Young's lamp; the temperature of the spirit in both cases being from 10 to 15 degrees above the temperature of the surrounding air; and this appears to be no more than is required for the proper action of lamps of this description. The button *f*, which deflects the inner current upon the flame, and forces the flame to take an outward direction and come into contact with the first outer current, has the form of an inverted cone, and the deflection of the air is consequently not so abrupt. The supply of air to the inside and outside of the cone is regulated by a series of holes drilled in the brass gallery, and the number and size of these holes are proportioned to the size of the burner, or to the quantity of air admitted through the internal channel.

Fig. 193.

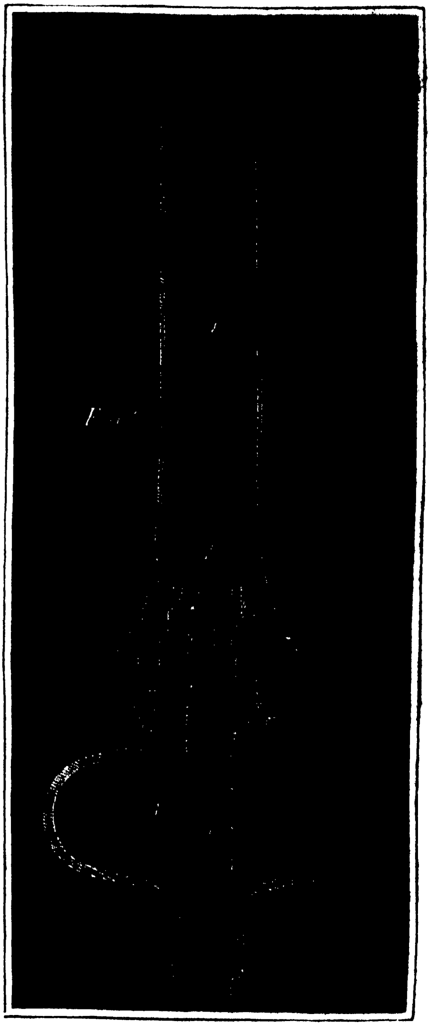
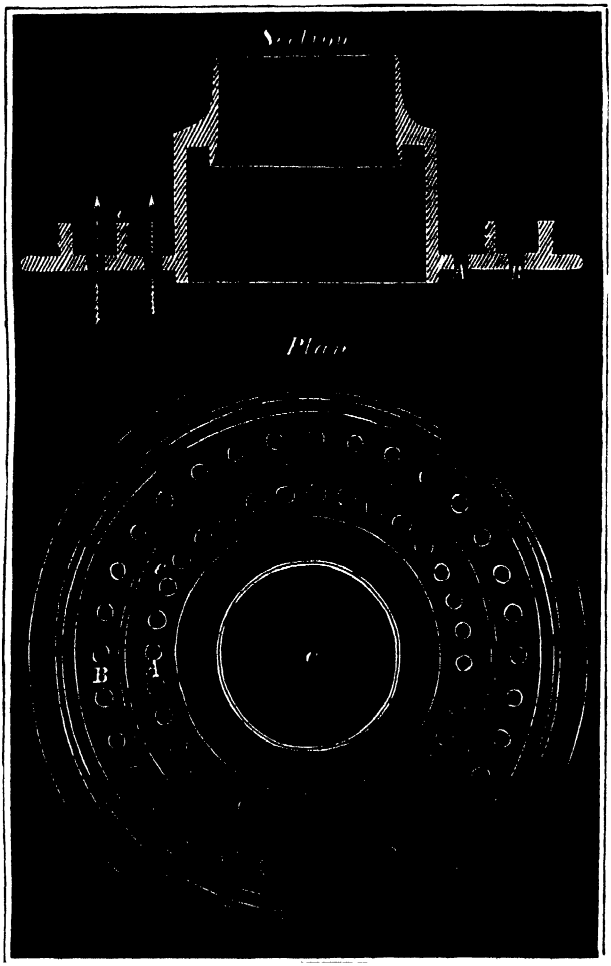


Fig. 194 shows a plan and section of the gallery, *C* is the space occupied by the inner current of air, deflected outwards by the button, *A* the first series of holes admitting air to the interior of the cone, and *B* the series of holes through which the air passes to the exterior of the cone. The circle *A* has 32 holes, drilled with a drill $\frac{1}{12}$th of an inch in diameter, the circle *B* has also 32 holes, drilled with a drill $\frac{1}{10}$th of an inch, this number and size of the holes having been found by a series of experiments most advantageous for a burner of the dimensions represented in the drawing. The cone *e*, Fig. 194, in this lamp rises above the level of the wick tube, so that the inner current of air and the first outer current meet the flame below the button at the point represented by the meeting of the two arrows, Fig. 193. The outer current of air, passing through the holes in the circle *B*, meets the flame at a higher level, and insures the complete combustion of any products that may have been unconsumed after passing the point where the arrows meet. The height of the chimney will of course materially alter the draught, and an additional quantity of air must be admitted if the chimney is heightened. The proper quantity of air and the direction of the different currents to those parts of the flame where they are most beneficial are the objects aimed at in the construction of this lamp, and they appear to have been attained more perfectly in the Gem lamp, than in any other spirit lamp yet invented. A Gem lamp of the larger form is reported to give a light equal to 20 wax candles; the light from one of the smaller size is equal to 13 wax candles.*

Fig. 194.



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* See above, p. 209, for a description of Greenough's chemical oil lamp, which closely resembles the above.—Am. Ed.

CANDLES.

The wicks for dip-candles are now cut by machinery in a very expeditious manner, and the wood-cut Fig. 195, will help in explaining how this is effected. Balls of cotton, previously made into loose roving or cord, consisting of a dozen or more threads each, but differing in thickness according to the size of the candles, are put into a box or drawer. The ends of these are then attached to a rod or broach, and equal lengths of cotton are cut off by drawing a knife

Fig. 195.

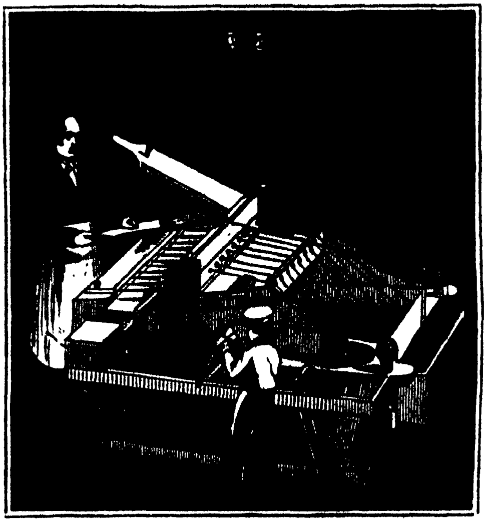
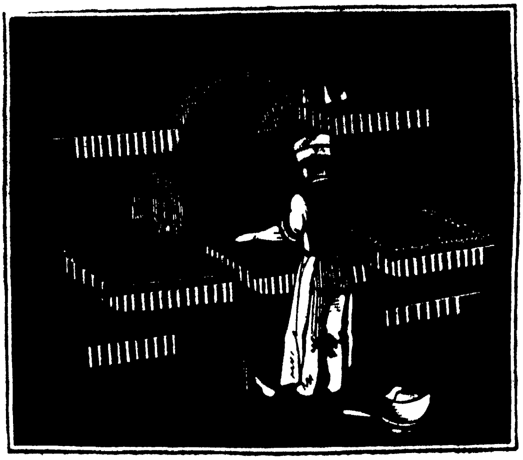


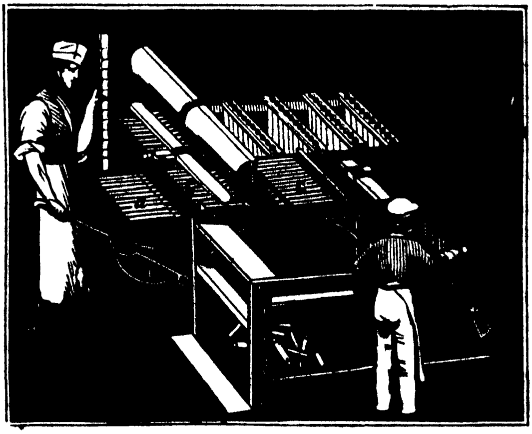
Fig. 196.



along a whole range of them at once; a slight twist being given to the whole of them by the action of the machine. The operation of dipping candles is also performed more rapidly by a machine similar to that represented in Fig. 196, each broach being supplied with a number of wicks in the manner described above; 30 of these broaches are ranged side by side, and then constitute what is technically termed a *frame*. From 30 to 40 of these frames may be suspended upon the same machine, which will then support many thousand candles at the same time. A vessel of melted tallow is placed in the front of each machine, and the frames are brought one after the other immediately above it and dipped. By means of a lever moved by the foot, a wiping-board is lowered after each dipping, which wipes the excess of tallow from the lower ends of the candles. A kind of steelyard, which indicates the entire weight of the whole frame of candles, enables the workman to ascertain when they have been dipped a sufficient number of times, and when that has been effected, the frame is set aside, that the candles may become dry and hard.

The machine used in the manufacture of stearine, cocoa-stearine, composition, and other mould candles is still more deserving of notice, as in discharging the one set of candles from the moulds, it rewicks the moulds for the next process of filling, and thus saves a very great amount of labor and time; a frame of metallic moulds is furnished at the one end with a wick box, in which a separate ball of cotton is preserved for each mould. The wick-cottons enter the moulds at the top, and are forced forward all at once to the lower end, by the same contrivance as pushes out the candles already formed in the moulds; as soon as the wicks arrive at the lower end of the moulds they are held tight by a series of forceps attached to a rod, and the frame is then ready wicked for filling; the frame is pushed along the neighboring railway by a boy, as shown in Fig. 197; it passes through a hot cupboard that the moulds may be warmed to a certain tempera-

Fig. 197.



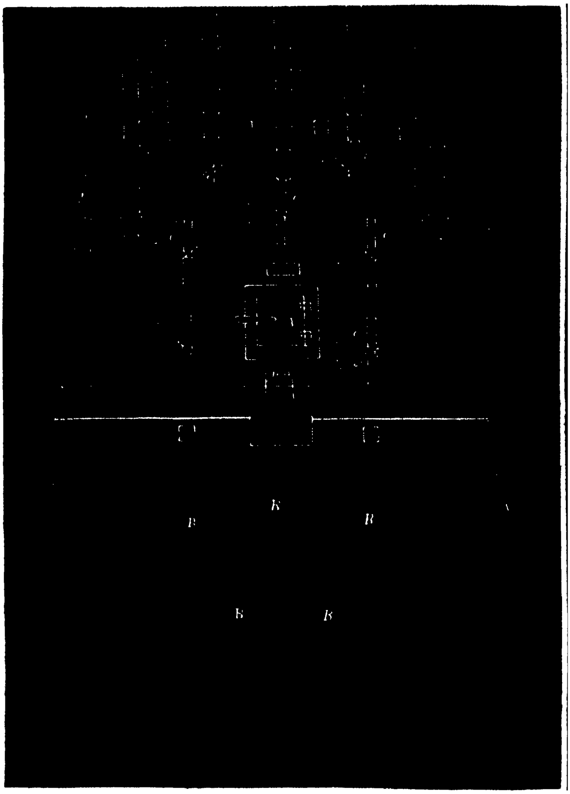
ture, and is then filled from a vessel containing the fluid fat by as many cocks or outlets as there are moulds to be filled; a certain time is then required for the material to harden, depending of course upon the nature of the mixture, the forceps and the superfluous tallow or composition is removed, and the frame is returned by the railway on the other side of the wicking machine. The working of this machine may be understood by referring to the rough sketch, Fig. 197; *b* is a frame of moulds from which the candles *a*, have just been discharged by the workman drawing forward the series of rammers *c*, which fit into the moulds and force out the candles, whilst the cotton for the fresh wicks is brought forward at the same time to the further end of the moulds; a circular knife is then passed along a groove between *a* and *b*, and cuts off the wicks of the candles that have just been forced from the moulds, and these are prevented from shifting their position .whilst the wicks are cut by pressing down the piece of wood, cut to fit them, which is seen in the hand of the workman in Fig. 197. The candles *a* are now finished and removed, and the fresh wicks, which slightly project from the empty moulds, are fixed all at once, by the forceps, and the frame is again sent along the railway to be filled. The number of candles which one set of men employed upon one of these machines can manufacture in a short time is surprising.

GAS FOR ILLUMINATION.

The numerous improvements which are constantly being introduced into the manufacture of gas for illuminating purposes, the improved methods of production, purification, distribution, measurement and consumption, are many of them of such a character, that the practical gas engineer is the only person capable of really estimating their respective values. We shall, however, venture to describe shortly, some of the more important improvements which have recently been brought into public notice.

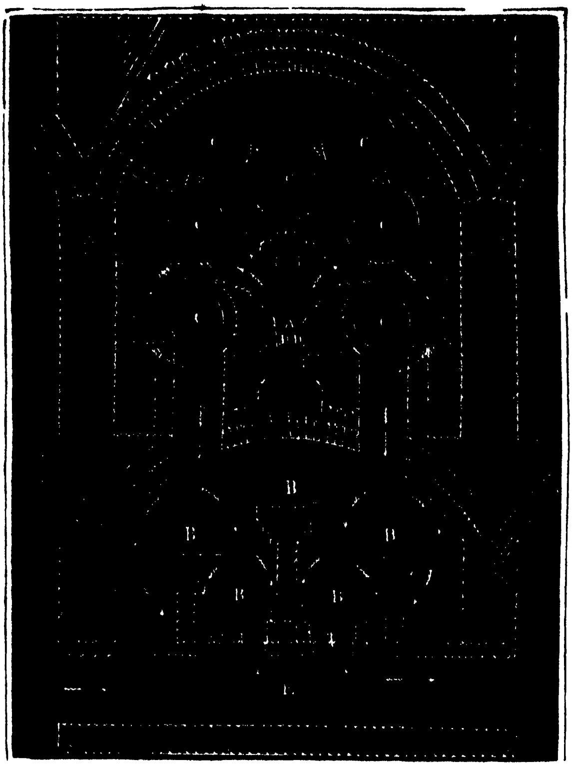
In the first place, with reference to *retorts* and *furnaces*, the wear and tear of the cast iron retorts exposed to the intense heat necessary for charring the coal in a proper manner in the ordinary gas furnace is so very considerable, that recourse has been had to several expedients for lessening or removing this evil. Grounds have been made of fire-brick in the shape of the retorts, and placed round them as a protection against the intensity of the flame; thus, the iron retorts are, as it were, placed within a clay retort, but, as the iron becomes rapidly oxidized on the outer side of the retort, and is in contact with the clay, the heat is often sufficiently intense to cause a fusion of the oxide of iron with the ingredients of the clay, and the retorts are found to wear away more rapidly when this is the case, whilst the brick-work supporting them is also destroyed; the fused mass is often deposited in the flues, or other parts connected with the furnace, impeding the draught, or otherwise forming an obstacle to the proper regulation of the process. The use of clay retorts entirely supersedes these difficulties; but as the clay retorts require a much greater intensity of heat, and consequently larger amount of fuel to heat them than retorts of iron, the consumption of fuel is wasteful or a great portion of the heat is lost when clay retorts only are employed. The observation of these facts has given rise to the adoption of both clay and iron retorts in the same furnace, in such a manner that the difficultly heated clay shall receive the great intensty of the furnace, whilst a number of iron retorts are exposed to the moderated action of the heat, which would otherwise escape unused. Fig. 198 is a front view, Fig. 199 a cross section, and Fig. 200 a longitudinal section of the ovens and retorts as constructed upon the plan of Mr. Croll.

Fig. 198.



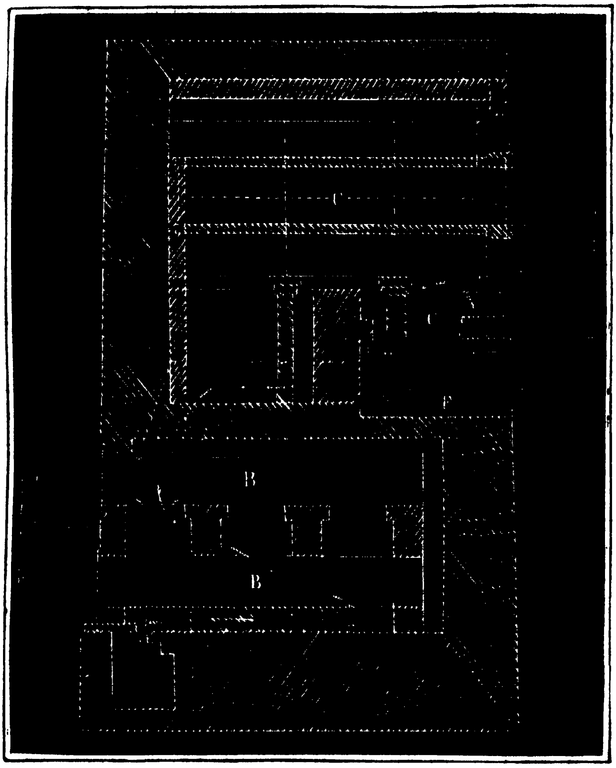
An oven is first constructed of given dimensions, according to the size of the retorts to be used, and five iron retorts *B B*, Fig. 198, are set upon three brick pillars each; three of the retorts are arranged towards the top of the oven, and the two lower ones are set upon flues 6 inches high, running the whole length of the retorts, (compare cross section, Fig. 199,) and open at the backs. Immediately above this oven is another of given dimensions, in which are placed seven retorts of fire-clay *C C C*, Fig. 198; five of these are above the furnace or firing *A*, and one is on each side of it. The furnace *A*, is 3 feet long, and 1 foot 6 inches wide, tapering to 7 inches at the bars *D D*, of which there are two. *F*, Fig. 200, is a trough containing water for cooling the bars, &c. The fuel in this furnace assumes the form of a wedge, the object of which will be afterwards explained. Coke is the fuel used in this furnace, and it will be seen by referring to the direction of the arrows in the cross section, Fig. 199, that the flame proceeds from the furnace over the two lower clay retorts, and from thence (see longitudinal section, Fig. 200,) passes along their bottoms to the further end, where it descends through openings in the arch to the oven below, and comes into contact with the front of the upper iron retorts, when they are arranged, as represented in Fig. 200, with their mouths on the opposite side of the retort stack; the heat then traverses obliquely to the bottom of the oven at the back end, where it passes underneath the two lower iron retorts, and is conveyed to their front, descending at last into the main flue *E*, Fig. 199, which runs transversely with the settings, and thence to the chimney, which is only about 3 feet above the ridge of the retort house. It is found,

Fig. 199.



that the five upper clay retorts are heated quite sufficiently by the radiated heat from the furnace, although the flame is conducted below them to the lower oven. The clay retorts in this arrangement are heated by the most intense part of the flame, which, when it reaches the iron retorts below, is so moderated that no casing of clay is needed, nor is the brick-work in contact with the iron fluxed or melted away. The furnace *A* is wedge-shaped, that the fuel may sink gradually as it consumes, and that the same quantity of air may always be admitted, which is not the case when the fuel burns irregularly in oven fires of the ordinary description.

Fig. 200.



In the gas-works at Tottenham, where Mr. Croll's plans are fully carried out under the superintendence of Mr. Anderson, the retorts are usually charged with 260 lbs. of coal, which quantity may be raised, in case of necessity, to 300 lbs., and this is worked off in 4½ hours. The clay retorts are said to last the usual time, but the iron retorts in the lower oven will last much longer than ten months, which is the average time of duration upon the old plan; the same retorts have already been used fourteen months without undergoing any material alteration, nor is the brick-work upon which they are supported in any way the worse for wear. A very considerable saving of fuel is also effected by the use of the arrangement described above; only 24 per cent. of the coke produced being consumed in heating the furnace, whilst upon the old plan, 45 to 50 per cent. is generally required.*

It may be proper here to mention Mr. Lowe's reciprocating retort, which is of very much larger dimensions than that in common use, and is open so as to be charged at both ends, and furnished with two sets of pipes, one at each end, for conveying off the gas. One of these pipes can be caused to dip less deep into the hydraulic main than the other, under which circumstances the gas will escape by that aperture at which the less pressure is exerted by the liquid in the main, and by reversing this pressure, the gas will take the opposite direction, and escape by the other pipe. The retort is charged only half way at first, when the tar escaping in contact with the hot uncharged portion of the retort is partially converted into gas, and thus the quantity of gas increased. When this portion has been worked off, the retort is charged from the other end, and the exit pipe at the opposite side is subjected to the lesser pressure, by altering the level at which the pipes dip into the fluid of the main. The gas generated from this second charge traverses the hot coke of the former charge, and the tar mixed with it, is again partially converted into gas. This retort is said to give more gas, and that of better average quality than is produced by those in ordinary use. The air for sustaining the fire in the furnace may also be heated before it has access to the fuel, by passing it through channels already heated by the furnace, thus effecting a saving of fuel. This plan of heating the air before its admission to the grate, has been introduced into France, where fuel is expensive, and economy in its use important.

Purification of Gas.—Numerous plans have been suggested at different times, for completely separating the ammonia by means of acids from gas, but most of them have been relinquished, or not carried out from the expense necessarily incurred by the apparatus, from other practical difficulties, or in consequence of the illuminating power of the gas being deteriorated by traversing the acids. Mr. Croll has, however, succeeded in carrying out this desirable object in a manner to which these objections do not apply, and obtains, moreover, a valuable product in return, which is extensively used in agriculture, and useful for many other purposes. This purifying process consists in passing the gas, either before or after its passage, through the wet or dry lime purifiers into a weak solution of sulphuric acid, which is gradually increased in quantity as the acid becomes saturated. The gas is conducted into a circular vessel, Fig. 201, constructed like those in use for the purpose of washing gas, and lined with lead, that metal not being acted upon by weak sulphuric acid. This vessel is separated at the bottom into a number of compartments, (re-

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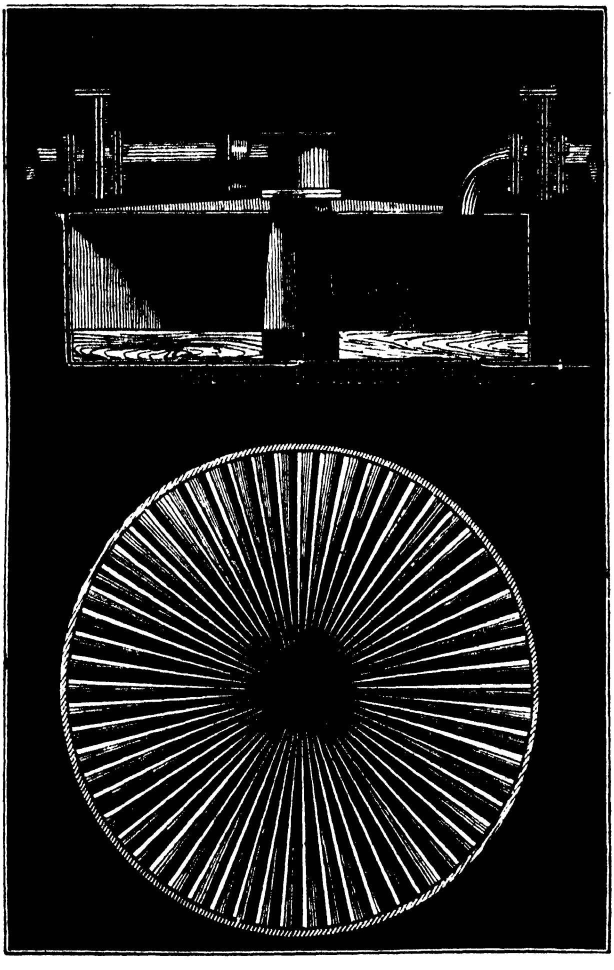
* At the Philadelphia gas works in 1844, the amount of coke used for heating retorts, all of iron, was 59 4 per cent., and in 1847, 56.4 per cent. of the whole quantity produced. See below our table of the action of Phila. Gas Works.—AM. ED.

presented below in Fig. 201,) 8 or 10 inches in height, which support a leaden plate covering the whole surface of the vessel with the

Fig. 201.



exception of about 5 inches round the edge. The vessel is charged up to the height of the plate with dilute acid, containing about 2¼ lbs. of acid in 100 gallons of water; the gas then entering from above, passes under the leaden plate, and is disseminated through all the compartments under the plate, and thus brought into intimate contact with the acid solution. The gas passes through, leaving the whole of its ammonia in combination with the sulphuric acid; this, however, soon becomes saturated with ammonia, and loses its power of absorbing a fresh quantity; a reservoir of sulphuric acid is consequently connected by a stop-cock with the vessel, and supplies fresh acid whenever it is required. It is desirable to use two such vessels in large gas-works one after the other, and when these are 10 feet in diameter, and 3 feet deep, they will purify 500,000 cubic feet of gas every twenty-four hours, and will require re-charging with acid about every second day. The liquor thus obtained, yields 80 ounces of sulphate of ammonia for every gallon that is evaporated, instead of 14 ounces, which is the average quantity obtained from the ordinary ammoniacal liquor of the condensers.

Chloride and sulphate of manganese, or chloride and sulphate of zinc, may be used for the same purpose instead of sulphuric acid, and the bases of these salts may be again combined with acid, and reapplied to the purifying process. It is desirable in all cases where the retorts are exposed to much pressure, which causes them to become rapidly coated with charcoal, and is particularly requisite when wet lime purifiers are employed, to pump out the gas from the retorts by a small exhausting syringe, which may be worked at little expense, by a small engine, supplied with fuel from the refuse brees of the coke. The waste steam from this engine may be employed for evaporating the sulphate or muriate of ammonia, and a portion of it may be introduced into the main pipe after it has left the condenser, and thus help to condense some of the noxious vapors before the mixture of gases enters the lime purifier.

One great advantage of Mr. Croll's purifying process is, that it enables the manufacturer to use dry instead of wet lime purifiers. When the former were used, without any previous absorption of the ammoniacal compounds—as was formerly, and is still the case, in many places—and the vitiated lime was afterwards exposed to the action of the atmosphere, the hydro-sulphuret of ammonia, which had been mechanically kept back by the lime, escaped into the air and gave rise to a most offensive and noxious stench. The whole of the ammonia being previously extracted from the gas by an acid, no objection of this kind can be raised to the use of dry lime. The illuminating power of the gas is also said to be increased 5 per cent. by separating the whole of the ammonia, and the brass and copper stopcocks, tubes, and burners through which the gas is conveyed, are much less corroded and stopped up than formerly; indeed, the use of certain burners, which will be mentioned in the sequel, is incompatible with gas from which the ammonia has not been separated, in consequence of the formation of an ammoniacal oxide of copper which stops up the fine apertures of the burner. The fetid exhalations from the soil surrounding the gas mains, though generally attributed to tar and naphtha, is probably due in great part to ammonia and its compounds, and it is anticipated that this nuisance will be much diminished by the use of acids in the purification of the gas.

Mr. Lowe proposes the use of a coke column similar to that used for the condensation of muriatic acid, through which weak acid or ammoniacal liquor is flowing downwards, whilst the gas is passing upwards, and is thus freed on arriving at the top of the column from all ammoniacal vapors.

Mr. J. R. Johnson has very recently patented a new mode of purifying gas from ammonia and its compounds, which consists in the use of dry absorbents, and obviates the increased pressure exerted by the gas upon retorts, &c., when it is caused to pass through liquid purifiers. He employs two classes of substances for this purpose, such, viz. as absorb the ammonia only and liberate, or only partially absorb the acids with which it was previously in combination; and secondly, substances which absorb the compounds of ammonia entirely, both acid and base. To the first class belong the solid acids, boracic, phosphoric, &c., and the salts with an excess of acid, as the bisulphates of potash, soda, or ammonia, the biphosphates of the same bases and other salts of this class, the salts of alumina and some other earths.

To the second belong the metallic salts containing the requisite quantity of water in their composition, but the salts of iron and manganese are preferred on account of their low price.

The mode of carrying out this process of purification is very simple, and quite analogous to that practised in the dry lime purifiers. Commercial sulphate of iron (green copperas) for instance, which contains a large quantity of water of crystalization, is reduced to powder in the ordinary manner, the finer the powder, the more energetic is the action of the salt, and is spread upon the pierced shelves of a dry lime purifier in the same manner as dry lime; the gas is then allowed to traverse it in one or more compartments of the purifier, until turmeric or other test paper shows that the material ceases to absorb ammonia; when this occurs, the gas is conducted through a fresh purifier and the saturated copperas is exchanged for a fresh supply of the salt. It is found preferable when one of the latter class of substances is used, to allow the gas to pass through it before entering the lime purifier, as time is then saved in the purification, the acids as well as the ammonia being absorbed, and a useful product generated by the union of the hydrocyanic acid with the iron. When employed subsequently to the passage of the gas through the lime purifiers, one of the substances of the former class will be found most advantageous. A slight addition of water to the powdered copperas causes it to hang together, and rest better upon the shelves of the purifier.

Acid phosphate of lime, containing some sulphuric acid, as obtained by the action of oil of vitriol upon bone earth, has been applied with success for the purposes of purification by some of the London gas companies; and the product, the phosphate of lime and ammonia containing some sulphate of ammonia, forms a still more valuable manure than sulphate of ammonia alone.

Naphthalized Gas.—The illuminating power of gas is very much increased by the presence of volatile hydro-carbons, and it is now many years since Mr. Lowe first introduced, or rather proposed a plan for saturating inferior qualities or ordinary coal gas with naphtha or with the spirit distilled from coal tar, and thus augmenting its illuminating power nearly one-half. The remarkable increase of light, however, produced by naphthalized gas, frightened the gas companies, who foresaw nothing but ruin in the diminished quantity of gas which would necessarily be consumed for the production of an equal amount of light. Cold water was consequently thrown upon the project, and the invention has only been of benefit to individuals and not to the public at large, which would have been the case had it been introduced upon a large scale.

Another objection to the introduction of naphthalized gas into private houses was raised by the insurance companies, the use of so inflammable a substance as naphtha being considered dangerous under any circumstances; but this objection can hardly apply at present, when nothing has been heard of the danger of burning camphine, a still more inflammable body, and consumed in a manner much more liable to give rise to accidents, than that proposed by Mr. Lowe for the use of naphtha. The original plan proposed was to fill the ordinary wet gas-meter with purified naphtha, which was kept filled to the same height from a reservoir in connection with it, upon the principle of the common bird fountain. The gas was thus measured and saturated with naphtha at the same time. As danger was apprehended, however, from the large quantity of naphtha necessarily contained in the meter, a box with a lid closed by a water valve was substituted for it. This box was supplied with shelves, and separated into partitions, as shown in Fig. 202, and naphtha was poured upon the shelves from the funnels above in small quantities at a time, or sponges were saturated with it and laid upon the shelves. The box was inserted at any convenient locality in the circuit of the supply pipe, and the gas forced to traverse the different partitions in the box in the manner represented by the arrows in Fig. 202. The box may also be replaced by an ornamental metallic vase, containing a sponge filled with naphtha, and connected with the gas-pipe in the manner represented in Fig. 203. The advantages attending the use of naphthalized gas are, however, not confined to the increased intensity and brilliancy of the flame, and the consequent diminution of the quantity of gas required for the production of an equal amount of light,

Fig. 202.

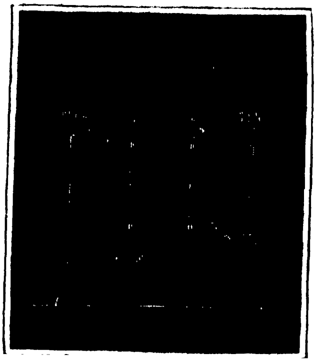
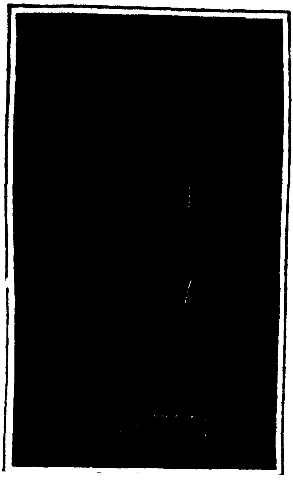


Fig. 203.



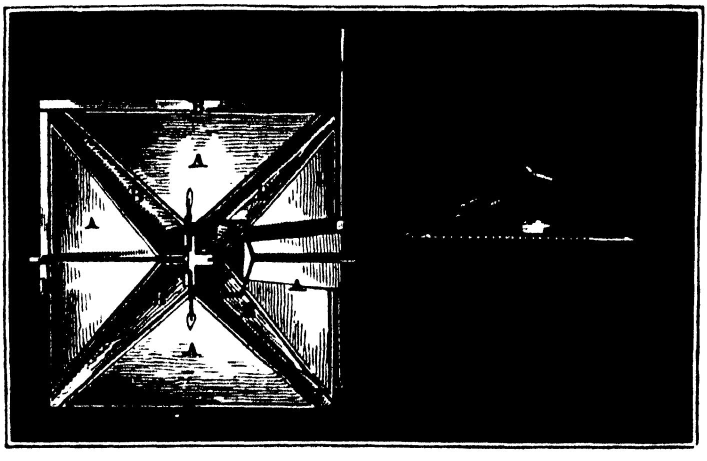
but it is of no less importance, that very much less heat is generated by the combustion of naphthalized gas than is produced by that of coal gas, when the same intensity of light is generated from either source. It has been assumed, that in ordinary cases, the heating power of common coal gas is to that of naphthalized gas in the ratio of about four to three for equal quantities of light. It is obvious, therefore, that naphthalized gas will be greatly preferable to common coal gas for lighting ill-ventilated or crowded localities, and particularly during the summer season, when the external temperature is high. The light produced by the flame of naphthalized gas is also found to be more analogous to that of the sun, hence objects illuminated by it, as pictures, scenery, the face, &c., appear more in their natural colors, and the human face in particular, does not assume the pallid hue which is peculiar to it when illumined by a flame of ordinary coal gas. Lastly, it is probable that inferior kinds of gas, containing a less proportion of carbon, (such, for instance, as are evolved from coke furnaces, where the object of the manufacture is to retain as much carbon as possible in the coke,) will by impregnation with different hydro-carbons be converted into illuminating gas of as good, if not better quality than that obtained from ordinary coal. Some slight alterations in the construction of gas-burners may be necessary for consuming gas, highly impregnated with carbon, without smoke; and there is, perhaps, danger of the naphtha being condensed, and deposited in the gas-pipes in an injurious manner, particularly if the gas be too much saturated with the vapor, but there appears little reason to doubt that these difficulties, and particularly that arising from the condensation of the naphtha, would be obviated or remedied, if a fair trial were only vouchsafed the plan upon an extensive scale.

GAS-METERS.

The ordinary wet gas-meter, described at page 182, is unexceptionable where fraudulent means are not employed for under-estimating the amount of gas consumed, but its construction admits of great deceptions being practised by dishonest consumers. If, for instance, the water level in the meter be lowered more gas will pass through than is registered by the instrument; if the case of the meter be tilted forward to an angle of from 5° to 13°, according to its construction, and a proportion of the water drawn off, so as to expose the outlet of the measuring chamber, the gas will pass through it without affecting the index, and without being registered at all. This is constantly done, and the large amount of gas which is unaccounted for in the calculations kept at the gas works, and which is frequently attributed to leakage, is no doubt traceable to this nefarious practice. In cold weather the water in the meter is liable to freeze, and the passage of the gas is then completely stopped. Mr. Lowe has proposed the use of a solution of caustic potash or soda, which is not so easily affected by frost, to replace the water in the meter, which will also tend to render the gas more pure, should either carbonic acid or sulphuretted hydrogen have escaped the general purifiers. The grave objections to the use of the wet meter stated above, have given rise to great ingenuity in the construction of a variety of measuring instruments, in which the use of water or any liquid is dispensed with, and in which the gas is measured by the number of times that a certain bulk will fill a chamber capable of undergoing contraction and expansion by the passage of the gas. These alternate contractions and expansions of the chamber set certain valves and simply constructed arms in motion, which, by the aid of a few wheels, can be made to turn the hand of a dial, as in the ordinary wet meter. We must restrict our remarks upon dry meters to two of the most recent inventions, which appear the best calculated for affording accurate measurements. These are the meters of Defries, and of Messrs. Croll and Richards.

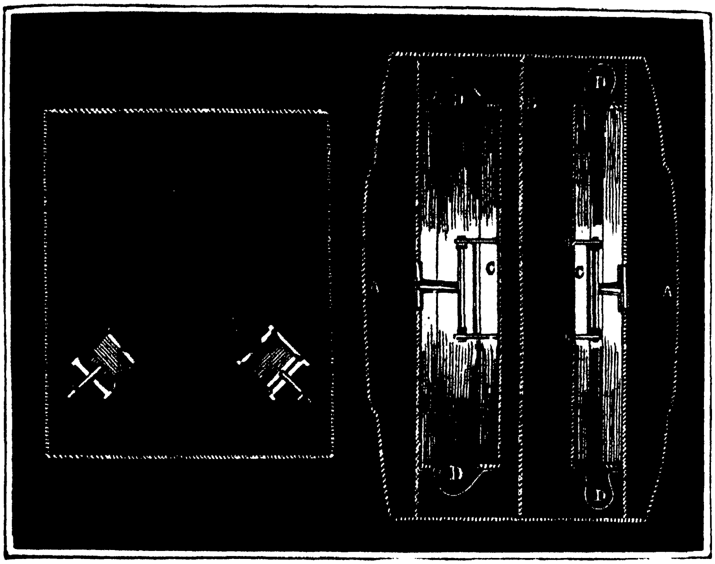
Defries' meter consists of three measuring chambers, separated from each other by flexible partitions of leather, partially protected from the chemical action of the gas by metal plates. The metallic protection is shown at *A A A* in Fig. 204, and the flexible leather at *B B B B*. The pressure of the gas expands the flexible partition, which then assumes the form of a cone, as represented by the small side cut Fig. 204; the motion of this flexible cone backwards and forwards on both sides of its base sets the machinery in action, and measures the amount of gas which passes through the meter. The object in introducing three chambers into the meter is, that its action may be continuous like that of a three-throw pump, and that oscillation of the lights may be avoided, which sometimes results from the use of two chambers only.

Fig. 204.



Messrs. Croll and Richards' meter claims superiority over that just described, in rendering the flexible leather hinge no part of the measuring arrangement, so that any contraction or expansion of this cannot alter the registration of the gas. The meter consists of a cylinder or case *A A*, Fig. 205, divided by a plate *B* in the centre into two

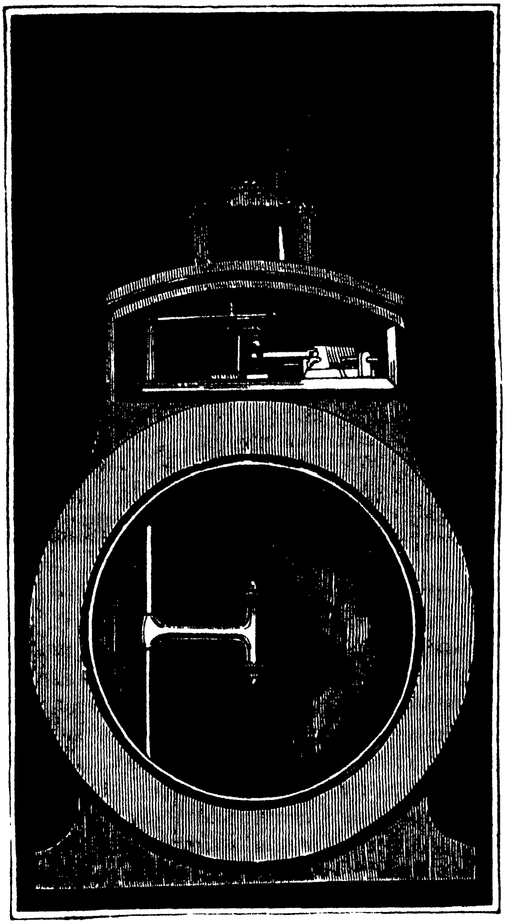
Fig. 205.



separate cylindrical compartments, which are closed at the opposite ends by metal discs *C C*. These metal discs serve the purpose of pistons, and are kept in their places by a kind of universal joint attached to each; the space through which the discs move by the action of the gas, which affords the means of measurement in this meter, is governed by metal arms and rods, shown in the side cut, Fig. 205, which space, when once adjusted, cannot vary. To avoid the friction attending a piston working in a cylinder, a band of leather *D D* is attached, which acts as a hinge, and folds with the motion of the disc; this band is not instrumental in measuring the gas, so that its contraction or expansion would only decrease or increase the capacity of the hinge, the disc being still at liberty to move through the required space only. The leather is also attached in such a manner that it can only bend in one direction, and this renders it much more durable.

The machine is quite comparable to a steam engine measuring its steam, which it does in all cases by the strokes of the piston. The gas enters the cylinder at the top, from the space occupied by the arms, valves, &c., Fig. 206, and forces the discs bodily forward through a certain space, the motion communicated by the discs to the arms and rods causes the supply of gas to be cut off, and admits of its escape by another valve; at the same moment the gas is admitted to the other side of the disc, and this is forced to return to its original position, traversing, of course, the same space as before. Each backward and forward motion consequently indicates the passage of a constant quantity of gas, and the same apparatus which admits and

Fig. 206.



shuts off the supply by means of valves is connected with clock-work, and thus the motion of the disc, or the quantity of gas which has passed through the meter can be indicated upon a dial-plate, as in the ordinary wet meter.

BURNERS.

A great variety of gas-burners have been successively brought into public notice, all of which lay claim to the production of an increased intensity of light with a smaller consumption of gas. It is impossible, however, from a mere inspection of the flame produced by these burners, without accurately measuring the amount of gas consumed by each, to arrive at any conclusion as to which form is the most economical or generally desirable. Until impartial comparative experiments have been instituted with all, decided preference cannot be ascribed to any one in particular.

Fig. 207.

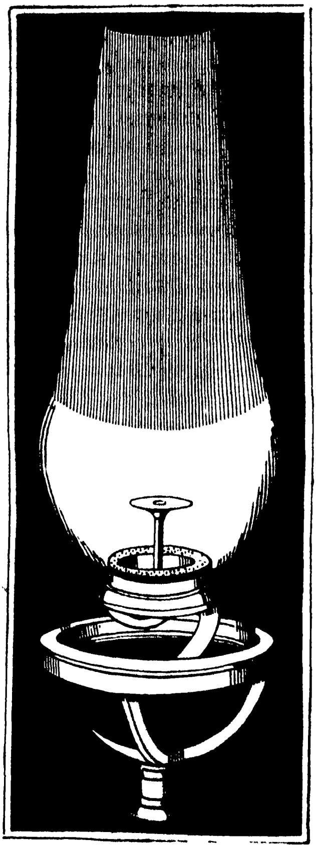


Fig. 207 is a representation of Whinfield's lucent burner, in which the Liverpool button is applied to an Argand gas-burner, and the peculiar form of chimney causes an external current of air to impinge at a certain angle upon the flame, producing the same effect as the metallic cone in the Solar lamp before described; a basket of wire gauze is fitted into the crutch of the burner, which moderates the supply of air from below, and prevents the flickering caused by sudden draughts. By fixing the chimney to a circular ring, which screws up or down upon the triangular support, Mr. Lowe is enabled, in his improvement upon this form of burner, to alter the direction of the external current caused by the contraction of the chimney, and by converting the button into a screw, its height can also be altered and the internal current regulated.

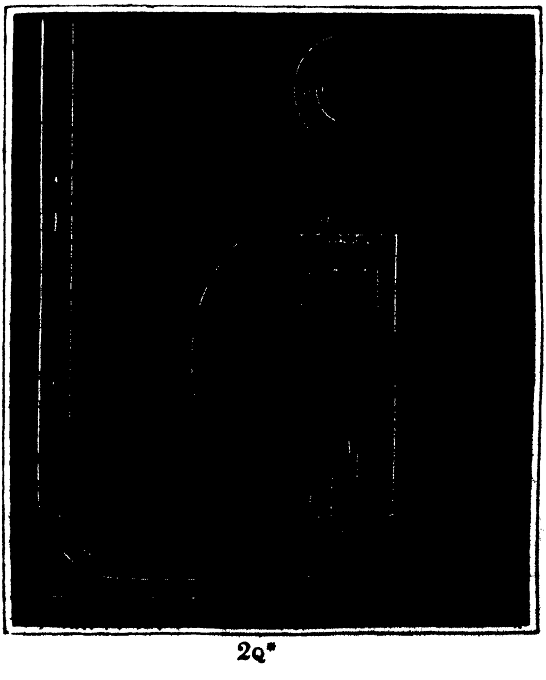
Fig. 208 shows a form of burner, patented by Mr. Leslie, in which the gas is caused to flow through a number of small copper tubes, instead of from the apertures of an Argand burner. The object of this is to effect a more complete combustion of the gas by surrounding each single jet with abundance of air, as it issues from the orifice, and the low form of chimney or combustion chamber diminishes the velocity of the draught, and adds, consequently, to the illuminating power of the flame. This burner was alluded to on a former oc-

Fig. 208.

casion, as an instrument for testing the purity of gas. If the gas is impure, which is the case with that supplied by many companies, the orifices of the copper tubes become stopped up, either with sulphuret of copper, or the ammoniacal oxide, and require to be cleansed with a stiff brush. The only effectual remedy for this objection to the burner is the use of purer gas, and this must be obtained, when not supplied in a pure state from the gas works, by the use of a separate purifier in each house.

Ventilation of Gas-Burners.—Serious objections still stand in the way of the introduction of gas-light into private dwellings, unless some means can be adopted for removing the products of combustion. For every cubical foot of gas burnt, rather more than a cubic foot of carbonic acid is produced. A pound of London coal-gas contains, on an average, 0.3 of hydrogen, and 0.7 of carbon; it produces, when burnt, 2.7 of water, and 2.56 of carbonic acid gas; consumes 4.26 cubic feet of oxygen, which is the quantity contained in 19.3 cubic feet of air. It is thus obvious, that the air of a close chamber must soon be vitiated by the combustion of gas, and that the effects of breathing an atmosphere impregnated with a large proportion of carbonic acid, must consequently soon be felt by the inhabitants. The water evolved at the same time, in the state of steam, is found to be seldom free from sulphurous and sulphuric acids, derived from impurities in the gas; and this, condensing upon the furniture, books, goods in shops, &c., very soon damages them in a very perceptible

Fig. 209.



manner. The serious injury sustained by the library of the London Athenæum club from this cause, and the large quantity of water evolved from the Bude-burner in light-houses, condensing on the glass windows, and materially impeding the passage of the light, attracted the attention of Mr. Faraday to the invention of some means for effectually removing the noxious products of combustion. After several more or less successful trials, the method illustrated by Fig. 209 has been adopted, and exhibits a beautiful adaptation of the principle of a descending draught to a lamp-burner; *a* is an ordinary Argand burner, with a common straight chimney *e e*; the glass holder *c* is, however, so constructed, as to sustain not merely the chimney, but an outer cylinder of glass also *f f*, larger and taller than the inner one *e e*; the glass holder has an aperture *d*, connected by a mouthpiece with a metal tube *i*, which serves as a ventilating flue, and which, after passing horizontally to the centre of the chandelier, ascends to produce draught, and carry off the products of combustion into the chimney or the open air; *d* is the pipe connected with the burner for supplying gas. The outer cylinder *f* is closed at the top by a plate of mica, *g*; or still better, by two plates of mica, one resting on the top of the glass, and the other *h* dropping a short way into it. They are connected together by a metal screw and nut, which also keeps them a little apart from each other. The chimney and burner may then be surrounded by a ground-glass globe, which has no opening, except at the bottom, for the admission of air to the burner. The course of the current of air, carrying with it the products of combustion, is indicated by the direction of the arrows.

It is stated that the intense heat produced by the hot current of air traversing the space between the two glass cylinders, causes the glass to become more or less opaque, and thus obstruct the passage of the light. To avoid this objection, and at the same time the unsightliness of a descending tube, which must of course throw a shadow, Mr. Rutter has applied the same principle, in a still more elegant and perfect manner, to his ventilating gas-burner, a section of which is represented in Fig. 210; *b* is the burner, with an ordinary chimney, discharging the products of combustion into the metal tube *F*; *K* is a large glass tube, open at the top, in the vicinity of the metal flue *F*, from which

Fig. 210.

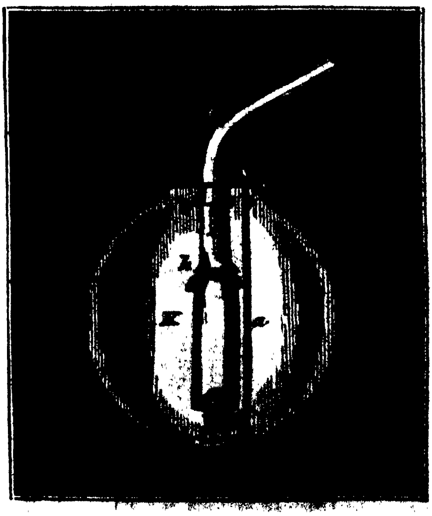


Fig. 211.

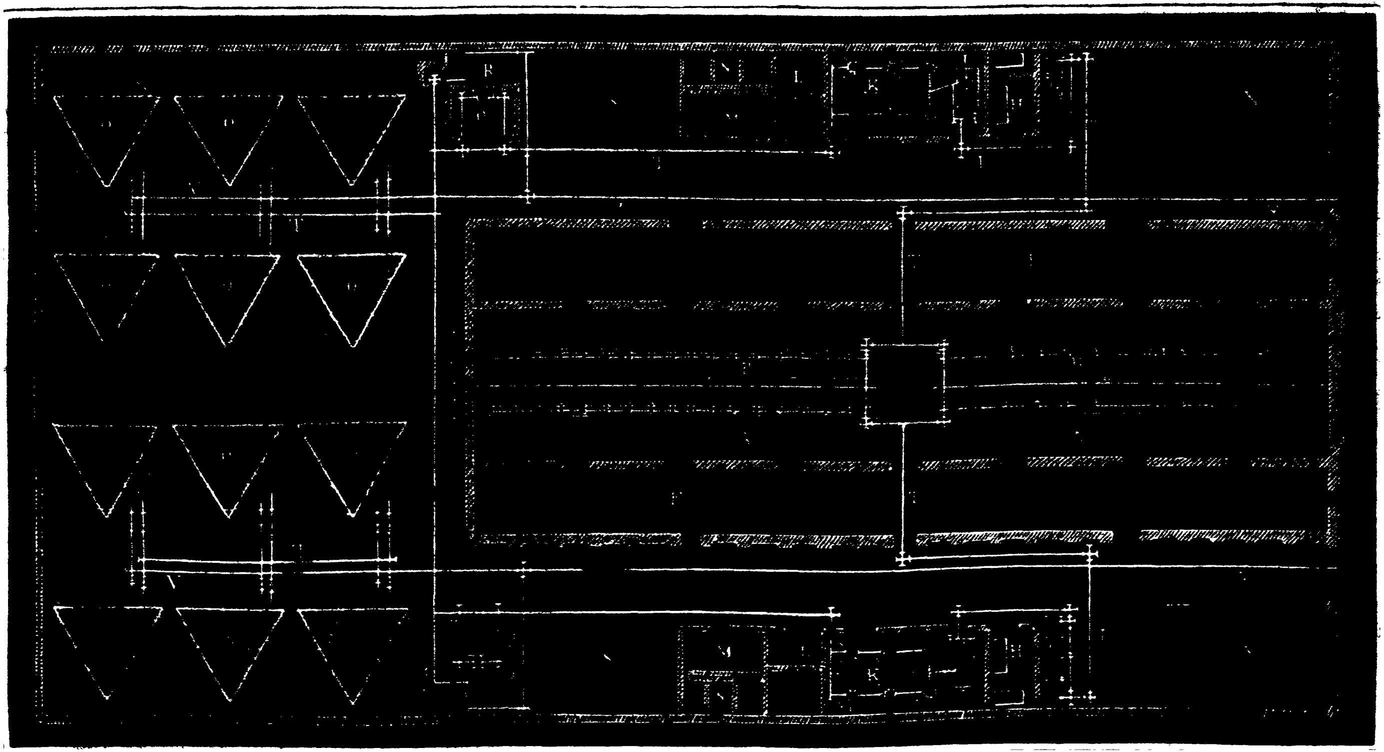


FIG. 212 IS THE SIDE ELEVATION (FRONT VIEW) OF THE GAS-WORK CAPABLE OF HOLDING 400 RETORTS, AND ALL THEIR DEPENDENCIES.

Fig. 212.

it is suspended. The air for feeding the flame descends in the direction of the arrows, enters the burner at *b*, and is carried off through the flue *F C*, after having supplied oxygen to the flame and become vitiated.

Ventilating burners of this kind not only prevent the diffusion of the products of combustion through the apartments in which they are erected, but with the hot current of gas ascending through the metal tube, a large quantity of air from the room is also carried away, and thus a proper circulation established. Some slight difficulties occurred on the first introduction of these ventilating arrangements, which now appear to have been successfully overcome. One of these arose from the large quantity of water which collected in the more distant and cooler part of the ventilating flue, and flowing back upon the burner, extinguished the light. By inclining the tube, and carrying it into the chimney of the room, this may be avoided, particularly when a fire is burning at the same time under the chimney. Another difficulty was raised by the insurance companies, who objected to a hot tube, or flue being carried nearer than within a certain distance of the beams in the ceiling of the room, which precluded, in many cases, the flue from entering the chimney, as the beams supporting the floors frequently lie in a direction at right angles to the course of the chimney, and the flue was consequently obliged to be carried parallel with the beams into the open air; in this case the burner is frequently subjected to a draught in an opposite direction from without, and the steadiness of the flame is very much impaired. When the flue is constructed of a double casing of metal enclosing a stratum of air, or when porcelain or stone ware tubes are used, there appears no good reason for apprehending danger from this source, whilst the advantages gained, both in health and comfort, as well as the less injury sustained by furniture, &c., by the use of ventilating burners, will, it is to be hoped, render them very general, and enable the public to profit by the use of gas for the illumination of their dwelling-houses.

Fig. 211 is the plan of a large gas-work, drawn by Mr. Hedley, for Dr. Ure's dictionary. It is calculated for the arrangement of 400 retorts, 12 wet lime purifiers, and 2 washers; 12 large double or telescopic gas holders, capable of storing 1,000,000 cubic feet of gas; and coal stores capable of holding 10,000 tons of coal. *A* is the retort house, 300 feet long, 56 feet wide; *B* are the retort beds; *C* the chimney stack; *D* flues; *E* hydraulic mains; *F* coal stores, each 300 feet long, 30 feet wide; *G* condensers; *H* engine houses; *J* wash vessels; *K* purifiers and connections; *L* lime store and mixing tub; *M* smith's and fitter's shop; *N* refuse lime-pits; *O* meter houses; *P* tar-tank; *Q* tanks, gas-holders, bridges, columns, valves and connections; *R* governors; *S* coke-stoves; *T* inlet-pipes; *V* outlet-pipes; *W* house and offices; *X* stores.

Analysis of Coal-gas.—The following analyses of the coal-gas supplied to Greenock and Newcastle, are the results of experiments, only just completed, and serve to give an idea of the nature of the gaseous mixture.

COMPOSITION OF COAL GAS.

	1	2	3	4	5
Olefiant gas . . .	14.50	17.50	20.00	10.19	9.25
Carburetted hydrogen .	66.49	59.94	47.77	31.35	36.05
Carbonic oxide . .	7.07	12.00	11.76	16.28	11.42
Hydrogen . . .	12.29	11.46	17.32	28.80	30.17
Carbonic acid . .	. .	. .	. .	trace	trace
Atmospheric air . .	. .	. .	. .	0.48	0.50
Naphtha vapor . .	. .	. .	. .	traces	traces
Ammonia . . .	. .	. .	. .	traces	. .
	100.35	100.90	96.85	87.10*	87.39*

Nos. 1, 2, and 3, gas made from cannel coal, supplied to Greenock, analyzed by Dr. T. Thomson.

Nos. 4 and 5, gas made from caking coal, supplied to Newcastle, analyzed by Dr. T. Richardson.

[*Cost of Manufacturing Illuminating Gas.*—The Philadelphia Gas-works having been constructed in 1835, after extended investigations in Europe, by the engineer charged with their erection, it was natural to expect that every improvement which long experience had suggested should be introduced without delay, and that the cost of making gas at the lowest rates then known, should be speedily arrived at.

But we find, from the published annual reports of those having immediate charge of the works, that the opinion expressed at their commencement, that the cost of manufacture would always bear a direct relation to the quantity produced, has by no means been verified. The works have now been in operation twelve years, which being divided into periods of four years each, show the following as the amount of payments for *materials, freights, rents, salaries, wages, repairs, and all incidental charges* for the manufacture and distribution of gas during each period.

	Cubic feet of gas made.	Cost of making and selling.	Cost per 1000 c. ft.
1st period 1836 to 1839 inclus.	90,389,000	$221,112.39	$2.45
2d " 1840 to 1843 "	196,401,000	294,442.53	1.50
3d " 1844 to 1847 "	286,662,000	372,420.83	1.30

In the above are included all the items of expense except the *interest on capital invested, and no deduction is made on account of income from incidental products.* The works consist of a retort-house with four divisions of cast iron *D* retorts, embracing 114 in all, (with room for 6 more,) each 7 ft. long, 2 ft. wide, and 1 ft. high, arranged in 38 furnaces;—of sets of washers, refrigerators, and condensers, together with 28 dry-lime purifiers, 3 large station meters, coal sheds,

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* In the English edition these two columns are footed 100.35 and 101.40 respectively. What the source of so enormous errors may have been, it is of course impossible for us to conjecture.—Am. Ed.

a limekiln, 8 gas holders, each 50 feet in diameter, and 18 feet high, and one "telescope gas-holder" 80 feet in diameter, and 40 feet high, the total capacity of them all being about 490,000 cubic feet.

The distribution consists of 76⅜ miles of street mains, varying from 1½ to 16 inches in diameter, and of service pipes to 1455 public and 62,477 private burners, the latter supplied through 6209 metres, varying in capacity to furnish gas for 3—100 lights each. The works have been repeatedly reported to be in as "good condition as when new," and have, therefore, by their earnings, kept themselves in complete repair.

The report rendered on the 20th of January, 1848, gave the following "state of the works," as to *permanent investment*, stating the

separate cost of "Works on the Schuylkill" at .	$277,992 39
" " "Distribution street mains,"	304,143 08
" " "Service pipes and meters,"	123,311 23
" " "Public lamps,"	11,814 02
Making a total permanent outlay of . . .	$717,260 72

Had no part of this investment been paid out of profits of the works, the annual interest would amount at 6 per cent. to $43,035 64, and with the actual amount chargeable to the year 1847, for the several items above enumerated, of expense of *making and disposing of gas*, viz. $114,889 80*, would make up the total expense of producing and selling 91,457,000 cubic feet of gas = $157,925 44, or $1 72 per 1000 cubic feet. From this, however, are to be deducted whatever sums were received for the incidental products of the manufacture, such as lime, coke, tar, &c. The sales of coke amounted to 179,379 bushels, which at 6 cents per bushel gave $12,116 74, and the spent lime to 45,127 bushels, which, at the selling price of 3 cents per bushel, must have given $1353 81.

The tar produced has been stored for future disposal, and the ammoniacal liquor is allowed to run wholly to waste, which is the more surprising amidst an agricultural population, where the salts of ammonia are in particular request, for the purposes of the soil. The two items of income from incidental products of the works above mentioned (coke and lime), together reduce the cost of every thousand feet of gas 15 cents, or bring the total cost to $1 57 per 1000 feet.

In point of fact, however, the *interest on capital* invested, is now less than $26,000 per annum, instead of $43,035 64 as above; the profits of the works having not only furnished a great part of the means of their gradual enlargement, but also provided a sinking fund of $254,781 17 towards the extinguishment of the *loans* authorized, which latter have never exceeded 600,000 dollars. With this reduction, the cost of making a thousand cubic feet of gas did not in 1847 exceed $1 39. The efforts on the part of incorporated companies to

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* The materials for gas on hand at the *beginning* of 1847 exceeded the liabilities contracted for them by $6142 58, and at the end of the year the liabilities for the same exceeded the value of the stock by $10,219 80. These sums, with the cash receipts make up the amount $114,889 80.

keep up the price of gas, or at least to render large quantities of an inferior article necessary for the consumer, has been referred to above (page 478), while speaking of naphthalized gas. The combination among different companies for the same purpose is also distinctly alluded to in the same connection.

The city of Philadelphia fortunately declined to throw herself irrevocably into the power of a company, and hence, though, in the beginning, she suffered the works to be erected by a set of trustees under the control, in part, of persons contributing *stock* for that purpose, yet it was with the express reservation that she might at any time take possession of the works, on giving her own bonds to replace the stocks held in private hands. This desirable change was consummated early in 1841. Before that time the gas had all been manufactured from bituminous coal, and, of course, partook of the general characters of coal gas elsewhere produced. The engineer who constructed the works utterly repudiated rosin, and all other materials except coal for that purpose, and his successor did not venture on any change in this particular, until after the works came under the sole control of the city government.

The use of rosin, in combination with coal, was commenced in 1842, and the proportion used has been steadily increased ever since, with improving quality of gas, and diminishing cost of production.

It does not, however, appear that in other respects any successful efforts at economizing materials have been made. The following table will show that within the first four years of their existence, the works yielded residuary products (coke, tar, lime, &c.) which amounted to at least 8 per cent., and sometimes to more than 18 per cent., as much as the *gas itself.*

It is only to be regretted that the annual reports are so little in detail as not to afford the means of a complete comparison in respect to this and other items of expense, especially "repairs and incidentals." The amounts are unfortunately presented to the public in lumping sums. They enable us, however, to show that, while in the earlier times of the works, from 22 to 25 cents per 1000 cubic feet of gas were received by the *stockholders* as profits from the *incidental products*, only about 15 cents per thousand feet were placed to the credit of the *city* works for the same products in 1847. Thus, though the price of gas has been reduced from $3.50 to $2.50 per thousand cubic feet, the economizing of secondary products has been so little successful, as to have fallen below 7 per cent. of the income from sales of gas even at this diminished rate of charge. Improvement has here a wide field.

The table also shows that the cash receipts for gas and other materials sold, have exceeded the total amount of payments for making and distributing the gas, and for *every incidental expense of sustaining the works in complete repair*, by the sum of $687,677 39, which is $1 20 per 1000 cubic feet for all the gas manufactured since the works were in existence, including that lost by leakage, as well as that sold for street lamps at half the price paid by private consumers.

Concise Tabular View of the Operations of the Philadelphia Gas Works from their commencement in 1836 *to the end of the year* 1847.

Year.	Cubic feet of gas manufactured in each year.	Total cash payments for making gas, including materials, freights, rents, salaries, wages, repairs, and all incidental charges for manufacture and sale of the products of the works.	Cash receipts for all the products of the works, including gas, coke, tar, lime, &c.	Receipts for incidental products separate from those for gas.	Ratio of the receipts for incidental products, to the total receipts for gas per ct.	Cents per 1000 cu. ft. of gas received for incidental products of the works.	Remarks.
1836	6,481,300	$14,244.00	$16,234.71	$2507.58	18.	38.7	Managed for the profit of stockholders.
1837	17,078,700	43,069.42	49,345.29	3688.11	8.	21.5	
1838	27,357,000	71,845.62	79,992.63	6831.42	9.8	24.9	
1839	39,473,000	91,953.26	112,310.18	8658.37	8.3	21.9	
1840	45,410,000	61,999.25	132,571.19	not reported	—	—	
1841	51,290,000	96,330.32	155,882.94	11,419.00	7.9	22.3	Managed under the sole authority of the city government.
1842	50,811,000	77,316.57	158,492.85	10,754.00	7.3	21.1	
1843	48,890,000	58,796.39	146,041.57	10,068.00	7.4	20.6	
1844	54,748,000	62,090.16	158,886.84	not separately reported	—	—	
1845	65,003,000	80,528.85	168,107.26	do.	—	—	
1846	75,454,000	121,054.60	180,883.08	do.	—	—	
1847	91,457,000	98,527.42	206,684.76	13,470.55	6.9	14.9	
Total	573,453,000	877,755.86	1,565,433.25				

Longer experience in managing the works thus appears to have led to a less ability, or a less inclination to economize their incidental products.

By reference to pages 450 to 453 of this volume, it will be seen how far the incidental products of gas works have been economized in England, and how great reductions may eventually be made here in the actual *cost* of gas, when similar care shall be taken of the residues, especially when the tar and ammoniacal liquor shall be applied to their proper purposes.

But in order that these reductions should be speedily made, it is evidently necessary that those having the superintendence and control of the works should have no interest, direct or *indirect*, in keeping up the price of gas, but rather an urgent motive for finding a market for the incidental products of the works, and for every other species of economy.

Besides the economizing of incidental products, other means of diminishing the cost of gas are evidently yet to be applied at the Philadelphia works, in order to bring them to the state of perfection of which they are susceptible. The preceding pages furnish evidence of what has been done in England within a few years in these respects.

There is, in the first place, a vastly greater consumption of fuel for the purpose of carbonization than in almost any works in Europe where any economy at all in that material is studied, and it does not appear that much if any variation has been made in the Philadelphia works, looking to an improvement in this particular. But without referring to more recent improvements abroad, we may first see what was doing abroad at the time these works were erected.

The following statements by Dr. Ure, will serve to show how far the economy of heating materials had been carried in England at the period alluded to.

Thus, the fuel to carbonize one ton of coals was, at
Birmingham, ¼ of a ton of slack (fine) coal.
Manchester, 4⅔ cwt.
Liverpool (old gas company), 6½ cwt. of coal.
Liverpool (new do.), 5½ do.
Bradford, 8½ cwt. of coke.
Leeds, 5¼ cwt. of coke.
Sheffield, 3½ cwt. of coke.
Leicester, ⅓ of the coke.
Derby, ⅓ of the coke.
Nottingham, ⅓ of the coke.
London in 1834, 13 bushels of coke.
London in 1837, 13 bushels of coke.

If these statements, which have been published and republished without essential alterations, be true, there must be means of economizing fuel not known, or certainly not practised at the Philadelphia gas works, where, instead of "⅓ of the coke," (33 per cent.) being consumed as fuel under retorts, it appears that 60 per cent. is about the average, or instead of 13 bushels to carbonize a ton of coal, as in London, 23 bushels is the least average for any one year, and 25.8 bushels, or almost exactly double that number, is the general average, as seen in columns 13 and 14 of the following table of the operations from 1841 to 1847 inclusive.

By reference to the description of Mr. Croll's improvements (see above, p. 541), it will be observed that the coke used for fuel is at Tottenham only 24 per cent. of the whole amount produced.

The introduction of anthracite for fuel under the retorts at the Philadelphia works, was formerly suggested, but is believed to have engaged no serious attention, notwithstanding that the demand for coke is equal to all which the works can supply.

Table of the Operations of the Philadelphia Gas Works since they became the property of the City, in March 1841.

Date.	Cubic feet of gas manufactured during the year.	Bushels of coal, of 75 lbs. each, carbonized during the year.	Barrels of rosin, of 250 lbs. each, used with the coal during the year.	Sum of the weights of coal and rosin used in the retorts during the year, in lbs.	Weight of the two materials used in the retorts, in tons of 2240 lbs. each.	Proportion of rosin to the whole material distilled, per cent.	Cubic feet of gas procured, per ton, of the two materials distilled.	Cubic feet of gas produced from 1 lb. of mixed coal and rosin distilled.	Total number of bushels of coke produced during the year.	Bushels of coke produced from 1 bushel of coals.	Bushels of coke used in heating retorts during the year.	Bushels of coke used in heating retorts, per ton, of the mixed coal and rosin.	Per centage of all the coke produced which was used in heating retorts.	Struck bushels of lime used for purifying gas during the year.	Cubic feet of gas purified by one struck bushel of lime.	Cost of coal per bushel in cents.	Cost in cents of rosin per barrel of 250 lbs.	Cost of lime per bushel in cents.	Cost of gas made during the year, exclusive of interest on capital, but including all payments for materials, freights, rents, salaries, wages, repairs, and all incidental expenses of the manufacture and distribution.	Cash receipts during the year for gas, coke, lime, tar, &c.	Per centage by which the receipts for gas, &c., exceeded the payments on account of manufacture and distribution.	Price paid for gas, per 1000 cubic feet.
1841	51,290,000	194,317	000	14,573,775	6586	0.00	7787	3.52	296.000	1.52	167,654	25.4	56.6	47,114	1088	20¼	—	2.34	$96,330 32	$155,892 94	61.8	$3.50
1842	50,811,000	187,147	500	14.161,025	6321	0.88	9038	3.58	not reported	—	165,175	26.1	—	54,536	931	21	1.48	2.59	77,316 57	158,492 85	105.0	3.50
1843	48,890,000	154,002	2509	12,077,900	5392	4.30	9067	4.04	not reported	—	152,609	28.3	—	54,602	895	16½	90	2.44	58,796 39	146,041 57	148.3	3.50
1844	54,748,000	164,742	2867	13,072,400	5836	5.48	9381	4.19	274,246	1.66	169,110	28.9	61.6	55,792	981	16¼	70		62.090 16	158,866 84	155.9	3.50
1845	65,003,000	197,218	3725	15,722,600	7019	5.92	9262	4.13	288,356	1.46	174,352	24.8	60.4	57,776	1125	21¼	70		80,528 86	168,107 26	108.7	3.00
1846	75,454,000	234,103	4692	18,728,225	8360	6.25	9020	4.02	310,042	1.32	201,921	24.1	65.0	61,818	1220	21	75		121,054 60	180,883 03	49.3	2.80 2.50
1847	91,457,000	285,117	6545	23.020,025	10277	7.10	8899	3.97	411.555	1.44	236,176	23.0	57.3	80,508	1136	17¼	80		98,527 42	209,684 76	112.8	2.50

It seems probable from the above comparison of the operation of the works for the last seven years, that one efficient cause of the diminished cost of making gas in the recent period, as above proved, has been the introduction of a considerable portion of rosin into the material distilled. This, as above mentioned, was first used in 1842.

It was proved at the Christiana light-house in 1844 (see above, p. 212), that 70 lbs. of rosin are capable of yielding, when completely decomposed, 486 cubic feet of gas, or almost exactly 7 cubic feet of gas to the pound. As 6545 barrels, supposed to weigh 250 lbs. each, or 1,636,250 lbs. of rosin were used at the works in 1847, this rosin, if as economically used as in the case just mentioned, must have produced 11,453,750 cubic feet of gas, or about 12½ per cent. of the entire quantity of 91,457,000 cubic feet of gas manufactured during that year.

Deducting the weight of rosin from the whole weight of the mixture used in the year as contained in column 5th, we obtain 21,383,775 lbs. of *coal* carbonized (say 285,117 bushels of 75 lbs each), to give 91,457,000—11,453,750 = 80,003,250 feet of gas; and, consequently, one pound of coal yielded 3.74 cubic feet of gas, and a ton 8377.6 cubic feet, while a *bushel* of coal (75 lbs.) gave 280.5 cubic feet for 17½ cents worth of material. To produce the same bulk of a much richer gas, from rosin, would require $\frac{280.5}{7} = 40.07$ lbs., which at 65 cents per barrel of 250 lbs., cost 10.41 cents, or at 80 cents per barrel, would cost 12.82 cents. Now, as a given bulk of poor gas costs 17½ cents worth of coal, and the same bulk of much richer gas costs 10.41 — 12.82 cents worth of rosin, it is evident that great economy must result from the proper use of rosin, and it should therefore seem that economy required the still further increase in proportion of rosin, until the quantity of coal used should only be sufficient to furnish coke for heating the retorts. Whether even this should be the limit of reduction may remain a doubt, so long as bituminous coal commands its present high price, and other species of fuel, such as anthracite, are so low.

It appears from the 16th column of the above table, that, during the years 1845, 1846 and 1847, a considerable diminution in the proportion of lime to the bulk of gas purified, has been allowed, so that in 1846 every bushel of lime was made to purify 1220 cubic feet of gas. That a diminution of lime to some extent should be made since 1842 is very reasonable, on account of the large proportion of rosin introduced, the gas of which (at least when made by itself), needs no purification; but in the latter part of the year 1847, owing to the bad properties of the coal or other causes, the impurity and nauseous odor of the gas became matters of very general complaint. This induced the superintendent to add to the ordinary dose of dry lime 10 or 12 lbs. of acetate of lead, with some chloride of lime at each charge of a purifier. The year's operations are therefore charged with 12,000 lbs. of acetate of lead, and 14,512 lbs. of chloride of lime. This greatly enhanced the cost of gas for the year.

INDEX.

END OF VOL. I.

ERRATUM.

Page 187, lines 26 and 29, for "cwts." read tons.