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LECTURES ON CHEMISTRY.

LECTURES

ON

CHEMISTRY;

INCLUDING

ITS APPLICATIONS IN THE ARTS:

AND THE

ANALYSIS OF ORGANIC AND INORGANIC COMPOUNDS.

BY

HENRY M. NOAD,

MEMBER OF THE CHEMICAL AND ELECTRICAL SOCIETIES OF LONDON;
LECTURER ON CHEMISTRY;
AUTHOR OF LECTURES ON ELECTRICITY, ETC., ETC.

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TO

THOMAS GRAHAM, ESQ. F. R. S. L. & ED.,

PROFESSOR OF CHEMISTRY, IN UNIVERSITY COLLEGE, LONDON;
PRESIDENT OF THE CHEMICAL SOCIETY;
CORRESPONDING MEMBER OF THE ROYAL ACADEMIES OF
BERLIN AND MUNICH, ETC.

My dear Sir,

When, at the commencement of the following Lectures, I ventured as a stranger, to request that you would allow them to appear under your patronage: you kindly consented, leaving it open to me to change my mind when the period of completion arrived. Since that time I have had the pleasure of making your acquaintance, and your own "Elements of Chemistry," have been presented to the public in a complete form, and allow me to assure you, that both these circumstances, so far from inducing a desire on my part to revoke my former request, have made me more anxious to inscribe to you an Elementary Work on the Science which you have pursued with such distinguished success. Accept then this small token of the admiration and esteem of

Dear Sir,

Your's very faithfully,

THE AUTHOR.

PREFACE.

In the composition of the following Lectures, the aim of the Author has been to steer between a too familiar and a too scientific treatment of his subject—to build as it were an intermediate stepping stone between the "handbooks" and "alphabets" of Chemistry, and the Treatises, Manuals, and Systems of the Professors:—Such a work appeared to be wanting, and it is for the Public to judge how far it is here supplied. The bearings of Chemistry on AGRICULTURE are now so acknowledged, and the interest naturally attached thereto, is so rapidly increasing, that the original design of the 12th Lecture has been somewhat altered, in order to give a view (necessarily a very condensed one,) of the present state of this important subject. A large folded Table, giving a general view of the metals, has also been added, and as great pains have been taken to make it correct, it is confidently hoped, that it will be found to add most materially to the usefulness of the work.

The Author acknowledges the great assistance he has derived from the works of Graham, Kane, Turner, Brande, Thomson, Henry, Daniell, Mitscherlich, Rose, and in the composition of the 12th Lecture, from the admirable Essays of Liebig, and the no less important "Lectures on Agricultural Chemistry and Geology" of Johnston.

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LECTURE II.

ADDITIONAL ERRATA.

The reader is requested to make the following corrections, which escaped the Author's notice whilst revising the proof sheets.

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140.. Fourteen lines from the top, for "one hundred weight of charcoal," read *one pound of charcoal.*

151.. Eight lines from the top, after the words "from one equivalent," add *or* 1366 *grains.*

202.. Ten lines from the top, for "10 cwt. of charcoal consume 32 cubic feet," read 1*lb. of charcoal consumes* 32 *cubic feet.*

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backed by the most convincing evidence, and by appeals to common sense, is notorious as a matter of history.

Francis Bacon, Lord Verulam, one of the most remarkable men of whom any age can boast, performed the distinguished task of reforming this system of philosophy. This he effected, by pointing out where the weakness of the Aristotelian philosophy lay, and by substituting for it a stronger and better, based on the observation of nature.

This great man was born in 1561, and history informs us that he wrote against Aristotle, before he had completed his sixteenth year. All his studies appear to have aimed at the reform in the system of human knowledge. He examined the whole circle of the sciences; investigated their relations, and attempted to arrange them according to the different faculties of the human mind to which each belongs: here he perceived he was in want of a well founded and natural division of the powers of the mind; this he explains in his Instauratio Magna. He further became convinced, that in all branches of natural science, observation of nature is most essentially requisite, and he illustrates in several places how this observation is to be directed, and how nature is to be examined.

The effect which the writings of Bacon produced amongst the literati of his day was immense, as was also the impulse given to science, and as a natural consequence, attention being directed in the right manner, discoveries multiplied, and fresh treasures were continually turned up, from the hitherto unbroken soil of nature: facts multiplied, laws and generalizations commenced, and as an elegant writer has remarked, "so rapid was the career of discovery, so signal the triumph of the inductive philosophy, that a single generation, and the efforts of a single mind, sufficed for the establishment of the system of the universe, on a basis never after to be shaken."

Although then, chemistry as a science, cannot be dated at an earlier period, than the beginning of the seventeenth century, I may, perhaps, without being tedious, advert briefly to the writings of the earlier alchymists, the oldest of which singular class of students, appears to have been Hermes Trismegistus, who is said to have lived in the year of the world 2076; the works generally attributed to him, are, however, supposed by persons qualified to form a judgment, to be entirely spurious, belonging to a much later period; they all refer to the attempts at the transmutation of the base metals into gold, and various matters relating to the Philosophers' stone, by means of which, "through the permission of the Omnipotent, the greatest disease is cured, and sorrow, distress, and evil, and every hurtful thing evaded: by help of which we pass from darkness to light; from a desert and wilderness, to a habitation and home, and from straitness and necessities to a large and ample estate." Hermes was an Egyptian, and from him chemistry and alchymy came to be called the *Hermetic* art.

From the Egyptians, the Grecians derived their fondness for magic and alchymy; the Grecians again initiated the Romans, and when true science was persecuted under the Roman tyrants, superstition and false philosophy flourished more. The prodigality of the Romans, causing a scarcity of gold, occasioned that study, which held out the prospect of obtaining it instantaneously and abundantly, to be eagerly pursued. Caligula, we are told, made experiments with a view of obtaining gold from orpiment, while on the other hand Diocletian condemned the pursuit, and ordered all the books treating on alchymy to be burned.

At a later period the subject was taken up by the Arabians, amongst whom the second name renowned in alchymy flourished, Geber, who lived in the seventh or eighth century, the exact period being unknown.

His three books on alchymy, which are among the oldest chemical treatises in existence, were published in Strasburgh in 1520, and are considered by Boerhaave, if genuine, to indicate the Author's right to be numbered amongst the first-rate philosophers of his age.

The works ascribed to Geber are more intelligible than those of other alchymistical writers, though the same metaphorical expressions which obscure the writings of that period, are to be found in his; for instance, in speaking of the transmutation of the base metals into gold, he says, "bring me the six lepers that I may cleanse them," meaning silver, mercury, copper, iron, tin, and lead, which, with gold, were the only metals known at that time. It is supposed by Dr. Johnson, that the word *Gibberish*, or *Geberish*, was originally applied to the language of Geber and his followers.

Prominent among the alchymists of the thirteenth century, stands the name of our countryman Roger Bacon, who was born near Ilchester, in the county of Somerset, in the year 1214. He was a monk of the Franciscan order, and his works, unintelligible to his less acute fraternity, and supposed by them to be the offspring of witchcraft, drew down upon him their hatred and jealousy, and a persecution so inveterate, that he narrowly escaped falling a sacrifice to their ignorance, and superstition, at the stake.

The celebrated work of Roger Bacon, is his Opus Majus, in which a strong resemblance to the writings of his great successor Chancellor Bacon, is to be discovered; his expressions are perspicuous and comprehensive, and betoken a rare and unclouded intellect. He is very plausibly considered to be the inventor of gunpowder, though the discovery has also been given to Bartholomew Schwartz, a German monk, and the date of 1320 annexed to it.

One of the most famous alchymists of the thirteenth century was Raymond Lully, of Majorca, who was born in 1236, and died in 1315. A story is told of him, that during his stay in London, he changed for King Edward 1st, a mass of 50,000lbs. of quicksilver into gold, of which the first rose nobles were coined.

As unsuccessful experiments multiplied, so in proportion was the degree of faith placed in alchymy shaken; but the following extract from a work published by Dr. Salmon in 1692, will serve to show with what ardour the believers in transmutation pursued their investigations, and how little *they* were disheartened by their innumerable failures.

"As to the great and philosophic work," (meaning transmutation,) "it is my opinion and belief that there is such a thing in nature; I know the matter of fact to be true, though the way and manner of doing it is as yet hid from me. I have been an eye witness of so much as is able to convince any man endued with rational faculties, that there is a possibility of the transmutation of metals: yet for all these things will not advise any man, ignorant of the power of nature, and the way of operation, to attempt the work, lest, erring in the foundation, he should suffer loss and blame me. Without doubt it is a gift of God from above, and he that attains it must patiently await the moving of the waters; when the destined angel moves the waters of the pool, then is the time to immerge the leprous metal, and cleanse it from all impurities."

Again, Van Helmont says, "I am constrained to believe in the making of gold and silver, though I know many exquisite chemists to have consumed their own and other men's goods in search of this mystery: and to this day we see these worthy and simple labourers, cunningly deluded by a diabolical crew of gold and silver sucking flies and leeches. But I know that many will contradict this truth; one says it is the work of the Devil, and another that the sauce is dearer than the meat."

In the preface to the Bibliotheca Chemica Curiosa, the following history of a transmutation, is given by Mangetus, on the authority of M. Gros, a clergyman of Geneva; with it I shall conclude this short sketch of alchymistical absurdity, and pass on to a notice of some of their far more philosophical contemporaries.

"About the year 1650, an unknown Italian came to Geneva, and took lodgings at the sign of the Green Cross. After remaining there a day or two, he requested De Luc, the land-lord, to procure him a man acquainted with Italian, to accompany him through the town, and point out those things which deserved to be examined. De Luc was acquainted with M. Gros, at that time about twenty years of age, and a student in Geneva, and knowing his proficiency in the Italian language, requested him to accompany the stranger. To this proposition he willingly acceded, and attended the Italian everywhere for the space of a fortnight. The stranger now began to complain of want of money, which alarmed M. Gros not a little, for at that time he was very poor, and he became apprehensive, from the tenour of the stranger's conversation, that he intended to ask the loan of money from him. But instead of this, the Italian asked him if he was acquainted with any goldsmith whose bellows and other utensils they might be permitted to use, and who would not refuse to supply them with the different articles requisite for a particular process which he wanted to perform. M. Gros named a M. Bureau, to whom the Italian immediately repaired. He readily furnished crucibles, pure tin, and quicksilver, and the other drugs required by the Italian. The goldsmith left his workshop that the Italian might be under less restraint, leaving M. Gros with one of his own workmen as an attendant. The Italian put a quantity of tin into one crucible and a quantity of quicksilver into another. The tin was melted in the fire and the mercury heated. It was then poured into the melted tin, and at the same time a red powder enclosed in wax was projected into the amalgam. An agitation took place and a great deal of smoke was exhaled from the crucible, but this speedily subsided, and the whole being poured out *formed six heavy ingots having the colour of gold.* The goldsmith was called in and requested by the Italian to make a rigid examination of the smallest of the ingots. The goldsmith not content with the touchstone and the application of aquafortis, exposed the metal on the cupel with lead and fused it with antimony, but it sustained no loss. He found it possessed of the ductility and specific gravity of gold; and full of admiration, he exclaimed, that he had never worked before upon gold so perfectly pure. The Italian made him a present of the smallest ingot as a recompense, and then, accompanied by M. Gros, he repaired to the mint, where he received from M. Bacuet, the mint-master, a quantity of Spanish coin, equal in weight to the ingots which he had brought.

To M. Gros he made a present of twenty pieces on account of the attention that he had paid him: and after paying his bill at the inn, he added fifteen pieces more to serve to entertain M. Gros, and M. Bureau for some days, and in the meantime he ordered a supper, that he might on his return have the pleasure of supping with these two gentlemen. He went out but never returned, leaving behind him the greatest regret and admiration. It is needless to add that M. Gros, and M. Bureau continued to enjoy themselves at the inn, till the fifteen pieces which the stranger had left were exhausted."

We are not informed of the exact weights of the tin and quicksilver employed in this *wonderful* transmutation, but from their forming *six heavy ingots of gold*, we may conclude that the quantity of the precious metal produced at least equalled the weights of the materials out of which it was formed, and although this carries absurdity on the very face of it, yet the story was most implicitly believed.

I might quote several equally, and even more absurd accounts of transmutations, in which the most reverential confidence was, at the time, and long after their publication, placed; the above will however probably suffice.

The year 1400 is marked in the annals of Chemistry, as the period of the birth of Basil Valentine, the *first* experimentalist whose labours contributed to the foundation of the modern science.

In his "Triumphant Chariot of Antimony," republished at Amsterdam in 1671, there is a good deal of curious information upon a variety of chemical subjects, and when it is said that to him we owe the first accurate directions for the preparation of those two important acids the sulphuric and nitric, his claims to be noticed as a chemist of very considerable merit will be at once allowed.

Next came Paracelsus, who is more noted for his successful labours in the department of pharmaceutical chemistry, to which he gave an important turn, than for his contributions to the science itself. He was a man of dissolute habits, and died in poverty at Saltsburg, in 1541.

We must not here forget to mention a very celebrated astronomer, whose acute and powerful intellect was not proof against the superstition and credulity of the age, and who was not only a profound believer in alchymy, but who also devoted much of his time to a search for the universal medicine, the elixir vitæ, Tycho Brahe, who was born in 1546, and who died in 1601. Although it is known that this celebrated philosopher spent much of his time and money in the study of *terrestrial* astronomy, (chemistry,) yet it is not found that he ever published an account of his experiments, nor are there among his writings any traces of his chemical enquiries. The reason he gave for his silence was very similar to the excuses of many other alchymists. "On consideration," says he, "and by the advice of the most learned men, I thought it improper to unfold the secrets of the art (of alchymy) to the vulgar, as few persons were capable of using its mysteries to advantage and without detriment."

Tycho Brahe was the pretended discoverer of a specific against the epidemic diseases which were then ravaging Germany. This Elixir went by his name, and excited so much attention, that the Emperor Rudolph applied to Tycho for the receipt. The Astronomer gave it, humbly beseeching the Emperor to keep it a secret, and to reserve the medicine for himself alone!

The base of this important medicine is stated to have been Venetian treacle, which undergoes an infinity of chemical operations and admixtures before it is ready for the patient. When properly prepared, the Emperor was assured that it is better than gold, and that it may be made still more valuable by mixing with it a single scruple either of the tincture of corals, or sapphire, or hyacinth, or a solution of pearls, or of potable gold, if it can be obtained free of all corrosive matter!*

The works of Paracelsus excited the attention and genius of Van Helmont, who flourished in the early part of the seventeenth century; he appears to have been a man of real philosophical habits, very different from his predecessor Paracelsus. In his writings the word *gas*, as applied to all aëriform bodies differing from atmospheric air, first occurs: he also distinguished between condensible gases or vapour, and incondensible or permanently elastic fluids. Van Helmont may be considered as the last of the alchymists.

Glauber of Amsterdam, deserves next to be noticed. His works, translated into English in 1689, abound in original and important information. Amongst the most useful of his discoveries may be placed that of the production of vinegar of wood, which has lately become a manufacture of much importance, and of muriatic acid, which he obtained by distilling common salt with sulphuric acid, and he gives a sufficiently clear account of the nature of the chemical change that ensues.

The residue of this operation still goes by the name of Glauber's salt, or as he termed it *sal mirabile*. Glauber had a great idea of the medicinal value of this compound, but that he did not suppose it an *elixir vitæ*, in the sense of the alchymists, is evident from this extract from his writings. "Salt" says he, "is the beginning and the end of all things, and it increaseth and exalteth their powers and virtues: it is the true universal medicine; not that I would have any man persuade himself, that in these words I would assert immortality, for my purpose tendeth not thither; seeing that I am not ig-

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* See the Life of Tycho Brahe in Sir D. Brewster's Martyrs of Science, before alluded to.

norant that there is no medicine against death." Glauber was the inventor of much useful chemical apparatus.

In the year 1662, the Royal Society was established, for the improvement of mental knowledge; belonging to which body, the first names that arrest our attention, in connection with the present subject, are those of Boyle and Hooke; the former of which celebrated men was born at Lismore, in the province of Munster, in Ireland, in 1627, and died in London, in 1691, and the latter in the Isle of Wight, in 1635, and died in London, in 1702.

In the writings of Boyle and Hooke we have the first genuine samples of the influence of Lord Bacon's doctrines, the effects of which were as great as they were beneficial. It was through their experiments, that attention was first directed to the important part performed by the presence of atmospheric air in combustion, and Boyle first showed that a candle would not burn, and that gunpowder could not be ignited by collision of flint and steel, under the exhausted receiver of an air pump. Hooke went much further, and speculated in an exceedingly ingenious manner, on the phenomena of combustion. It is impossible here to go into a detail of his opinions, and it will suffice to say, that he in a degree anticipated results which were gained at a much later period. He asserted that air was the universal dissolvent of inflammable bodies; that this dissolution generates heat, which we call fire, as is the case in many other dissolutions; that this dissolution is made by a substance mixed with the air that is like to, or *the very same* as, that which is fixed in saltpetre,—that of the burning body, one part is turned into air, and another portion is indissoluble, &c.

Contemporary with Hooke and Boyle, was the celebrated German chemist, Beccher, who may be considered as the author of the first Theory of Chemistry. He published in 1669, a work entitled "Physica Subterranea," a work which forms a very important era in the history of Chemistry; it then, as Dr. Thomson observes, escaped for ever from the trammels of alchymy, and became the rudiments of the science as we find it at present.

The theory of Beccher was simplified, and so far remodelled by his successor and editor Stahl, that it became entirely his own, and has been ever since distinguished by the name of the Stahlian theory.

The explanation offered for the phenomena of combustion, was that which afterwards excited so much attention, under the name of the Phlogistic Theory.

The elements of bodies, according to Beccher, are air, water, and three earths, one of which is inflammable, another mercurial, and another fusible. The three earths combined with water constitute an universal acid, which is the basis of all other acids. The combination of two earths produce lapideous bodies: and in the metals, the three earths are united in various proportions.

Stahl rejected the mercurial earth of Beccher, and retained as elements water, acid, earth, and fire; or, as he termed it, *Phlogiston*, a principle of extreme tenuity, and prone to a kind of vibratory motion, in which it appears as fire. He adduced numerous experiments in support of his theory; for example, when phosphorus is burned it produces an acid, with the evolution of much heat and light, consequently phosphorus consists of acid and phlogiston: if this acid be now heated with charcoal, or any other body abounding in phlogiston, phosphorus will be reproduced.

When zinc is heated to redness, it burns with a brilliant flame, and is converted into a white earthy substance or calx. Hence zinc consists of this earth and phlogiston.

Now, although no notice is taken by Stahl of the *increase of weight* in these experiments, which is referred by Mayow distinctly to the fixation of Hooke's nitro-ærial particles, still, the plausibility of his theory was such, that it excited universal admiration, and the names of Hooke and Mayow were heard nothing of for more than 50 years, during which time the

Stahlian theory maintained an unimpeached dominion, till upset by the ingenuity and genius of the unfortunate Lavoisier.

The great talents of Mayow were not appreciated nearly as much as they deserved in his own time, nor was it till after the fall of the Phlogistic Theory that his penetration and acuteness were fully perceived. He was the first writer who offered views worth recording upon the subject of respiration, and his speculations concerning the causes and effects of chemical affinity were quoted and enlarged upon by Newton, in the Queries annexed to the third book of Optics. They are indeed at once clever and correct, and afford a striking contrast to the rude and groundless notions that were previously entertained on the subject.

Mayow was the first to show that no *annihilation* of the particles of a compound takes place on their union, as was universally supposed. " When," says he, " spirit of salt is mixed with sal volatile, sal ammoniac is produced, in which it is true neither the properties of acid or alkali are apparent; yet if salt of tartar be distilled with sal ammoniac, the volatile alkali will be displaced, with all its previous characters, because, there is greater attraction between spirit of salt and tartar, than between spirit of salt and volatile alkali." Again, to show that the acid is not destroyed in saline combinations, he instances the decomposition of nitre by oil of vitriol, which, he says, displaces the nitric acid, and the residuum in the retort furnishes vitriolated tartar. It may be asked, why, when nitre is heated, the nitric acid does not rise, for it is as we have just seen, very volatile: the reason is, that it is restrained and kept down by its attraction for the tartar, and can only be dispelled by bodies which have a stronger attraction for tartar than it.

All this is strictly true, and will serve as a specimen of the penetration of the author.

Newton, in following up the views of Mayow, observes, "how these attractions are performed, I do not here consider; what

I call attraction, may be performed by impulse, or by some other means unknown to me: I use that word to signify any force by which bodies tend towards one another, whatever be the cause."

These simple expressions of facts, completely superseded the hypothesis of hooks, rings, points, and wedges, by which the component parts of bodies were supposed to be held united.

We come next to the founder of Pneumatic Chemistry, Dr. Stephen Hales, who was born in Kent, in the year 1677, and died in 1761. Hales was a man of indefatigable perseverance, and his writings are particularly distinguished by their simplicity and perspicuity. He was the first person who paid any considerable attention to the gazeous products of bodies, for which he invented a variety of apparatus, some of which nearly resemble those used at the present time.

In the course of his experiments he met with a great number of curious and important facts, to which he did not pay sufficient attention, and which were reserved for the genius of his successor, Priestley, to examine and explain.

In his experiments on respiration, he obtained results of great interest, which he passed over just at the time when he was apparently arriving at something like an explanation of them. He appeared to have had a great dislike to following up new facts, his object was to multiply them.

The researches of Hales relating to the motion of sap in vegetables, were pursued upon a much more regular and digested plan. They were published under the title of "Statical Essays," in 1727. He ascertained by experiments with the sunflower the quantities of matter imbibed and perspired by plants, and the influence of leaves upon the absorption of water by the root; he made sundry experiments on the rise of sap, which he found was much influenced by the leaves; he collected the matter transpired from the branches and leaves by enclosing them in flasks and retorts, and stated that the fluid he thereby procured appeared to be water slightly tainted by vegetable matter.

Dr. Hales also made some very curious remarks relating to the force with which trees imbibe moisture. He exposed the roots of a pear tree, and cut off the end of one half an inch in diameter; the stump was cemented into the upper end of a tube twenty-six inches long filled with water, and dipping at its lower extremity into mercury. The root imbibed water so vigorously that in six minutes time, the mercury rose eight inches in the tube. This experiment was made in August.

In the Philosophical Transactions, are published several papers of Dr. Hales on other subjects; they are not however of sufficient importance for insertion.

Contemporary with Dr. Hales was the celebrated Boerhaave, who was born near Leyden, in December, 1668. Hermann Boerhaave was one of the most distinguished ornaments of the eighteenth century; his life has been written by the masterly hand of Dr. Johnson, who observes, with respect to his writings " they have made all encomiums useless and vain, since no man can attentively peruse them without admiring the abilities, and reverencing the virtues of the author."

Boerhaave was originally intended for the Church, but an obstinate ulcer on his left thigh, which for seven years resisted all medical remedies, was the means of directing his thoughts and inclinations to the study of medicine, and it is worthy of remark that he learned by his own solitary study, a science on which he afterwards exerted so important an influence.

Of his numerous works, his Elements of Chemistry is perhaps the finest specimen, a good translation of which, with notes, was edited in 1753 by Dr. Shaw; this work is still valuable, notwithstanding the entire revolution which has taken place in the science since his day; his original investigations were nearly the same as those of Hales; his experiments are remarkable for their accuracy, and in disclosing his views, he has certainly sketched an outline of one of the modern theories of combustion. His remarks on organic bodies are also exceedingly good.

So extensive a sphere of action gained for Boerhaave a fame that few learned men have enjoyed. People came from all parts of Europe to consult him. Peter the Great visited him on his travels, and a Chinese Mandarin wrote to him with the address, "To Boerhaave, the celebrated Physician in Europe": he died in September, 1738.

The name of Dr. Black occurs at this period in the history of Chemistry. He was born on the banks of the Garonne, in 1728, and was initiated into the mysteries of chemical science by Dr. Cullen, a celebrated physician of Glasgow.

The name of Dr. Black is so intimately associated with the history of Latent Heat, that I shall reserve the notice of his celebrated discoveries on that subject for the next lecture.

In 1766 Dr. Black was called to the chemical chair of Edinburgh, an office which he filled with such talent, industry, and perseverance, that he excited a general taste for the science. As a lecturer he was particularly distinguished by his simplicity and clearness; he was very successful in his illustrations, and judicious in their selection, and "while" says his biographer Professor Robinson, "he scorned the quackery of a showman, the simplicity, neatness, and elegance with which his experiments were performed were truly admirable."

His writings, though few, are masterpieces of scientific composition; he was the first that introduced into Chemistry that severe system of inductive logic found in the works of Newton, in consequence of which he was particularly cautious in submitting his opinions to the public, fully aware of the multitudinous facts upon which a theory that is to stand firm, must be founded, and averse to all hypotheses.

Dr. Black was the discoverer of carbonic acid, or as he termed it fixed air. When he commenced his chemical career, the causticity of lime was referred to different causes; by Stahl the limestone was supposed to have absorbed certain *igneous* particles by the operation of heating; by others, Macquer and Meyer in particular, to an acrid acid contracted in the fire.

Black, finding that the magnesia obtained by adding a mild alkali to solution of Epsom salt, effervesced upon the addition of an acid, but did not do so when heated red hot, and also lost considerably in weight by the operation, was induced to try the same experiment with lime; he found this attended with the same result, the lime lost weight, hence he concluded that its causticity was occasioned by a *loss,* not a *gain* by heat. He next distilled some magnesia in a retort, but finding no product but a small quantity of water not nearly equal to the weight the magnesia had lost, he conceived the possibility of the loss of gaseous matter, and on pouring a quantity of acid on some magnesia in a proper apparatus, he succeeded in collecting a permanently elastic fluid; this he repeated with chalk and the mild alkalies.

This discovery gave a new form to Chemistry, and may be considered the basis of many of those which have immortalized the names of Priestley, Cavendish, and Lavoisier.

Dr. Black was for a long time opposed to the new Chemical Theory, but was at length convinced of its superior accuracy, and did full justice to its merits. His admirable lectures were published in 1803, in two volumes, by Robison. He died suddenly in 1799, at the age of seventy one.

We next come to Priestley, to whose indefatigable perseverance Pneumatic Chemistry is under such deep obligations. Dr. Joseph Priestley was born at Fieldhead, near Leeds, in 1733; he first turned his attention to Chemistry, as a relief from his more serious Theological avocations in 1767. It was in consequence as he says, in the opening chapter of his three volumes on air, of living for some time in the neighbourhood of a public brewery, that he was induced to make experiments on fixed air, and one experiment leading to another, he soon collected those materials, which he laid before the Royal Society in 1772. He was the inventor of nearly all the apparatus used in the examination of gaseous bodies at the present day, of which he gives in the introduction to his work a detailed description.

Dr. Priestley discovered dephlogisticated air or oxygen gas, on the first of August, 1774; the following is the account he gives of the discovery. "At the time of my first publication, I was not possessed of a burning lens of sufficient power to make many of the experiments I had projected, but having afterwards procured one of twelve inches diameter and twenty inches focal distance, I proceeded with great alacrity to examine by the help of it, what kind of air a great variety of substances, natural and factitious, would yield, putting them into flasks filled with quicksilver, and inverted in vessels of the same. With this apparatus, on the 1st of August 1774, I endeavoured to extract air from mercurius calcinatus per se, (red precipitate of mercury,) and I presently found that by means of the lens, air was expelled from it very readily. Having got about three or four times as much as the bulk of my materials, I admitted water to it, and found that it was not imbibed by it. But what surprised me more than I can well express, was, that a candle burned in this air with a remarkable vigorous flame, very much like that enlarged flame with which a candle burns in nitrous air, exposed to iron or liver of sulphur: (nitrous oxyd as it is now termed); but as I had got nothing like this remarkable appearance from any kind of air beside this peculiar modification of nitrous air, and I knew no nitrous acid was used in the preparation of mercurius calcinatus, I was utterly at a loss how to account for it.

"At the same time that I made the above experiment, I extracted a quantity of air of the very same property from the common red precipitate, which being produced by a solution of mercury in spirit of nitre, made me conclude that this peculiar property, being similar to that of the modification of nitrous air, depended upon something being communicated to it by the nitrous acid, and since mercurius calcinatus is produced by exposing mercury to a certain degree of heat, when common air has access to it; I likewise concluded that this substance had collected something of *nitre* in that state of heat from the atmosphere."

In another place, he says, "As I never make the least secret of any thing that I observe, I mentioned these experiments to all my philosophical acquaintance at Paris and elsewhere, having no idea at that time to what these remarkable facts would lead."

For some months Dr. Priestley thought that dephlogisticated air was the same as common air; he did not at first observe that when mixed with nitrous gas the fumes produced were of a darker colour, or that the diminution in volume was greater than with common air, he says, "I particularly remember my telling Dr. Price, that I was myself perfectly satisfied of its being common air, as it appeared to be so by the test of nitrous air, though for the satisfaction of others I wanted a mouse to make the proof quite complete." On the 8th of March, 1775, he tried this experiment, and found that the animal lived *double* the time in a given measure of the air from the mercurius calcinatus, that it could in common air; still he did not think that this circumstance warranted him in concluding that the dephlogisticated air was *better* than common air. Since there is little accuracy in this method of ascertaining the goodness of air, he was however induced from it, to repeat the experiments with nitrous gas very carefully, the result was his conviction that dephlogisticated air is *not* the same as common air, but *much better.*

Among the most interesting of Priestley's researches are those relating to the purification of air deteriorated by respiration or combustion, by means of vegetation. He appears to have been led to this subject, from reading some experiments of the Count de Saluce, in which it was pretended that air in which candles had burned out, was perfectly restored by exposure to a considerable degree of cold, and also by compression; and on the other hand that *heat* only, as the reverse of cold renders air unfit for supporting combustion. "Having" says he, "failed in these experiments, I have been so happy as by accident to have hit upon a method of restoring air, which has been injured by the burning of candles, and to have discovered at least one of the restoratives which nature employs for this purpose. It is *vegetation*." He then goes on to relate, that on the 17th of August, 1771, he put a sprig of mint into a quantity of air in which a candle had burned out, and found that on the 27th of the same month, another candle burned perfectly well in it; this experiment was repeated several times in the course of the summer, with a similar result. He remarked that this restoration of air depended on the *vegetating state* of the plant; that it was not peculiar to mint, or to any aromatic effluvia, vitiated air being equally well restored by groundsel, which usually ranks among weeds, and which has an offensive smell.

The celebrated Dr. Franklin, who was with Priestley while these experiments were going on, entered into them with considerable interest, he thus remarks upon them, "That the vegetable creation should restore the air which is spoiled by the animal part of it, looks like a rational system, and seems to be of a piece with the rest. Thus fire purifies water all the world over. It purifies it by distillation when it raises it in vapours, and lets it fall in rain; and further still by filtration, when, keeping it fluid, it suffers that rain to percolate the earth. We knew before that putrid animal substances were converted into sweet vegetables, when mixed with the earth, and applied as manure: and now it seems that the same putrid substances mixed with the air have a similar effect. The strong thriving state of your mint in putrid air, seems to show that the air is mended by taking something from it, and not by adding to it."

Dr. Priestley himself suggests the following queries. May not plants restore air diminished by putrefaction, by absorbing part of the phlogiston with which it is loaded? The greater part of a dry plant, as well as of a dry animal substance, consists of inflammable air, and it seems to be as probable that this phlogistic matter may have been imbibed by the roots and leaves of plants and afterwards incorporated into their substance, as that it is altogether produced by the power of vegetation. May not this phlogistic matter be even the most essential part of the food and support of both vegetable and animal bodies? Dr. Priestley was a staunch supporter of the phlogistic doctrine, and the last work he ever wrote was a tract in its support, entitled "The Doctrine of Phlogiston Established, and that of the Composition of Water Refuted."

In 1778, Dr. Priestley made the capital discovery of the evolution of oxygen gas by aquatic plants, growing in water containing carbonic acid; that the presence of light was essential to this change, and that in sunshine it was most rapid. He observes, that, as air combined with water is liable to be phlogisticated by respiration, and to be dephlogisticated by vegetation, as much as air in an elastic state out of water; one of the great uses of weeds, and other aquatic plants with which fresh water lakes and even seas abound, is doubtless to purify the air made foul by the fishes, as well as to supply them with food; and again, he explains the loss of fertilizing power in water employed in floating meadow land, by supposing that when it issues from the earth, it contains air of an impure kind; that is, air loaded with phlogiston. This principle the roots of the grass extract from it; so that it is then replete with dephlogisticated air, and consequently the plants it afterwards comes into contact with, have nothing to feed upon.

The experiments of Priestley relating to the physiology of vegetation, were considered by the council of the Royal Society so valuable, that in November, 1783, they awarded him the Copley Medal, on which occasion a handsome eulogium was pronounced on him by the President Sir John Pringle.

Besides the important contributions to chemical science, that have been enumerated, Priestley first produced and investigated nitrous gas, (which was indeed his first discovery,) sulphurous acid, fluoric acid, muriatic acid, ammoniacal, carburetted hydrogen, carbonic oxide, and nitrous oxide gases. Though he did not discover hydrogen gas, yet his experiments on it were highly important, and contributed essentially to the revolution brought about in Chemistry. Azotic gas was discovered before he began his career; but we are indebted to him for most of the properties of it yet known. To him again, we owe the first knowledge of the acid produced when the electric spark is taken for some time in common air: a fact which led afterwards to the knowledge of the constituents of nitric acid, which contributed so essentially to the establishment of the new chemical doctrine. He first discovered the great increase of bulk which takes place when electric sparks are passed through ammoniacal gas: a fact which led directly to the analysis of ammonia by Berthollet, who merely repeated Priestley's experiments.

Upon his philosophical writings the reputation of Dr. Priestley must rest; his theological opinions are most deservedly condemned, and his political tenets drew down upon him so severe a persecution, that in the riots which took place in Birmingham, in 1791, on the day of the anniversary of the French Revolution, his meeting-house, and dwelling-house were burnt: his library and apparatus destroyed; and many manuscripts the fruits of several years industry, were consumed in the conflagration. He escaped himself with difficulty, and such was the ferment against him, that nobody would let him a house: the members of the Royal Society refused to notice him, and he lived in a state of insulation: accordingly soon after the commencement of the last American war, he followed his sons who had emigrated thither, and there he died in 1804, after being only two days confined to his bed.

The great fault observable in the philosophical writings of Dr. Priestley is precipitancy, "and indeed" says his biographer Dr. Thomson, "from the way he went on thinking as he wrote, and writing only one copy, it was impossible he could be otherwise." But as he was perfectly sincere and anxious to obtain the truth, he freely acknowledged his mistakes as soon as he became sensible of them. The immediate and successful followers of Priestley, were Bergman, Scheele, Cavendish, and Lavoisier, a short sketch of each of which eminent men, I shall now proceed to give.

Torbern Olof Bergman, was born at Catherineberg, in the Swedish province of West Gothland, on the 9th of March, 1735, and obtained, after many difficulties, the permission of his family to devote himself entirely to the sciences. He is eminently distinguished as being almost the founder of the art of chemical analysis, and in his Essay on Mineral Waters, he points out with great precision the principal re-agents and precipitants useful in their examination: he then goes into a detail of the process to be adopted in minutely examining the nature of their contents, both gaseous and saline, and displays in his formula a surprising degree of ingenuity.

Bergman also wrote a splendid Dissertation on Chemical Attraction, and was the first to employ and recommend the *humid method of assaying;* he also published a table showing the relative weights of precipitates, procured in different ways from one hundred parts of metals, showing the fallacy of the prevalent opinion, that the relative weights of precipitates were in all cases the same, and proving that the difference of weights depends upon the different proportions of the precipitant contained in the precipitate, and upon the occasional retention of a portion of the solvent.

In 1774, Bergman read before the Royal Society of Sciences at Upsal, his Essay on Fixed Air, which he proves to be an acid, forming crystallizable compounds with alkalies, destroying at the same time their causticity; he gives a table of the electric attractions of fixed air, which, he says, appears to be the weakest acid known.

We are indebted to Bergman, for a knowledge of the characters which distinguishes nickel from other metals, and for the first good classification of minerals: he died in 1784, in his forty-ninth year, thoroughly exhausted by his exertions; he was succeeded in analytical Chemistry, amongst other men of eminence by Klaproth, Vauquelin, and Chenevix.

But it is not to his researches alone, that Chemistry is indebted to Bergman, he was the means of introducing to the science another of its brightest ornaments, Scheele, of whom he was the patron and disinterested friend. It has been said, that the greatest discovery of Bergman, was the discovery of Scheele, for he was the first to remark his promising genius and rising merit.

Scheele was born at Stralsund in 1742, of obscure parentage: his youthful days were spent in the house of an apothecary at Gottenburg, where, by perseverance and industry, he acquired a valuable stock of chemical information. In 1773 he removed to Upsal, where he accidentally became acquainted with Bergman.

The first publication of Scheele, was his "*Chemical Observations and Experiments on Air and Fire,*" in which he treats of the analysis of atmospheric air by solution of liver of sulphur, and certain other sulphureous compounds, which he shows abstract the empyreal part: and that upon adding to the residuary portion a quantity of empyreal air equal to that absorbed by the sulphureous liquor, an air similar in every respect to that of the atmosphere, is again compounded. He endeavours to prove that heat is a compound of empyreal air and phlogiston, and draws attention to the difference between heated air, and heat emanating in straight lines, or, as he calls it, radiant heat.

Scheele was the discoverer of dephlogisticated marine, or muriatic acid, chlorine, as it is now called, and his views relating to it, and the nature of the muriatic acid, are remarkably correct, if we substitute hydrogen for phlogiston. He first investigated the arsenic, and molybdic acids, and pointed out the difference between plumbago and molybdenum, proving the existence of iron and carbon in the former. His other contributions to Chemistry are Essays on fluor spar, arsenic of copper, (as a paint,) milk, and sugar of milk, and on Prussian blue, in all of which a very superior degree of talent is displayed. He died at Koping, near Stockholm, in 1786.

The Honourable Henry Cavendish was born on the 10th of October, 1731; he was a very eccentric character, and remarkably shy and bashful; but his talents were of the highest order, and his education very complete; he was an excellent mathematician, a profound electrician, and a most acute and ingenious chemist: our business is with the last qualification only.

The Chemical Papers published by Cavendish, contain five capital discoveries. 1st. The nature and properties of hydrogen gas. 2nd. The solution of lime in mineral waters by carbonic acid, and its separation by boiling. 3rd. The exact proportion of the constituents of atmospheric air, and the fact that these constituents never sensibly vary. 4th. The composition of water, (conjointly with James Watt). 5th. The composition of nitric acid. He was also the first person who showed that potash has a stronger affinity for acids than soda.

"The most splendid and valuable of Mr. Cavendish's chemical papers," observes his biographer Dr. Thomson, "are those two on air, published in the Philosophical Transactions for 1784 and 1785." The object of these was to determine what happened during the *phlogistication of air*, as it was at that time termed; that is, the change that air underwent, when metals were calcined in contact with it; when sulphur and phosphorus were burnt in it, and in several other similar processes. He showed in the first place that there was no reason for supposing that carbonic acid was formed, except when some animal or vegetable substance was present; that when hydrogen gas was burnt in contact with air, or oxygen gas, it combined with that gas and formed water; that nitrous gas combined with the oxygen of the atmosphere, and formed nitrous acid: and that when oxygen and azotic gases are mixed in the requisite proportions, and electric sparks passed through the mixture, they combine and form nitric acid. The first of these opinions occasioned a controversy between Mr. Cavendish and Mr. Kirwan, who had maintained that carbonic acid is always produced when air is phlogisticated. Two papers on this subject are published in the Philosophical Transactions by Mr. Kirwan, and one by Mr. Cavendish, each remarkable examples of the peculiar manner of the respective writers. All the arguments of Kirwan are founded on the experiments of others; he displays great reading and a strong memory, but does not discriminate between the merits of the chemists on whose authority he founds his opinions. Mr. Cavendish, on the other hand, never advances a single opinion which he has not put to the test of experiment; and never suffers himself to go further than his experiments will warrant: whatever is not accurately determined by unexceptionable trials, is merely stated as a conjecture upon which little stress is laid.

In the first of these celebrated papers, Mr. Cavendish has drawn a comparison between the phlogistic and the antiphlogistic doctrines, and has shown that each of them is capable of explaining the phenomena of Chemistry in a satisfactory manner: that it is impossible to demonstrate the truth of either; and he has given the reasons which induced him to prefer the phlogistic theory to the other, which the French Chemists were unable to refute, and which they were wise enough not to notice.

The talents of Mr. Cavendish are thus emphatically eulogized by one eminently qualified to form an opinion:— the late Sir Humphry Davy. "Cavendish was possessed of a minute knowledge of most of the departments of Natural Philosophy: he carried into his chemical researches a delicacy and precision which have never been exceeded: possessing depth and extent of mathematical knowledge, he reasoned with the caution of a geometer upon the results of his experiments: and it may be said of him, what perhaps can scarcely be said of any other person, that whatever he accomplished was perfect at the moment of its production. His processes were all of a finished nature; executed by the hand of a master, they required no correction; the accuracy and beauties of his earliest labours even, have remained unimpaired amidst the progress of discovery, and their merits have been illustrated by discussion and exalted by time."

Cavendish died on the 4th of February, 1810, in the 79th year of his age, leaving behind him the immense sum of nearly £1,300,000.

Anthony Lawrence Lavoisier was born in Paris, in 1743, of opulent parents, from whom he received a good education. He is celebrated in Chemistry as a Theorist, and as the introducer of a new nomenclature, which ended in the banishment of phlogiston: "Lavoisier must be regarded," says Davy, "as one of the most sagacious philosophers of the eighteenth century, indeed except Cavendish, there is no other inquirer, who can be compared with him for precision of logic, extent of view, and sagacity of induction. His discoveries were few, but he reasoned with extraordinary correctness upon the labours of others. He introduced weight and measure, and strict accuracy of manipulation into all chemical processes. His mind was unbiassed by prejudice; his combinations were of the most philosophical nature: and in his investigations upon ponderable substances, he has entered the true path of experiment with cautious steps, following just analogies, and measuring hypotheses by their simple relation to facts."

Lavoisier published his celebrated "*Elemens de Chimie,*" at Paris, in 1789, and an English translation of it with notes appeared soon after, by Mr. Robert Kerr.

It is divided into three parts. The first treats of the formation and decomposition of aëriform fluids; of the combustion of simple bodies, and the formation of acids. The second treats of the combinations of acids with salifiable bases, and of the formation of neutral salts; and the third is occupied with a description of the instruments and operations of Chemistry.

The following extracts from the preface will serve to show the *spirit* with which this important work was written. "When I began this work my only object was to extend and explain more fully the Memoir which I read at the public meeting of the Academy of Sciences, in the month of April, 1787, on the necessity of reforming and completing the nomenclature of Chemistry, but while I thought myself employed only in doing this, and while I proposed to myself nothing more, than to improve the chemical language, my book transformed itself by degrees, without my being able to prevent it, into a Treatise upon the Elements of Chemistry." Again, "The rigorous law from which I have never deviated, of forming no conclusions that are not fully warranted by experiment, and of never supplying the absence of facts, has prevented me from comprehending in this work, the branch of Chemistry which treats of affinities, although it is perhaps the best calculated of any part of Chemistry for being reduced into a completely systematic body, I thought it improper to involve those simple and plain elements, which I flatter myself the greatest part of my readers will easily understand, in the obscurities and difficulties which still attend that other very useful and necessary branch of the science."

Speaking of Elements, he says, "all that can be said upon the number and nature of elements, is in my opinion confined to discussions entirely of a metaphysical nature. The subject only furnishes us with indefinite problems which may be solved in a thousand different ways, not one of which in all probability is consistent with nature. I shall, therefore, only add upon this subject, that if by the term *elements*, we mean to express those simple and indivisible atoms, of which matter is composed, it is extremely probable that we know nothing at all about them; but if we apply the terms *elements* or *principles of bodies*, to express our idea of the last point which analysis is capable of reaching, we must admit as elements, all the substances into which we are able to reduce bodies by decomposition."

In answer to some objections that had been raised against his book, that he had not given an account in it of the opinions of his predecessors, but only stated his own; he says, "It is not the history of the science or of the human mind that we are to attempt in an elementary treatise. Our only aim should be ease and perspicuity; and with the utmost care to keep every thing out of view which may draw aside the attention of the student. It is a road which we should be continually rendering more smooth, and from which we must endeavour to remove every obstacle which can occasion delay."

In the third chapter of his Elements, Lavoisier describes his interesting experiments on the analysis of atmospheric air. He introduced into a matrass of thirty-six cubical inches capacity, four ounces of pure mercury, and having bent the neck he introduced its extremity under a bell-glass inverted over, and partly filled with mercury; he then heated the matrass till the mercury nearly boiled, and continued the heat for twelve days, at the end of which time finding no further calcination take place, the fire was extinguished.

The whole quantity of air in the matrass and bell-glass, at the commencement of the experiment was about fifty cubical inches, at the conclusion it was diminished to between forty-two and forty-three, one sixth had consequently disappeared; the remaining five-sixths Lavoisier found to be unfit for respiration or combustion. The quantity of calx of mercury produced amounted to forty-five grains; this he heated in a small retort, and in a few minutes after it became red hot it entirely disappeared; 41½ grains of running mercury were collected in the recipient, and 7 or 8 cubical inches of elastic fluid in the bell-glass. In this air a taper burnt with dazzling splendour, and charcoal threw out such a brilliant light that the eyes could hardly endure it. "This species of air was discovered" says Lavoisier, "about the same time by Dr. Priestley, Mr. Scheele, and myself," in saying which, it must be acknowledged that he did his distinguished English friend injustice, as he was perfectly aware of the priority of his claims to the discovery of this gas, *dephlogisticated air* as he named it.

Lavoisier considered all aëriform fluids as compounds of a ponderable basis, with caloric and light; in the experiment just described, the ponderable part of the dephlogisticated air unites to the mercury, but the union is effected so slowly, that the phenomena of combustion are not perceived: if however, red hot iron wire be introduced into the air evolved from the calx of mercury, it acts readily upon it, heat and light are emitted and the iron increases in weight.

He shows that one of the most general properties of dephlogisticated air, is to form acids, hence he gives it the name of *oxygen gas*: the other element of atmospheric air he calls *azotic* gas, from its fatal effects on animal life.

Lavoisier fell a victim to the sanguinary tyranny of Robespierre, in 1794, on the charge of being a conspirator, and of having adulterated the tobacco with ingredients obnoxious to the health of the citizens.

Among the eminent countrymen and fellow labourers of Lavoisier, in the celebrated reform of Chemical Nomenclature, we find the names of Guyton Morveau, Fourcroy, and Chaptal.

Guyton Morveau was born in 1737, and died in 1815. He was a man of extensive acquirements, and, as a chemist, of great ingenuity; besides the part he took in establishing the new nomenclature, he is deservedly celebrated as the inventor of the means of destroying infection by acid vapours, the efficacy of which he pointed out in 1773.

Fourcroy was born in 1755, and died in 1809. He is well known in the scientific world as the author of the *first* system of Chemistry, a work which was translated into English, with notes, by Mr. John Thomson.

Chaptal, Comte de Chanteloup, was born in 1756, and died in April, 1832, in the 76th year of his age. He was the author of many works on Chemistry; on the application of Chemistry to the arts; on the application of Chemistry to agriculture; and on the art of dyeing wool and cotton, &c. His Elements of Chemistry were translated into English by W. Nicholson.

We have now in chronological order, to give a brief sketch of the discoveries of a countryman of our own, a man inferior to none who have hitherto been mentioned in intellectual endowments, and who probably exceeded them all in the number and importance of his contributions to Chemistry, both philosophical and practical.

The late Sir Humphry Davy was born the 17th of December, 1778: he entered upon the Science of Chemistry as a branch of Medical studies, in December, 1797, when he just entered his nineteenth year; and as was the case with Priestley, Scheele, and many other distinguished men, his means being very limited, his first experiments were performed with the simplest apparatus, such as common Apothecaries' phials, wine-glasses, tea-cups, tobacco-pipes, &c., but so ardent was his pursuit of his new study, and so rapidly did he advance in it, that in less than four months from the time he took it up, we are told he was in correspondence with Dr. Beddoes on his researches in "Heat and Light". In 1799, his essays on these subjects were published together with others on Respiration, the Generation of Oxygen gas, and the causes of the colour of Organic Beings. In 1800, appeared his "Researches, &c. on the Nitrous Oxyd," a work which considering the age and circumstances of the author, must be considered as a wonderful performance, and contributed not a little to the advancement of Chemical Science.

In the February of the year following, Sir Humphry was elected assistant lecturer on Chemistry to the Royal Institution, and on the 31st of May, 1802, he was appointed Professor.

It was in the year 1800, that Volta made known his great invention of the Voltaic pile, and in the same year its remarkable effect in occasioning the decomposition of water was first noticed, by Messrs. Nicholson and Carlisle. Davy immediately saw the importance of this instrument, and set to work in the field of inquiry which it laid open. In 1801 he presented his first paper to the Royal Society, on "Some Galvanic Combinations, formed by the arrangement of single metallic plates and fluids, analogous to the galvanic apparatus of Volta," and in 1806, his first Bakerian Lecture, "On some Chemical Agencies of Electricity" was read; a paper, constituting as Dr. Thomson has remarked, "one of the most important contributions ever made to chemical philosophy," and for which a prize, founded by Napoleon, for the most important discoveries in galvanism, was awarded to the author by the Institute of France.

In 1807, Davy announced the decomposition of potash and soda, and proved that these alkalies are metallic oxydes, "Many vague and unfounded notions," says he, "had been formed of the nature and composition of this body, (the vegetable alkali). It had been supposed by some of the Italian and French chemists, to consist of lime and hydrogen; by others it had been regarded as containing nitrogen. The suspicion strongest in my mind was, that it might consist of phosphorus or sulphur united to nitrogen; for as the volatile alkali was regarded as a compound of an extremely light inflammable body hydrogen, with nitrogen, I conceived that phosphorus and sulphur, much denser bodies, might produce denser alkaline matter; and as there were no known combinations of these with nitrogen, it was probable that there might be unknown combinations. In my first trials on potash I used strong aqueous solutions,—dry potash is a non-conductor; I then employed *fused potash*, and in this instance inflammable matter was produced. Then a piece of potash moistened; and to my great surprise, I found *metallic matter* formed. October 6th. This matter instantly burnt when it *touched water*—swam on its surface reproducing potash. In dry oxygen gas it likewise burnt into perfectly dry potash. Soda was decomposed in the same manner."

In 1810 Davy demonstrated the nature of muriatic acid, and showed that what was called oxymuriatic acid, was really an undecompounded substance to which he gave the name of Chlorine.

In the Philosophical Transactions from 1815 to 1817, are his five celebrated papers relating to the Safety Lamp, which, together with his other discoveries, will be entered into at length in subsequent lectures.

In November 1820, Sir H. Davy was elected President of the Royal Society, which office he continued to hold for seven successive years, at the end of which time his health became much impaired, and in May, 1829, he terminated his memorable life at Geneva.

Of this celebrated Chemist two biographical Memoirs have been published, one by Dr. Paris, one by his brother Dr. John Davy, and his works are now being given to the public in a collected form by the latter, a series of interesting volumes, which ought, and probably will, find a place in the library of every lover of science.

I shall conclude this brief historical sketch, with one more notice, that of Dr. Wollaston, the contemporary and friend of Davy.

Wollaston was a philosopher of great ingenuity and exactness; it is to him we owe the promulgation in this country of the Theory of Definite Proportions and its important practical applications. He was the discoverer of Palladium and Rhodium, and the inventor of the method of rendering platina malleable, by which process he realized a large fortune; it was kept a secret till a short time before his death, when he made it known in the Bakerian Lecture to the Royal Society.

Wollaston died in December 1828, in the fifty-third year of his age.

I have thus endeavoured to give a concise outline of the rise and progress of Chemistry, which will not, I trust, be considered uninteresting, or out of place, as an introduction to the series of Lectures I am about to undertake; in these it will be my object to present to the general reader a popular view of the Science as it is at present: to describe some of the most important experiments and observations which have been made by various eminent individuals, since the period to which I have brought the history, to give a sketch of the new views that have been thereby developed, particularly in that most interesting but difficult branch Organic Chemistry, and to dress the whole in language as simple as the subject will allow, with a hope that something more than a mere interest in this grand branch of human knowledge may be excited, that it may stimulate some of those individuals who have time and means at their disposal to enter this richly extensive and fruitful field, the paths of which are in so inviting a manner opened to them.

LECTURE SECOND.

ON HEAT.

ITS UNIVERSALITY—CALORIC—THE TERM UNNECESSARY—OPINIONS OF DIFFERENT PHILOSOPHERS CONCERNING THE NATURE OF HEAT—PROPOSED DIVISION OF THE SUBJECT FOR DISCUSSION. FIRST.—EXPANSION—UNIVERSAL EFFECT OF HEAT—VARIABLE IN DIFFERENT BODIES—EXAMPLES—PRACTICAL APPLICATIONS OF THE LAW—THE PENDULUM—FAMILIAR INSTANCES OF THE EFFECTS OF EXPANSION—PRODIGIOUS FORCE EXERTED BY BODIES WHILST UNDERGOING EXPANSION FROM HEAT—INSTANCES. STATES OF EXPANSION OF METALS—WEDGEWOOD'S AND DANIELL'S PYROMETERS—EXPANSION OF LIQUIDS—SIMPLE METHODS OF PROVING—LAWS GOVERNING THE DILATATIONS OF LIQUIDS BY HEAT—REMARKABLE EXCEPTION TO THE GENERAL EFFECT OF HEAT ON LIQUIDS, EXHIBITED IN WATER—IMMENSE IMPORTANCE OF THIS DEVIATION—ILLUSTRATION—LAW OF DILATATION OF ÆRIFORM BODIES, DISCOVERED BY DALTON AND GAY LUSSAC—METHOD OF CALCULATION—RULES FOR REDUCING ANY GIVEN VOLUME OF GAS TO THE MEAN TEMPERATURE 60°—RULE FOR PRESSURE-THERMOMETER—AIR THERMOMETER OF SANCTORIO—MERCURIAL THERMOMETER—METHOD OF MAKING—RELATION BETWEEN THE THERMOMETERS OF FAHRENHEIT, CENTIGRADE, AND REAUMUR.—OUR NOTIONS OF HEAT VERY

LIMITED—TABLE EXHIBITING CERTAIN CIRCUMSTANCES IN THE RANGE OF TEMPERATURE. SECOND.—SPECIFIC AND LATENT HEAT.—ILLUSTRATIONS OF SPECIFIC HEAT—WATER POSSESSES THE GREATEST CAPACITY FOR HEAT OF ALL BODIES—IMPORTANCE OF THIS FACT.—METHOD OF DETERMINING THE SPECIFIC HEAT OF BODIES—SPECIFIC HEAT MATERIALLY AFFECTED BY DENSITY—INSTANCES—DR. BLACK'S DISCOVERY OF LATENT HEAT—HIS CELEBRATED EXPERIMENTS—DR. THOMSON'S EXPERIMENTS—QUANTITY OF HEAT REQUIRED FOR LIQUEFACTION.—THEORY OF FREEZING MIXTURES—TABLE OF INGREDIENTS—ICE NOT REQUIRED.—CONGELATION OF MERCURY.—EXTREME COLD PRODUCED BY THE EVAPORATION OF HIGHLY VOLATILE LIQUIDS, PARTICULARLY LIQUID CARBONIC ACID.

Of all the active natural agents concerned in producing chemical changes, *Heat* demands our first attention. Its effects are perhaps the most astonishing of any which nature exhibits; it is the grand principle employed by her in balancing the power and natural effects of attraction: it is every where present, and is continually altering or modifying every thing; without it, we should possess nothing but solid and compact bodies, and should see nothing of those varieties of consistence, under which they are now presented to our observation.

"The Chemist," says Dr. Lardner,* "in all his proceedings is beset with the effects of heat in aiding or impeding his researches. Now, it promotes the division of combined elements; now fuses into one uniform mass the most heterogeneous materials. At one time he resorts to it as the means of arousing dormant affinities; at another he applies its powers to dissolve the strongest bonds of chemical attraction. Composition and decomposition are equally attended by its evolution and absorption; and often to such an extent as to produce tremendous

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* See the Treatise on Heat in the Cabinet Cyclopœdia.

explosions on the one hand, or cold, exceeding the rigours of the most severe polar winter on the other."

It was proposed by Lavoisier, when he was engaged in his celebrated reformation of Chemical Nomenclature, to distinguish the *cause* of heat, or that exquisitely elastic fluid which produces it, by the name of *caloric*. In considering the effects of this agent, he was disposed to refer them to a real and material substance or very subtile fluid, which insinuating itself between the particles of bodies separates them from each other. This substance, whatever it may be, the *sensation* in other words, that we call *warmth*, being caused by its accumulation, could not he thought, in strict language be distinguished by the term *heat*, because the same name would then very improperly express both cause and effect. In a Memoir published in 1777, he gave it the names of *igneous* fluid, and *matter of heat*, but subsequently thinking it necessary to reject all "*periphrastic expressions*," which both lengthen physical language and render it less distinct, and which even frequently do not convey sufficiently just ideas of the object intended, he, in conjunction with, and with the approbation of Morveau, Berthollet, and Fourcroy, gave it the name of *caloric*.

There does not however seem any necessity for adopting this term. It is usual to speak of the heat of the sun's rays, and this form of expression seems to convey as clear an idea, as the *caloric* of the sun's rays. The *heat* which we feel is another equally common form of expression, which applies to the sensation produced, while the former use of the word marks the cause, whatever it be, that produces the sensation; now as there is no sort of ambiguity attached to either of these expressions, it is unnecessary to run the risk of creating any, by the introduction of a fresh term, which indeed implies that heat *is matter*, a fact which has never yet, and probably never will be proved.

Since then every thing that can be offered upon the subject of the nature of Heat, is mere hypothesis, I shall not occupy my readers with a recapitulation of all the arguments that have been advanced in support of its materiality on the one hand, and its immateriality on the other.

During the seventeenth century, from the time of Bacon to that of Newton, it was the fashion to refer the phenomena of heat to a property of matter, to a motion of a peculiar kind. Drs. Cullen and Black taught in their lectures the other doctrine, which from the popularity of these professors became in their time equally prevalent. Count Rumford in the beginning of the present century again reverted to the old opinion, and his example was followed by Sir H. Davy and Dr. Thomas Young, and some of the most popular writers on Chemistry.

Dr. Thomson thinks the first three effects of heat are best explained by considering heat as a substance. "Indeed," says he, "it is difficult to form any clear conception of them upon any other supposition. If heat be a peculiar substance, there is no difficulty in conceiving, how, by its entering into bodies, it increases their bulk, and how the bulk diminishes when it is withdrawn. There is no difficulty in conceiving how, much more heat may be requisite to produce a given effect upon one body, than upon another, or why the *specific heat* of different bodies is different, on the supposition that heat is a body; though if heat were mere motion, neither the property which it has to expand bodies, nor the different capacity of bodies for heat could be explained in a satisfactory manner. The radiation of heat admits of an equally simple explanation, if heat be a body; and so do fluidity and evaporation."

The last two effects of heat, namely, ignition and combustion, are thought by this celebrated Chemist, to derive a more satisfactory explanation from the other theory. It is difficult to give an intelligible explanation of the phenomena of ignition, without supposing that heat and light are mutually convertible into each other; and the phenomena of combustion; of the evolution of heat and light in cases of rapid combination, which have sometimes been considered as the result of the union of the opposite electricities, with which the bodies combining together were charged, and which at first sight appears plausible, are not, he thinks, sufficiently explained by it; since if chemical affinity be merely the consequence of different states of electricity, and if bodies unite merely because they are in different electrical states, it is clear that they could not continue united, unless these different electrical states were permanent. But, if the plus and minus electricity were to combine and fly off under the form of fire, there would be an end of the different electrical states which caused the bodies to unite, and, of course they would cease to continue united, which is contrary to matter of fact.

Combustion then is only to be explained on the supposition that heat is a property of matter, and since therefore neither view is sufficient to explain all the phenomena, it will be best to lean to neither; to acknowledge the problem as incapable of solution, at least in the present state of our knowledge.

In considering the effects of Heat as connected with our present subject, it will be convenient to divide them into five heads. First. The property of expansion. Second. Specific and latent heat. Third. Conduction and Transmission. Fourth. Radiation. Fifth. Ignition and Combustion. Under these heads, though I must of necessity be concise, I shall endeavour to give the substance of what is at present known and its practical applications.

First. The Property of Expansion. This is occasioned by the repulsion which exists amongst its particles, in consequence of which when heat enters a body, it tends to overcome that cohesion which operates amongst its integrant molecules, removing them to a greater distance from each other. The less the cohesive force, the greater will be the expansive effect of heat, as is exemplified in the three states, in one of which all matter must exist. In solids, the force of cohesion is great, and consequently, the expansion trifling; in liquids, the force of cohesion being much less, the expansion arising from heat is much more considerable; and in aëriform or gaseous substances, amongst the particles of which the force of cohesion is least of all, the expansion is by far the greatest.

There is no exception to the law of expansion by heat, it is universal, and as long as the chemical constitution of the body is unaltered, the dilatation increases with the quantity of heat that enters into it.

But different solids do not expand to the same degree from equal additions of heat, as may be shown in an interesting manner by the following experiment.

Fig. 1.

Fig. 2.

Fig. 3.

Take two bars, one of steel and the other of brass, (silver and platinum answer still better) and solder or rivet them together as shown in *Fig.* 1. Now put this compound bar upon a heated plate, the steel or platinum being uppermost, it will soon warp as shown in *Fig.* 2, in consequence of the expansion of the brass or silver, being greater than that of the steel or platinum; now reverse the experiment, and apply cold, and the bar will be found to assume an opposite curve, *Fig.* 3, in consequence of the greater *contraction* of the brass or silver, arising from the loss of heat.

Many useful processes of art, and important operations of nature depend on this law of Heat, and the knowledge of it suggests some very useful practical applications. The expansions and contractions of the metals by heat and cold form subjects of serious and careful attention to chronometer makers, as will appear from the following statement.

The length of the pendulum vibrating seconds in vacuo, in the latitude of London, (51° 31′8″ North) at the level of the sea, and at the temperature of 62° has been ascertained with the greatest precision, to be 39·13929 inches; now as the metal of which it is composed is constantly subject to variation of temperature it cannot but happen that its length is constantly varying, and when it is further stated that if the bob be let down $\frac{1}{100}$th of an inch, the clock will lose ten seconds in twenty-four hours; that the elongation of $\frac{1}{1000}$th of an inch will cause it to lose one second per day, and that a change of temperature equal to 30° of Fahrenheit will alter its length $\frac{1}{6000}$th part, and occasion an error in the rate of going of eight seconds per day, it will appear evident that some plan must be devised for obviating so serious an inconvenience: many very ingenious contrivances have been invented with various degrees of success, but we cannot spare the space to enter into a description of them here, especially since most of them depend on the unequal expansion of different metals, an illustration of which has just been offered.

Wood is occasionally used as a pendulum rod, but it is inconvenient from its liability to alteration from atmospheric changes. In the construction of the clock of the Royal Society of Edinburgh, a slip of marble is employed.

All the solid bodies with which we are surrounded, are constantly undergoing changes of bulk, corresponding to the variations of temperature; in cold weather they shrink and contract their dimensions, but when the temperature increases they expand, their dimensions become enlarged, and these effects vary with the materials.

It is well known that if we pour hot water suddenly into a glass tumbler, the chances are that it will crack, but if we cautiously warm the glass first, the probability of fracture will be much diminished; this arises from the imperfect conducting power of glass, and its consequent unequal expansion by heat, when the hot water is poured in, the bottom suddenly expands while the sides retain their usual dimensions, a separation is the consequence; but if the whole be previously warmed, the sides enlarge as well as the bottom, and no tendency towards separation is evinced.

It frequently happens, that the glass stoppers of bottles, become from long lying by, so firmly fixed as to render their removal by force, an almost certain means of destroying the bottle: this is an unpleasant circumstance that frequently occurs in the Laboratory. The property of expansion by heat may here with great success be called to our aid; glass, as has been observed being a bad conductor, heat may be applied to the neck, by a cloth dipped in hot water, by this means the neck will become enlarged, while the stopper will remain unaltered in size, it will become loose, and may then be easily removed.

The methods adopted by coopers in securing the staves of vats, barrels, tubs, &c. by hoops of iron put on while hot, and by wheelwrights in fastening the tires on the wheels of carriages, are familiar, and every day examples of the application of this property of heat.

Amongst solids, the metals are the most altered in dimensions by heat, and their rates of expansion are best known. Lead appears to be the most expansible metal, and platinum the least. The following table exhibits the elongation of some of the metals and flint glass, on being heated from the freezing to the boiling point of water.

Lead........	1 on 351	Pure gold...	1 on 682
Silver........	1 .. 524	Iron wire....	1 .. 812
Copper......	1 .. 581	Platinum....	1 .. 1167
Brass........	1 .. 584	Flint glass ..	1 .. 1248

It will be observed that the difference between platinum and flint glass is very trifling; of this a very useful application for chemical purposes is made. If we were to attempt to fasten wires of iron or silver by cementation into glass tubes, on cooling they would inevitably separate and become loose; because the heat has a greater effect on these metals than on glass, but platinum expanding and contracting in so nearly the same degree as glass, may be fastened with complete security; and it fortunately happens that this is the metal, which from its chemical relations is best adapted for chemical purposes.

The force exerted by bodies whilst undergoing expansion from heat, is prodigious. This principle was beautifully applied by M. Molard, some years ago, in Paris. The weight of the roof of the large gallery of the Museum of Arts and Manufactures exerted such pressure on the walls, that they progressively bulged outwards, and the stability of the building was endangered. The following plan was suggested, and put into execution by the above named able mechanic. A series of strong iron bars was carried across the building from wall to wall; passing through holes made for the purpose, and secured by nuts on the outside. In this state, the bars were heated by lamps fixed beneath them. They expanded, and consequently the nuts which were previously in contact with the walls were no longer so. These nuts were then screwed up, so as to be again in close contact with the walls. The lamps were withdrawn, and the bars now allowed to cool, they contracted, and drew the walls somewhat nearer together. The process was repeated several times, till the walls were restored to a perpendicular position.

This immense force of expansion is frequently called into operation, in cases where the common observer would little expect it. It is not an unusual thing to clamp the cope-stones of walls with bars of iron: such bars, if of cast-iron which is brittle, often break on the first frost from a tendency to contract, more than the stone will permit; if of malleable iron, they generally crush the stone and loosen themselves in their sockets. All metallic structures such as bridges, pipes for the conveyance of water, gas, &c., are subject to similar effects, and if the parts of such structures be firmly united, their unequal expansion may be productive of fracture, in the same manner as a glass is broken by hot water. When cast-iron pipes are employed to conduct steam or hot air through a factory, they are never allowed to abut against a wall or obstacle which they might in expanding overturn.

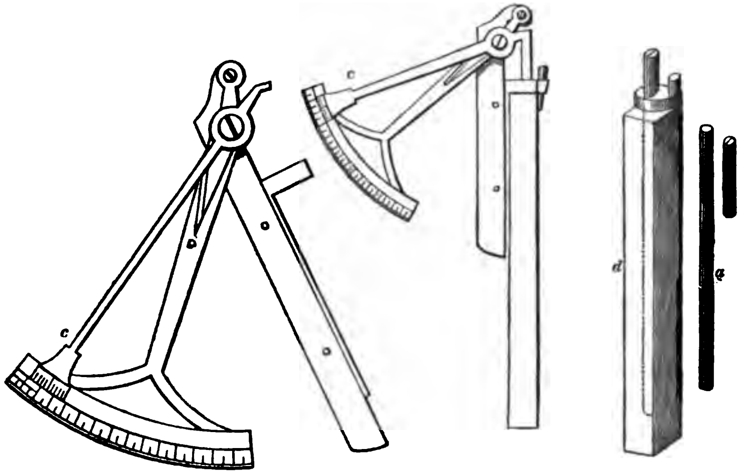
Dampers placed across chimneys to regulate the draught of air, are very apt to split, and thus occasion serious inconvenience in manufactories; by causing them to be made slightly curved instead of flat, an effectual protection is secured.

The unequal expansion of glass is frequently turned to good account in the laboratory; broken vessels may often be converted into very serviceable ones, by conducting a crack in a proper direction by means of an iron rod or a piece of tobacco pipe heated to redness; ample instructions for effecting this, are to be found in Faraday's invaluable "Chemical Manipulation," a work which ought to find a place in every laboratory.

Numerous instruments have been devised for measuring the intensity of Heat above the boiling point of mercury, by means of the expansion of solids. The first apparatus, pyrometer, as it is called, was that of Mr. Wedgewood. It depended on a peculiarity of clay, a certain species of which when raised to a very intense heat by means of a furnace, is observed to *contract* its dimensions, thus apparently offering an exception to the general law. It is *not* however an exception, for the reduced dimensions produced in the clay by the intense heat are *retained* when it is cool, nor is the constitution of the clay the same, it has lost water, which fluid, in consequence of its powerful attraction for the earth, is so intimately combined with it, as to be inextricable except by a very powerful heat. Wedgewood's pyrometer has been long out of use, it did not suit the refinement of modern Chemistry, being far too inaccurate.

Professor Daniell has invented a very valuable instrument which is shown in *Fig.* 4. It consists of a metallic bar *a*, of iron or platinum, which is contained in a tube of well baked black lead ware *d*. The metallic bar is shorter than the tube, and a short plug of earthenware is placed in the mouth of the tube above the bar, and so secured by a strap of platinum foil and a little wedge, that it slides with difficulty in the tube. The indications of the instrument depend on the difference in the expansion by heat, between the metallic bar, and the tube in which it is contained; when submitted to a high temperature the plug of earthenware is pushed outwards, by the superior elongation of the metallic bar, and remains in its new

Fig. 4.



position after its contraction on cooling, being retained in its place by the plug. The amount of expansion is measured by adapting to the instrument an index, *c*, which traverses a circular scale before and after the earthenware plug has been moved outwards. The degrees marked on the scale are in each instrument compared experimentally with those of the mercurial scale, and the ratio marked on the instrument, so that its degrees are convertible into those of Fahrenheit.

The superior expansive force of heat in liquids, is shown in a very simple manner, by putting the common thermometer into a jar of warm water, the dilatation of the liquid will be shown by its ascent in the stem; now, if mercury and glass, a liquid and a solid, underwent an equal degree of expansion from the same degree of heat, it is clear that no movement of the former in the stem would be perceptible, since, the glass bulb being enlarged, an additional space for the increased bulk of the mercury is provided, but we find that the fluid metal requires much greater space, and if it cannot get it, it will burst the bulb, hence in the common thermometer, we do not learn the exact amount of the expansion of mercury or spirit of wine, whichever it may be, from a certain quantity of heat, but the difference between the expansion of these liquids and the solids in which they are contained; we have the apparent not the *real* expansion. In the dilatation of liquids by heat, two general laws may be remarked. First. That the expansion is not the same in all liquids, some being much more affected than others. Second. That liquids are progressively more expansive at higher, than at lower temperatures.

With regard to the first law, it is found that on being heated to the same extent, spirits of wine are six times more expansible than mercury, and that the new liquids produced by the condensation of the gases, are characterized by an extraordinary dilatibility. Fluid carbonic acid was found by Thilorier, to be more expansible than air itself; heated from 32° to 86° twenty volumes of this liquid increase to twenty-nine, which is a dilation four times greater than is produced in air by the same change in temperature.

With respect to the second fact; all attempts to discover the law by which this progression is regulated have hitherto failed, mercury is less subject to variation than any other liquid, hence its value in the construction of the thermometer. If a fluid is heated from 32° to 122°, it will not expand as much as it would do in being heated from 122° to 212° though an equal number of degrees is added in both cases. In mercury the first expansion, according to De Luc, is to the second as 14 to 15; in olive oil as 13·4 to 15: in alcohol as 10·9 to 15; and in pure water as 4·7 to 15.

Some fluids are subject to this remarkable exception to the general effect of heat: namely, that at a certain temperature increase of heat causes them to *contract*, and its diminution makes them *expand*; water is a striking example; and presents a beautiful instance of the wisdom and benevolence displayed by the Great Creator, in adapting the properties of matter to the wants and conveniences of man.

Most liquids go on diminishing in bulk till they freeze, and get specifically heavier; not so water. This fluid obeys the usual law from its boiling point to the temperature of about 40°, after which the abstraction of heat produces *increase*, instead of diminution of volume, and at the moment of freezing it undergoes an increase amounting to one ninth of its volume, which sudden expansion is attended by the exertion of a prodigious force.

The consequence of this peculiarity is, that ice floats on the surface of water;—let us see how this operates in nature:—the cold season sets in, and the surface of our rivers and lakes become cooled by the contact of cold air and other causes. The upper surface of the water sinks, giving place to the warmer water from below, this in its turn becomes chilled, and sinks, and so on till the whole mass has arrived at about 40°, eight degrees above the freezing point, now, however the circulation ceases, the upper surface no longer sinks to the bottom, it expands as its heat diminishes, and remaining on the surface it becomes converted into ice, the imperfect conducting power of which, allows of a very feeble propagation of cold downwards, and the water therefore at a short distance below its surface, maintains an almost unvarying temperature of 40°.

Now, let us look at the inevitable consequences which any other arrangement would entail on us. If water continued to become heavier, until it arrived at the freezing temperature, the whole of it would be cooled to that point before ice began to be formed: and the consequence would be that the whole body of water would rapidly be converted into ice, to the destruction of every being that inhabits it. Our warmest summers would make but little impression on such masses of ice; and the cheerful climate which we at present enjoy would be less comfortable than the frozen regions of the poles.

Figs. 5 and 6, will perhaps serve to render this property of water intelligible. They are intended to represent two glass cylinders filled with water at 60°, *b b* are tin trays surrounding and closely fitting the exterior of each, *b* is fixed to the top of A *Fig.* 5, and *b'* to the bottom of A' *Fig.* 6. Both are filled with ice. Now the effect of the ice is found to be very different in these two cases; in both cylinders the temperature will be diminished by its first effect to 40°, but when the water in A *Fig.* 5 has reached this temperature, its lower parts remain stationary, while the surface continues to be affected by the cold, till it becomes converted into ice, at any rate till it reaches 32°. This case may be taken as an exemplification of a severe frost on a lake or river. But the action of the tray of ice reached the bottom of A' *Fig.* 6, is different, the water becomes cooled below its point of maximum density 40°, and consequently rises to the surface, from which the denser liquid descends, and so the circulation continues till the whole is frozen, or has reached the temperature of 32°, thus exemplifying what would take place in a lake, were it not for that exception to the general law of liquids, which has been stamped upon water by the fiat of the Almighty Creator.

Fig. 5 *and* 6.

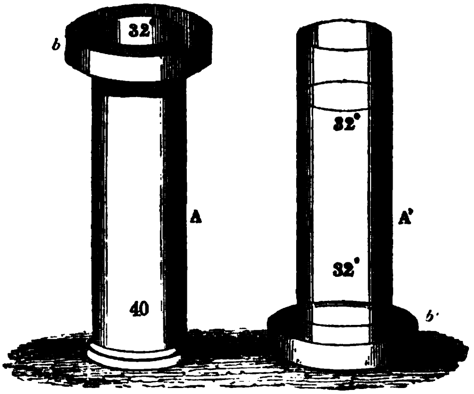
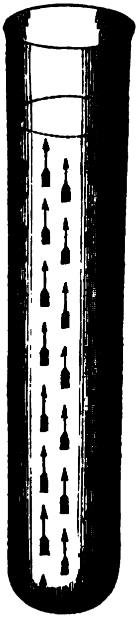


Fig. 7 represents an amusing experiment that may be made to illustrate the circulation of the currents of hot and cold

Fig. 7.



water, which takes place when heat is applied. A few particles of bruised amber may be thrown into a test tube of water, and the bottom gently heated. The arrows represent the solid particles rising from the centre of the bottom, and driving down the colder particles from the top.

Aëriform or gaseous bodies are in general of the three forms of matter, most affected by alteration of temperature, and unlike solids or liquids *are all affected alike*; so that when the expansion and contraction of one of the pure aëriform substances are accurately determined, we gain a knowledge of the expansions and contractions of all the rest; and this is to Chemists of the utmost importance, as will appear hereafter.

The law of dilatation in gases was discovered nearly at the same time by Dalton and Gay Lussac. From the experiments of the latter, it appears, that 100 parts of air in being heated from 32° to 212° Fahr: expand to 137·5 parts. The increase for 180 degrees is therefore 0·375 or $\frac{37\cdot5}{100}$ths of its bulk: and by dividing this number by 180, it is found, that a given quantity of dry air dilates to $\frac{1}{480}$th of the volume it occupied at 32°, for every degree of Fahrenheit's thermometer.

Having ascertained this, it is easy to find what volume any given quantity of gas should occupy at any given temperature. "Suppose a certain portion of gas to occupy twenty measures of a graduated tube at 32°, it may be desirable to determine what would be its bulk at 42°. For every degree of heat, it has increased by $\frac{1}{480}$th of its original volume, and therefore since the increase amounts to ten degrees, the twenty measures will have dilated by $\frac{10}{480}$ths. The expression will therefore be $20+20\times\frac{10}{480}=20\cdot416$. It must not be forgotten that the volume which the gas occupies at 32°, is a necessary element in all such calculations. Thus having 20·416 measures at 42°, the corresponding bulk for 52° cannot be calculated by the formula 20·416 + 20·416 $\frac{10}{480}$; the real expression is 20·416 + 20 $\frac{10}{480}$, because the increase is only $\frac{10}{480}$ths of the space occupied at 32°, which is twenty measures."—*Turner's Chemistry.*

The following rules for reducing any given volume of gas, to the mean temperature 60°, and the mean barometric pressure 30 inches, may be usefully inserted here.

Although the increase is not $\frac{1}{480}$th of the bulk at 60°, the proportion is easily ascertained by adding 28 (= to the number of degrees of the observed gas above 32°,) to 480, which producing 508, indicates that $\frac{1}{508}$th part of the bulk at 60°, is to be considered as the increase or diminution for every degree of change: because, supposing 480 parts of gas at 32°, at 33° they become 481 parts, and at 60° 508 parts, the increase being $\frac{1}{480}$th of the volume at 32°, and of consequence such part of the volume at any temperature, as is indicated by adding the number of degrees above 32° to 480°.

The rule is therefore:—

Add to 480, the number of degrees above 32°, divide the observed volume by this sum, this gives the expansion or contraction for each degree, at the observed temperature, multiply this number by the number of degrees between the observed temperature and that to which the gas is to be corrected, which will of course indicate the whole expansion or contraction; if the observed be above the corrected temperature, *subtract,* if below, *add* it: thus allowing for the contraction or expansion that would actually take place, if the temperature of the gas were really to be brought to the point to which by calculation it may thus be corrected.

For example—

To correct 100 cubic inches of gas at 70°, to the mean temperature 60°.

Difference between 32° and 70° = 38.

$38+480=518$ then $\frac{100}{518} = 0{\cdot}19305$ of a cubic inch = to the whole expansion for each degree, then,

$0{\cdot}19305 \times 10 = 1{\cdot}9305$ cubic inch = to the whole expansion, therefore

$100 - 1{\cdot}9305 = 98{\cdot}0695$ = to the volume the gas would occupy at 60°.

For temperatures below 60° the plan is the same, except that the whole expansion must now be added not subtracted.

Correction for pressure.

Compare the observed height with 30 inches, or the mean, and increase or diminish the observed volume inversely in the same proportion. Suppose 100 cubic inches to have been observed when the mercury stood at 30·7 inches, then:—

As 30 : 30·7 :: 100 : 102·333.

Suppose the mercury to stand at 28·9 inches.

As 30 : 28·9 :: 100 : 96·33.

Or to give a case more likely to occur in the laboratory.

Suppose twenty cubic inches standing over mercury in a jar the level of the fluid within, being three inches above that without, and the barometer at 29·4, then the three inches of mercury within the jar, counterbalancing three inches of barometric pressure, instead of 29·4, the latter is effectively only 26·4 and the correction will be

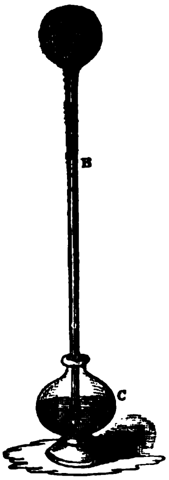
As 30 : 26·4 :: 20 : 17·6 c. i.

It is of no consequence which correction is made first, that for pressure or temperature; for example, one hundred cubic inches observed at 40° thermometer, 28 barometer, corrected first for pressure =93·33 c. i. then for temperature =97·158469 = to the true volume: or corrected first for temperature = 104·09836, and then for pressure, it becomes 97·158469 as before.

These details may appear somewhat dry, but it is hoped their importance will be a sufficient excuse for their insertion.

The first instrument that was devised for indicating variations in the intensity of heat, is usually ascribed to Sanctorio,

Fig. 8.



about the year 1590. It is called the air thermometer, and is shown in *Fig.* 8. It consists of a hollow glass globe attached to a long stem B, open at the opposite extremity. A portion of air is expelled from it by the expansive power of heat, and the end of the tube is then immersed in the vessel C, containing a coloured liquid, which is allowed to rise into the tube as the air contracts by cooling. When heat, that of the hand for instance, is applied to the bulb, the air in it is expanded, and depresses the column of coloured fluid in the tube. This instrument though extremely sensible to minute variations of temperature, is liable to the objection of being influenced by barometric changes of the exterior atmosphere.

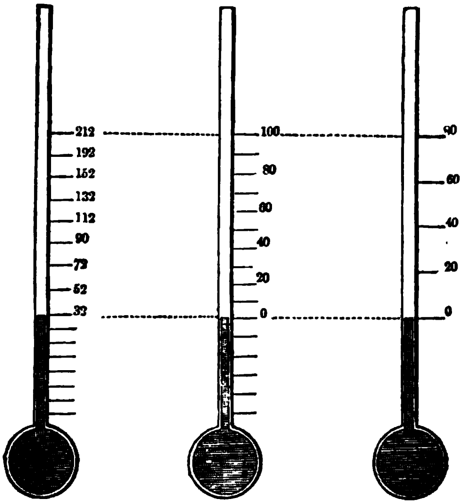
From this objection the mercurial thermometer is free, and is consequently the only one in general use; its construction requires very particular attention, and the total expulsion of atmospheric air by well boiling the mercury, in the bulb, is quite essential to its perfection.

The mercurial thermometer is graduated by first plunging its bulb into melting ice, and marking on the stem, the point to which the mercury falls, which is always uniform. This serves for a starting point; another fixed point is obtained by plunging the instrument into boiling water, by which the mercury will uniformly rise to the same height, provided certain precautions are attended to, the principal of which is, that the barometer be observed to stand at 29·8 inches when the boiling point is taken. The reason of this will be hereafter explained.

The space between these two points in the stem may be divided in any manner provided each degree is strictly the same, and the scale may be prolonged above and below these points, till the mercury boils or is converted into vapour, on the one hand, or frozen or solidified on the other.

There are however only three scales in use. Fahrenheit's, which is generally adopted in this country, in which the space between freezing and boiling is divided into one hundred and eighty equal parts: the Centigrade scale which is generally used over the continent, and in which the space is divided into one hundred equal parts; and Reaumur's scale, used in the North of Germany, in which it is divided into eighty parts. Of these, the second seems the most convenient, as it commences at 0, while in our scale from a whim probably of the inventor, but for no other assignable cause, the freezing point is fixed at 32° which brings the boiling point to 212°.

Figs. 9, 10, *and* 11.



Figs. 9, 10, and 11, show the relation between these scales, and the following rule may be useful for converting Centigrade degrees into degrees of Fahrenheit. Since one hundred degrees of the former, are equal to one hundred and eighty degrees of the latter, ten to eighteen and five to nine; multiply the Centigrade degrees by nine, and divide by five, and add 32, the result will give the corresponding number of Fahrenheit. Thus to find the degree of Fahrenheit, corresponding with 60° Centigrade.

$$\begin{array}{r} 60 \\ \underline{9} \\ 5\,\overline{)\,540} \\ \hline 108 \\ 32 \\ \hline 140 \\ \hline \end{array}$$

For measuring degrees of cold, below the freezing point of mercury, (— 39 F.) we must be guided by the contractions of spirits of wine, or alcohol, which has never yet been reduced to the solid state, by means of it 130 degrees below zero have been marked, and this is probably the lowest point to which we have descended, and we are consequently quite ignorant of the *real zero* of heat. The scale of temperature has been aptly compared to a chain extended both upwards and downwards beyond our sight. We fix upon a particular link, and count upwards and downwards from that link, and not from the beginning of the chain.

Professor Graham gives in his valuable Elements of Chemistry, now coming out in numbers, the following interesting circumstances in the range of temperature.

— 135°	Fahrenheit.	Greatest artificial cold.—Thilorier.
— 121°	..	Solid compound of alcohol and carbonic acid melts.
— 91°	..	Greatest artificial cold measured by Walker.
— 58°	..	Temperature of planetary space.—Fourier.
— 60°	..	Greatest natural cold observed by Ross.
— 55°	..	Greatest natural cold observed by Parry.
— 39°	..	Melting point of solid mercury.
— 70°	..	A mixture of equal parts of alcohol and water freezes.
+ 7°	..	A mixture of one part of alcohol and three parts of water freezes.

+ 20°	Fahrenheit.	Strong wine freezes.	
+ 32°	..	Ice melts.	
+ 50°	..	Medium temperature of the surface of the globe.	
+ 52°	..	Mean temperature of England.	
+ 98°	..	Heat of human blood.	
+ 150°	..	Wood spirit boils.	
+ 174°	..	Alcohol boils.	
+ 212°	..	Water boils.	
+ 442°	..	Tin melts.	
+ 594°	..	Lead melts.	
+ 662°	..	Mercury boils.	
+ 980°	..	Red heat.—	Daniell.
+ 1141°	..	Heat of a common fire.—	ditto.
+ 1869°	..	Brass melts.—	ditto.
+ 2233°	..	Silver melts.—	ditto.
+ 3479°	..	Iron melts.—	ditto.

Second. Specific and Latent Heat. It has been stated, that different solids and liquids undergo different degrees of expansion, from the same quantity of heat, we have now further to observe that equal bulks of different substances require the addition of different quantities of heat, to produce the same change of temperature.

The heat entering in this manner into the composition of various substances, is called their specific heat, and may be thus conveniently illustrated.

Take a pint of water at 100° and mix it with a pint at 50°, the thermometer will indicate the temperature of the mixture to be 75°, which is as might be expected, being the precise arithmetical mean: now mix a pint of mercury at 100° with a pint of water at 40°, and it will be found that the resulting temperature is not the mean 70°, but 10° lower, viz.—60°, so that the quicksilver will lose 40°, whereas the water will only gain 20°: notwithstanding which, it is clear, that the water has gained the whole heat that the quicksilver has lost. Hence water has a greater *capacity* for heat than quicksilver, or it requires a larger quantity of heat to raise it to a given temperature.

Again:—Take two similar glass bulbs, one containing water, and the other mercury, and immerse them at the same time in hot water, it will be found that the mercury bulb is heated up to the temperature of the water, in half the time that the water bulb requires; and if the two bulbs after having both attained the temperature of the water, be removed and exposed to the air, the mercury bulb will cool twice as rapidly as the other. All these experiments concur in proving that water has *twice* the capacity for heat that mercury possesses.

What is termed the specific heat of water, is not however to mercury as two to one. Since it is more convenient to express the capacities of different bodies with reference to weight than to measure, a pound of quicksilver at 40° agitated with a pound of water at 156°, produces a temperature of 152°3. The water thus losing only 3°7 of temperature, and the mercury gaining 112°3. Now 3°7 : 112°3 :: 0·033 : 1; consequently if water be taken as the standard of comparison as unity, the specific heat of quicksilver must be called 0·033, or, if which is more convenient, the specific heat of water be taken as 1000, then that of mercury will be 33.

Here we again have occasion to pause and admire the wisdom and benevolence of the Great First Cause, and to congratulate ourselves on the opportunities which science is perpetually affording us, of gaining distant gleams of the beauty and œconomy of the scheme of creation, opportunities which should be hailed with delight, and which ought to produce the effects for which it cannot be doubted we are permitted to learn them.

Water has of all bodies, whether solid or liquid, the greatest capacity for heat, and water covers four-fifths of the surface of our globe. What an immense magazine of heat is here! and how great and beneficial its influence in equalizing atmospheric temperature!

The most successful method of determining the specific heat of bodies, is to allow them to cool a given number of degrees, under circumstances precisely similar, enclosing them for instance in a highly polished vessel containing a thermometer, and standing under the exhausted receiver of an air pump. Dulong and Petit thus obtained the capacity for heat of the following substances.

Water....	1000	Iron.......	110	Mercury....	33
Sulphur...	188	Copper....	95	Platinum....	31
Glass.....	117	Zinc.......	93	Lead.......	29
		Silver......	56		

It must however be observed that it was ascertained by the same experimentalists in a very careful manner, that the specific heat of bodies increases as their temperature rises: so that it requires more heat to raise them a certain number of degrees when at a high, than when at a low temperature.

It may be shown also by familiar examples, that the capacity of bodies for heat, is very materially affected by their density. Suddenly compress a metal and it will become hot, because its capacity for heat is diminished; blacksmiths frequently light their fires in the morning by dexterously dealing a few heavy blows with a hammer on a piece of soft iron, the temperature of which becomes thereby sufficiently elevated to ignite a brimstone match. Indian rubber again becomes warm when stretched out, as may be proved by drawing it across the lip.

In fluids a very striking case is presented by mixing together sulphuric acid and water. It is found that sufficient heat is produced to boil water immersed in it in a test tube, and at the same time it may be noticed that the volume of the mixture is not the sum of the two fluids when separate, but less, showing a condensation to have taken place, which accounts for the diminution of capacity for heat. Alcohol and water present the same phenomena though in a much less degree.

Fig. 12.

In aëriform bodies an interesting case is presented in the fire syringe, *Fig.* 12, which is merely an air-tight tube of brass, to which is fitted a well packed and tight piston, the bottom of which is furnished with the means of retaining a piece of dry German tinder; on suddenly forcing in the piston, and compressing the air in the tube, sufficient heat is developed to ignite the tinder. It requires some little address to insure the ignition of the tinder, which is however soon acquired.

Persons who have ascended in balloons, have always experienced a diminution of temperature, increasing with the height; and on the other hand, those who have descended to great depths under the surface of the earth, in mines, have observed that the heat increases as they descend.

The cold on the summit of the Andes, although these mountains rise in the midst of burning plains, and almost under the line, is well known to be most intense, while the climate about half way up is genial and pleasant. These extraordinary differences in temperature, are well explained on the principles we have been adverting to; as the air becomes specifically lighter, which it does as it increases in distance above the earth's surface, its capacity for heat is increased, it therefore cools itself as well as the surrounding bodies; on the other hand, as it becomes specifically heavier, which it does as it increases in distance below the earth's surface, its capacity is diminished, and consequently heat is evolved.

High-pressure steam presents another remarkable instance of alteration in specific heat from change in density; a stream of it issuing from a small aperture into the atmosphere, instead of scalding feels scarcely warm to the hand held in it. Professor Brande gives also the following case in point. "A part of the machinery for working the mines at Schemnitz in Hungary, is a perpendicular column of water two hundred and sixty feet high, which presses upon a quantity of air enclosed in a tight reservoir. This air is consequently condensed to an enormous degree by this height of water, which is equal to between eight and nine atmospheres; and when a pipe communicating with this reservoir of condensed air is suddenly opened, it rushes out with extreme velocity, instantly expands, and in so doing it absorbs so much heat as to precipitate the moisture it contains in a *shower of very white compact snow*, which may readily be gathered on a hat held in the blast. The force of this is so great that the workman who holds the hat is obliged to place his back against the wall, to retain it in its position."—*Brande's Chemistry.*

It was mentioned in the last lecture, that the philosopher who first investigated the phenomena of latent heat, and who by the inquiry contributed so much to Experimental Philosophy, was Dr. Black, about the year 1757. Before this period, it was supposed that the state of fluidity was occasioned by the addition of a very small quantity of heat to a solid, when once raised to its melting point, and this was, primâ facie a reasonable supposition, it was also and with equal appearance of probability imagined that during the conversion, no greater addition of heat was received than the thermometer indicated.

It very frequently happens that facts which we have every day an opportunity of observing are disregarded however curious they may be, whilst those that occur rarely are much more likely to arrest our attention! In consequence of this craving for novelty, many highly interesting particulars escape us, till some master-mind, some philosophic spirit interposes, and opens from old materials, a new and extensive field of inquiry.

Thousands must have observed before the time of Black, that however cold ice may be, it soon becomes heated to its melting point when brought into a warm room, but that nevertheless it is a long time before it is entirely re-converted into water, and that a heavy snow always remains on the ground for a very long time after the breaking up of a frost, its reconversion into water being exceedingly gradual. Now, if the state of fluidity be occasioned by a small addition of heat to a solid raised to its melting point, the ice and snow ought to vanish presently, the heat continuing to be accumulated from the air around. This occurred to Dr. Black, who immediately set about inquiring what becomes of the heat that must keep continually entering the ice, without producing its liquefaction.

If a piece of ice be suspended in a warm room, the effect of the warm air, is rendered evident by the stream of cold air that constantly descends from it, and which may be felt on the hand. If the drops of water as they fall from it, be received on the bulb of a thermometer, the instrument will indicate the same temperature as the ice itself: viz.—32°.

Dr. Black made the following experiment:—He filled two similar globular glass vessels with water, one was afterwards frozen, and the other cooled as nearly as possible to the same point; they were then carried into a room the temperature of which was 47°, there being no other difference between them than that one contained water and the other ice. In half an hour the véssel containing the water had acquired the temperature of 40°; but in the other it required ten hours and a half to melt the ice, and to raise the water to 40°.

Now the access of heat being in both cases the same, and at the rate of 7° per half hour, it follows that in twenty-one half hours (the time required to thaw the ice, and elevate the temperature of the water to 40°,) it would have received $7 \times 21 = 147°$. The difference therefore between the increase of temperature in the ice, and water vessels, with equal accessions of heat is *one hundred and forty degrees*, which will express the quantity of sensible heat rendered *latent* by the operation of liquefaction.

The same number is brought out by other methods of experimenting. Equal weights of water at 32° and 212°, will, as we have shown before, produce on mixture the mean temperature of 122°: but equal weights of *ice* at 32°, and water at 212°, only produce after the ice has melted a temperature of 32°, the water loses 160°, while the ice acquires only 20°; now 160°—20°, gives 140° as before, for the quantity of heat expended in changing the ice to water; for the quantity of latent heat on which the fluid state depends. But this heat is not annihilated, although to the feeling, and to the thermometer it is insensible; this is proved by the following experiment, also made by Dr. Black. When the thermometer stood at 22° in the open air, he exposed two similar vessels, one full of water, and the other of brine, both at 52°; both lost heat till they were cooled to 32°, after which the brine (which does not freeze till cooled down to 4°) continued to lose heat without interruption, and gradually reached 22°, the temperature of the air, but the pure water remained stationary at 32°, when ice began very slowly to form; now, can any thing be plainer from this experiment, than that the reason of the water refusing all of a sudden to give out heat, is, that its temperature was maintained by the heat which it absorbed during its liquefaction, and which it slowly evolved during its conversion into ice?

Dr. Thomson has concluded from many experiments, that the quantity of ice which forms suddenly on the agitation of water, cooled down below the freezing point, bears always a constant ratio to the coldness of the liquid before agitation, and that from analogy it was probable, that for every five degrees of diminution of temperature below the freezing point, without congelation, one twenty-eighth of the liquid freezes suddenly on agitation. Therefore, if water could be cooled down twenty-eight times five degrees below 32° without congelation, the whole would congeal instantaneously on agitation, and the temperature of the ice would be 32°. Now, observes

Dr. Thomson, it deserves attention, that $5 \times 28 = 140$, gives us precisely the quantity of heat which, according to Black's experiments enters into the ice, in order to convert it into water. Hence it follows, that in all cases, when water is cooled down below 32°, it loses a portion of the heat which is necessary to constitute liquidity.

It is now seen why the point from which the graduation of the thermometer is taken, is always the same, the temperature of melting ice or snow never exceeding 32° Fahrenheit, and it also appears why snow and ice remain on the ground so long after the breaking up of a frost, for since water after being cooled down to 32°, cannot freeze till it has parted with 140° of heat, so ice, after being heated to 32°, cannot melt till it has absorbed 140° of heat, and hence we are spared from those overwhelming visitations of water, which would otherwise invariably attend the breaking up of severe frosts, attended with heavy falls of snow.

The quantity of heat required for liquefaction, is by no means the same for all substances, the following table exhibits the latent heat of a few, as determined by Dr. Irvine.

Sulphur	145°	Bees' wax	175°	Tin	500°
Lead	162°	Zinc	493°	Bismuth	550°

It appears also that solids admit of a variation in their structure and properties, from the assumption or loss of latent heat: sugar presents a very remarkable instance. If melted and allowed to cool to about 100°, and then while it is still soft and viscid, be rapidly and frequently extended and doubled up, till at last it consists of threads, the temperature of the mass quickly rises so as to become insupportable to the hand. Applying the thermometer, Dr. Graham found the temperature of a considerable mass to rise from 104° to 175° in less than two minutes. After the liberation of heat, the sugar on again cooling is no longer a glass, but consists of minute grains, and has a pearly lustre.

The loss of sensible heat in liquefaction is the basis of many artificial processes for producing cold. A table of convenient mixtures with the cold produced is given underneath.

Mixtures.	*Parts.*	*Thermometer sinks.*
Muriate of ammonia...... Nitre..................... Water....................	5 5 16	From 50° to 10°
Nitrate of ammonia........ Water...................	1 1	From 50° to 4°
Sulphate of soda........... Diluted sulphuric acid......	5 4	From 50° to 3°
Snow..................... Common salt..............	1 1	From 32° to 0°
Muriate of lime........... Snow.....................	3 2	From 32° to – 50°
Snow..................... Diluted sulphuric acid...... Diluted nitric acid.........	2 1 1	From –10° to –56°
Snow or pounded ice...... Common salt.............. Nitrate of ammonia........	12 5 5	From 18° to –25°
Muriate of lime........... Snow.....................	3 1	From –40° to –73°
Diluted sulphuric acid...... Snow.....................	10 8	From –68° to –91°

On looking at the fourth mixture, in the above table it will be seen, how dangerous is the common custom of sprinkling common salt on the snow lying on the stones at street doors; it is true the objectionable substance is thereby removed; but how injurious must be the diminution of temperature from 32° to 0° !

The ices that are used at table in summer are made by mixing roughly pounded ice, and salt together, and immersing the cream or other liquids to be frozen, contained in a thin metallic pan in the cold brine which is produced by the melting of the ice; but in the absence of ice, a very convenient substitute may be found in sulphate of soda, which dissolves in undiluted hydrochloric, (muriatic acid of the shops,) to a greater extent than in water, and the temperature sinks from 50° to 0°. The vessel in which the mixture is made, becomes covered with hoar frost, and water in a tube immersed in the mixture is speedily frozen.

The muriate of lime mentioned in the foregoing table, is used in its crystalline state, in which it is prepared, by dissolving marble or chalk in hydrochloric acid, and evaporating at a temperature of about 300° stirring it as it becomes dry, it is thus obtained in the form of a crystalline powder, being a combination of chloride of calcium with two atoms of water.

When it is attempted to freeze mercury, not less than three or four pounds of the materials should be employed. The metal is first cooled considerably by one portion, and then transferred into another, by which it rarely escapes being solidified.

By the evaporation of highly volatile liquids, fluid carbonic acid for instance, the most intense cold yet known is produced. Carbonic acid was first liquefied by Dr. Faraday, and Thilorier has constructed an apparatus, which we shall describe in the proper place, for obtaining the liquid acid in large quantities. When this liquid is allowed to escape from the reservoir by a small jet, a portion of it is frozen by its own evaporation, and forms a white soft mass like snow, which may be handled and does not evaporate very readily owing to its low conducting power, though its temperature cannot be more than −148°. With a little ether the solid acid forms a semi-fluid mass, by means of which mercury can be frozen in considerable quantities, and which if received on the hand occasions a very painful sore, which is very difficult to heal, and which is precisely similar in appearance and feeling to a burn.

LECTURE THIRD.

ON HEAT.

(CONTINUED.)

VAPORIZATION—STEAM—ITS IMPORTANCE AND PECULIARITIES—CONSTANCY OF THE BOILING POINT OF LIQUIDS UNDER SIMILAR CIRCUMSTANCES—LATENT HEAT OF VAPOURS.—BOILING POINT VARIES WITH THE ATMOSPHERIC PRESSURE.—ILLUSTRATION.—EVAPORATION AT LOW TEMPERATURES—NO SAVING OF FUEL.—SUM OF SENSIBLE AND INSENSIBLE HEAT OF STEAM THE SAME AT ALL TEMPERATURES.—ILLUSTRATION.—HEATING BY STEAM—STEAM ENGINE—SPONTANEOUS EVAPORATION—WOLLASTON'S CRYOPHORUS.—THE SAME LAWS OBTAIN IN THE FORMATION OF VAPOURS AT LOW, AS AT HIGH TEMPERATURES—HENCE THE COLD PRODUCED BY SPONTANEOUS EVAPORATION.—APPLICATION OF EVAPORATION IN THE ARTS—VAPOUR IN THE ATMOSPHERE—HYGROSCOPES—DALTON'S METHOD OF FINDING THE DEW-POINT—DANIELL'S AND MASON'S HYGROMETERS—DISTILLATION—LIEBIG'S CONDENSING TUBE—CONDUCTION—HEAT IS COMMUNICATED AMONGST THE PARTICLES OF SOLIDS IN A VERY DIFFERENT MANNER FROM ITS PROPAGATION THROUGH LIQUIDS.—DIFFERENCE OF CONDUCTING POWER IN DIFFERENT SOLIDS—TREVELYAN'S AND FORBES'S EXPERIMENTS.—RADIATION—EXPERIMENTS OF LESLIE—THE DIFFERENTIAL THERMOMETER—APPLIED

BY PICTET AS A PHOTOMETER—SOLAR AND TERRESTRIAL RADIANT HEAT—MELLONI'S EXPERIMENTS ON THE TRANSMISSION OF HEAT THROUGH TRANSPARENT BODIES—EQUILIBRIUM OF TEMPERATURE.—WELLS'S THEORY OF THE FORMATION OF DEW—CONDUCTION AND RADIATION PROBABLY REFERABLE TO THE SAME NATURAL LAW.—EXISTENCE OF A CENTRE HEAT.—CONCLUSION OF SUBJECT.

We now come to a very general and important effect of heat—evaporization, or the conversion of solids and liquids into impalpable aëriform matter, resembling common air in its mechanical properties.

The vapour of water, steam, is the most familiar example of this effect of heat, in this instance the increase of volume which accompanies the change of state is prodigiously great; a cubic inch of water expands into one thousand six hundred and ninety four cubic inches of steam, the same quantity of alcohol into six hundred and fifty nine cubic inches, and of ether into four hundred and forty three. The densities of these vapours are of course very different. Steam is lighter than atmospheric air, in the proportion of about ten to sixteen, but the vapours of alcohol and ether are much heavier. The specific gravity of the former being 1·61 and that of the latter 2·58. Air being one.

Numerous highly important facts have been discovered connected with the phenomena of vaporization, and particularly with the formation and peculiarities of steam, which, from its immense importance in the every day occurrences of life, is attended with an intense degree of interest; and as these Lectures are addressed more particularly to the uninitiated in science, it is presumed that no apology is required for going over this well explored ground somewhat in detail.

The high end and aim of science is to draw our attention to, and excite our admiration of the Almighty Creator, by unfolding some of the innumerable proofs of design and adaptation displayed in the properties he has conferred on matter, to show how fraught with importance peculiarities at first sight trivial and apparently accidental are, and to multiply the already immense collection of proofs that nothing is made in vain, and that man is endowed with reason and intelligence to enable him to trace relations and causes, and to draw from the rich and fertile soil of nature, riches, compared to which, gold and silver are but as dross, and to apply them to their destined uses.

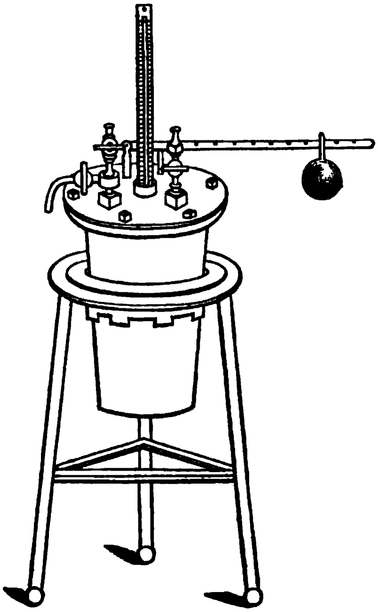
Look to every branch of civilized life, and see if you can find one, that is not indebted, deeply indebted to steam; look back to the times when its properties were unknown, compare them with the present, and see if you will not be obliged to admit that the vapour of water has been mainly instrumental in effecting those immense changes and improvements that will on all sides meet your eye, and then reflect that a few simple experiments, made with simple materials, but by an acute and powerful genius, were the foundation of these wonderful alterations, and refuse if you can to allow the triumph of reason, and the purpose for which it was given to man.

Now the first thing that arrests the attention in considering the properties of steam and other vapours, is the constancy under similar circumstances of the boiling points of the liquids from which they are produced, and the permanence of that temperature during the whole process of vaporization. Supposing a quantity of ice-cold water set over a steady fire, takes thirty minutes to reach the boiling point 212° F. barometer 29·8; it will take one hundred and fifty minutes to boil away entirely, the same heat being maintained, still it will not get hotter; apply the test of the thermometer at what time you will, and you will find the mercury will constantly rise to the same mark 212°, the barometer standing at 29·8 in.

There is then here an apparent annihilation of heat, but let us see if Dr. Black's theory of latent heat cannot usefully be applied in explanation; that it can, and that it is owing to the same cause as the conversion of solids into liquids, namely, to the combination of a certain dose of heat with a liquid without any increase of temperature, will appear from the following experiments.

First. In the experiment above alluded to, we suppose a certain quantity of water to be thirty minutes in rising from 32° to 212°, or 180°, and that it takes one hnndred and fifty minutes to boil entirely away; now the increase of temperature is in this case six degrees per minute, and it is perfectly reasonable to suppose that the same quantity of heat enters the water every minute during the whole operation, and is occupied in converting it into steam; if so, 6 x 150=900° will represent the whole quantity of heat which has entered the water, and become latent under the form of steam.

Fig. 13.



Second. If water be forcibly compressed in a Papin's digester, *Fig.* 13., it may be heated to 400° without boiling, but the instant the cock is opened, part of the water rushes out violently in the form of steam, and the remainder sinks to 212°; now as about one fifth of the water is converted into steam, that steam must contain not only its own 188° rendered latent by sinking from 400° to 212°, but also the 188° lost by the other four parts, or 188 x 5=940° of heat, the presence of which is not indicated by the thermometer.

Third. Water placed in a small thin glass vessel, surrounded with ether, and put under the receiver of an air pump, the air being suddenly drawn off, is frozen, while the ether enters into ebullition; here, it is plain that the vapour of the ether must carry off the heat from the water; and again, under similar circumstances, water, however hot, is soon reduced to the temperature of 70°, which shows that the heat must combine with the vapour and become latent.

It is now generally assumed that during the conversion of water into steam, as much heat disappears as is capable of raising one thousand times as much water by one degree: the experiments of Dr. Black gave 960° as the latent heat of steam; those of Mr. Watt 940°; and those of Lavoisier rather more than 1000°.

These experiments account then perfectly for the fact that the sensible heat of water does not alter during ebullition, and also for the progressive and steady nature of the process; were it not so indeed, and did it happen as was formerly imagined, that fluidity and vaporization are caused by small additions of heat to solids and fluids raised to their fusing and boiling points, a tea-kettle could not be placed on the fire without imminent danger, for immediately on the water reaching 212° the whole would burst into steam with terrific violence. This is in fact the case in the distillation of sulphuric acid, unless very great care be taken, for the specific heat of its vapour is very small, and it frequently happens that when it begins to boil, sudden explosions of dense vapour rush forth from time to time, exposing the retort to great danger of fracture.

If the process of boiling be attentively observed in a glass vessel, several instructive facts may be gathered. First. The air mechanically diffused through the liquid will be observed to pass off in the shape of minute bubbles; next, as the water gets hot, larger bubbles will be seen to form at the bottom, which rise higher and higher, getting smaller and smaller, till they disappear; as the water gets still hotter these bubbles rise higher towards the top, their motions get quicker, a bubbling agitation commences, and the water boils. These bubbles are steam. Now it will be further remarked that the steam as it rises in the neck of the flask is invisible, but as it issues from the mouth it presents a smoky appearance, which we are indeed in the habit of associating with it, seeing it issuing from the mouth of a tea kettle, urn, &c., but it must be observed that in these cases we see the steam *when it is beginning to be condensed,* and not in its pure form, and if the vapour as it rushes from the mouth of a tea-kettle boiling briskly, be attentively observed, it will be remarked that the smoky appearance does not present itself at the entrance of the spout, but some little distance from it, when it has mixed with a sufficient quantity of cold air to occasion partial condensation.

The temperature at which water boils, is marked on thermometers 212°, but it is by no means invariably at this point, being entirely dependent on the degree of atmospheric pressure to which it is at the time subject, and it cannot boil till its particles have acquired a degree of elastic force sufficient to overcome this pressure. Air though eight hundred and fifteen times lighter than water, exerts an enormous but constantly varying pressure upon the earth's surface. It has been calculated at about fifteen pounds to a square inch, or on the body of a man of ordinary size not less than fifty tons, though in consequence of the cavities of the body being filled with equally elastic air, counterbalancing this enormous weight, no inconvenience is felt.

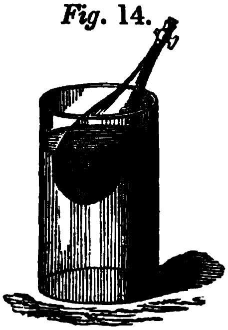
This atmospheric pressure is subject to a variation amounting to one tenth of the whole, which affects the boiling point of water to the extent of four and a half degrees. Thus, when the mercury stands at

	WATER BOILS.
27·74	208°
28·29	209°
28·84	210°
29·41	211°

	WATER BOILS.
29·8	212°
30·6	213°

It follows from this, that a difference in the boiling point ought to be found at heights above and depths below the surface of the earth, and this is the case. Saussure found that at the top of Mont Blanc water boiled at 187°, and an instrument has been devised by the Rev. Mr. Wollaston for ascertaining the heights of mountains on this principle. By it he found that an elevation of five hundred and thirty feet makes a diminution of one degree in the boiling point. The following interesting experiment will serve to show the influence of diminished pressure in facilitating ebullition. It consists of a Florence flask, *Fig.* 14, furnished with a stop cock; if a little water be poured into this vessel it may be readily boiled over a spirit lamp, and if, when the steam is freely escaping, the cock be shut, and the lamp removed, ebullition will soon cease, but on immersing it in a jar of *cold water* it will instantly recommence, and again cease on plunging it into another jar of *hot water*, presenting the apparently paradoxical phenomenon of water boiling by cold, and ceasing to do so by heat; on attending however to what takes place, we shall find the fact susceptible of easy explanation.

Fig. 14.



By the first application of heat, the air is expelled from the neck of the flask, and its place is supplied by vapour from the water, now, when the flask is immersed in cold water, the stop-cock being shut, the vapour is condensed, and a vacuum produced, beneath which the water boils at a very much diminished temperature; when however the flask is plunged in hot water, the vapour again rises, and exerting a pressure on the surface of the water prevents its boiling at so low a temperature; this vapour is again removed, a vacuum is again produced, and the water again boils on immersing it a second time in cold water, and the experiment may be repeated several times.

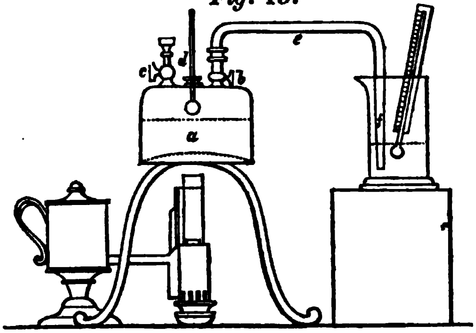
Of this property of liquids to become converted into vapours at low temperatures, under diminished pressures, considerable advantage is taken in the preparation of extracts for medical purposes. If the infusions from which they are prepared were boiled down in open vessels under atmospheric pressure, they would lose considerable portions of their active principles, this is avoided by conducting the evaporation in close vessels from which atmospheric air is removed. The manufacture of white sugar for which a patent was taken by Mr. Howard, is conducted on similar principles. The syrup is concentrated by being boiled in pans covered by air-tight lids, from which the air is extracted by pumps worked by a steam engine: the temperature required is only 150°, and the great advantage is the prevention of the browning or charring of the sugar, which is very apt to happen when the concentration is conducted under the usual pressure.

Now it may be imagined that there is also a great saving of fuel, in this plan of evaporating at low temperatures, but this is not the case, as was first ascertained by Mr. Watt.

It will be remembered that, it was stated in the last lecture, that steam under a high pressure when suddenly allowed to escape into the atmosphere, loses at the moment a great portion of its sensible heat, insomuch that the hand may be introduced into it with impunity; this is partly owing to its admixture with cold air, and partly to the greatly increased *specific heat of the steam* from the expansion it undergoes. Every variation of volume and elasticity in vapours, is attended with a change of specific heat, and consequent variation of temperature. When air confined within a bladder is suddenly dilated by means of an air pump, a thermometer placed within it will indicate the production of cold, and on the contrary, when air is compressed it causes an elevation of temperature in consequence of the diminution of specific heat, as was instanced in the last lecture by reference to the air syringe. Now, when water boils at a low temperature, its vapour is in a highly expanded state, and contains locked up within it a vast quantity of insensible heat, and the sum of the sensible and insensible heat contained in equal weights of steam is *exactly the same at all temperatures.* Steam at two hundred and twelve degrees, when condensed and reduced to thirty two degrees, gives out nine hundred and fifty degrees of insensible and one hundred and eighty of sensible heat, the sum of which is eleven hundred and thirty: the same weight of steam at two hundred and fifty degrees on being condensed and cooled to thirty two degrees, gives out likewise eleven hundred and thirty degrees, of which two hundred and eighteen are sensible and nine hundred and twelve insensible heat: whereas at one hundred degrees its sensible heat is only sixty eight, and insensible one thousand and sixty two degrees, forming the constant sum of eleven hundred and thirty degrees. The same is true of other vapours.—*Turner.*

Mr. Daniell has offered the following illustration of the fact, that the same weight of steam contains the same quantity of heat, whatever its density may be. "Let us imagine that in a cylinder furnished with a piston, we have a certain quantity of steam, and that it is suddenly compressed by a stroke of the piston into only half its bulk, without being reduced to the liquid state; it would acquire double elasticity, and its temperature would be increased. If we either suppose the cylinder incapable of transmitting heat, or take the moment instantly following the compression, before any heat has time to escape, it must be evident that the sensible and latent heat together *before* the compression, are precisely equal to the sensible and latent heat, *after* the compression, but in the dense steam the sensible heat is increased, and the latent heat diminished by equal quantities. Reversing this imaginary experiment, if we suppose only half the cylinder to contain steam at two hundred and twelve degrees, and the piston to be suddenly raised so as to double its volume, the density will of course be reduced to half, and its temperature will fall: but its sensible and latent heat together will remain unchanged." —*Introduction to Chemical Philosophy.*

Fig. 15.



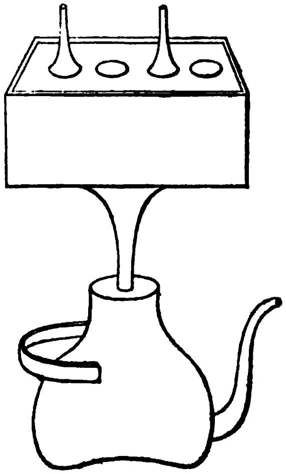
The small boiler shown in *Fig.* 15, will be found very convenient for illustrating in a small way the latent heat of steam.

The tube *e*, is screwed on the stop-cock *b*, and immersed into the glass of water *f*, containing a thermometer. The cock *c*, being closed, the steam arising from the boiling water *a*, will pass into the cold water *f*, the temperature of which will be much augmented by its condensation. Ascertain the increase of temperature, and weight, and the result will show how much a given weight of water has its temperature raised by a certain quantity of condensed steam. To another quantity of water of the same weight and temperature as that in the jar, at the outset of the experiment, add a quantity of water at two hundred and twelve degrees, equal in weight to the quantity of condensed steam: it will be found on comparing the resulting temperatures, that a given weight of steam has produced by its condensation a much greater elevation of temperature than the same quantity of boiling water. For example:—

Let one hundred gallons of water at 50°, be mixed with one gallon at 212°; the temperature of the whole will be raised by about one and a half degrees. Next, let a gallon of water be condensed from the state of steam in a still-tub containing one hundred gallons of water, and it will be found that the temperature will be raised eleven degrees, or nine and a half degrees more than it was by its mixture with a gallon of boiling water. If the heat imparted to one hundred gallons of water, by eight pounds of steam, could be condensed in one gallon of water, it would raise it to nine hundred and fifty degrees, and a gallon of water converted into steam of ordinary density, contains as much heat as would bring five and a half gallons of ice-cold water to the boiling point. The quantity of ice, that is melted by steam of mean density, is invariably seven and a half times the weight of the steam.

From the statement we have made relative to the vast quantity of latent heat in steam, its great use as a vehicle for the communication of heat to bodies, requiring an uniform temperature will become apparent: for heating extracts and organic substances it is much preferable to the open fire, all danger of empyreuma being avoided; for cooking food it has also of late years been much employed, for which purpose the steam is generally passed into a shallow tin box, in the upper surface of which are cut several round apertures of such size as exactly to admit the pans with the materials to be heated. The pans are then surrounded by steam, which condenses upon them with great rapidity, till their temperature rises within a degree or two of 212°. *Fig.* 16, represents a very simple and convenient arrangement for heating substances by steam in the laboratory. The lower vessel may be a common kettle, the handle of which folds down.

Fig. 16.



Sometimes the vessel to be heated is placed within another similar, but larger one, and steam admitted from a boiler between the two, this is the plan adopted by dyers for heating their indigo vats, for which purpose it is exceedingly convenient.

In applying steam to heat factories and dwelling-houses, it has been found by practice that the boiler must have one cubic foot of capacity, for every two thousand cubic feet of space to be heated to a temperature of 70° or 80°; and that of the conducting steam pipe, one square foot of surface must be exposed for every two hundred cubic feet of space to be heated.

Fig. 17.

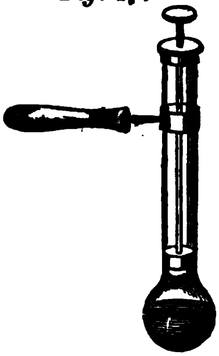


Fig. 17, is a little instrument devised by Dr. Wollaston, for conveying an idea of the application of steam in the old steam engines, where it was employed conjointly with the air's pressure as a moving power. It is a glass tube with a small enlargement at the lower extremity, held in a brass ring, furnished with a wooden handle, and having a piston fitted to it, with a hollow rod and screw at the top. When used, a little water is poured into the tube and boiled, the aperture in the piston rod being open; on closing the screw, and immersing the tube in the cold water, a vacuum is formed, and the piston descends, and on again boiling the water it is forced up, which alternate motions may be repeatedly performed by the alternate applications of heat and cold.

Mr. Watt has the imperishable honour of having greatly improved the construction and operations of the steam engine, and of rendering it available for the innumerable purposes to which it is in our time employed.

In Watt's engines steam is exclusively employed both for elevating and depressing the piston, but as my limits will not allow me to go into details on this interesting subject, I must refer my readers to some of the excellent treatises of Robison, Lardner, and others, and particularly to the Historical Eloge of James Watt, read at the public meeting of the French Academy of Sciences, by M. Arago, on the 8th of December, 1834, and recently translated into English by James Muirhead, Esq.

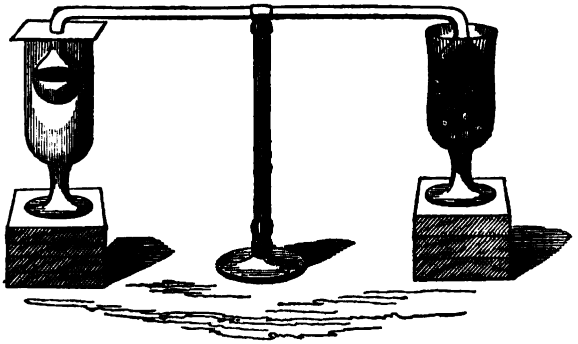
But it is not at their boiling points only that fluids undergo the change into aëriform bodies, they are, probably without any exception, continually giving off vapours at common temperatures. This process is called *spontaneous evaporation*: it takes place with a rapidity proportionate to the extent of surface exposed, the dryness of the air, the velocity of the current passing over it, the temperature, and the pressure.

In dry cold days in winter the evaporation is very rapid, but in summer though the air be many degrees warmer, if it contains much vapour, the evaporation is very slow.

The same laws which obtain in the formation of vapours at high temperatures, hold equally good in cases of spontaneous evaporation; there is the same passing of heat from a sensible to an insensible state, and the same absorption of heat: from this it follows that an appreciable degree of cold ought to attend all cases of evaporation, increasing in proportion to the rapidity of the process. That this is actually the case, any person may convince himself, by allowing a few drops of ether to evaporate from the hand, or from the bulb of a thermometer covered with lint, a strong sensation of cold will be felt in the one case, and measured in the other.

The same is very beautifully shown in the little apparatus represented in *Fig.* 18, contrived by Dr. Wollaston, and called by him the *cryophorus* or ice-bearer. It consists of two bulbs of glass, connected together by a long stem of glass; one of the bulbs is half filled with water which is boiled, till the included air is expelled by the generated steam through a small aperture in the other bulb, which is then sealed by a lamp. When cool the water in the bulb is greatly disposed to evaporate, but it can only do so to a certain extent, since the vapour produced, by its pressure soon prevents further progress. To get rid of this, and to keep up the vacuum the empty bulb is plunged into a freezing mixture which continually condenses the vapour within, the evaporation goes on unimpeded, and the cold produced is sufficient to freeze the water.

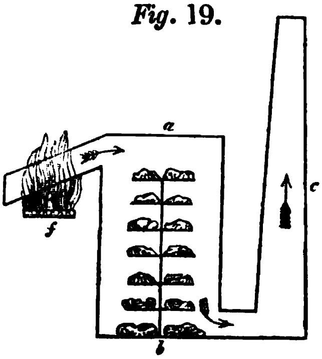
Fig. 18.



The conversion of water into vapour, and the condensation of vapour in the form of dew and rain, are processes of the utmost importance in the œconomy of nature, moisture is almost continually rising from the earth's surface, contributing very materially to the equalization of the temperature of the globe, and when this vapour by condensation in the upper regions forms clouds, it gives out its *latent heat*, the theory of the process being precisely the same where evaporation is slow and spontaneous, as when rapidly boiling.

In the arts evaporation is extensively used. It is sometimes found convenient to promote it by heating the surface of the liquid, or where solids which do not freely part with their moisture are to be gradually dried, the form of stove represented in *Fig.* 19, is found very useful in œconomizing the hot air, *a b*, is

Fig. 19.



a tight chamber having two apertures, one at the top, and another at the bottom, in this chamber the substances to be dried are placed on stages, and the hot air is admitted through *f*, and passes out loaded with moisture through *c*.

In hot climates ice is conveniently procured by having recourse to evaporation; for this purpose soft water previously boiled, is exposed in small unglazed earthen pots, in shallow excavations made in large open plains. The water is placed in these pans in the evening, and a part is usually found to be frozen in the morning, and is preserved by being deposited in pits surrounded by straw.

The methods of cooling wine by placing the bottles in unglazed and moistened pans, and exposing them to a current of air, or by wrapping them round with damp towels, as the travellers in the Arabian deserts are accustomed to do, and the refreshing coolness produced by sprinkling the curtains of beds in India with water, are all dependent on the absorption of heat which accompanies the change of liquid to vapour.

Hence also arises the great danger of sleeping in damp beds, and wearing damp clothes, by which the temperature so essential to the healthy performance of the bodily functions is very materially altered, inducing colds, agues, rheumatism, and a host of attendant ills.

From the Mediterranean sea the evaporation must be immense, it is the natural reservoir of all the water flowing from the Nile, the Danube, the Dneiper, the Rhone, the Ebro, the Don, and many other rivers; and as the only communication it has with the ocean is by the straits of Gibraltar, through which there is a never-ceasing *inward* flow of water, there must either be a strong under-current flowing *outwards* into the main ocean; or else the enormous quantity of water constantly supplied from these sources must be carried off by evaporation; and indeed the Mediterranean is extremely favourably situated for undergoing evaporation to a great amount, since the wind, whether it blows from the South, or from the

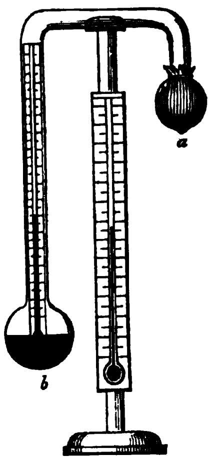
North, or from the East, has to pass over immense tracts of land, and is consequently in a state considerably below saturation with respect to moisture.

The atmosphere always contains more or less moisture, and various instruments have been invented for measuring the quantity, such instruments are called hygroscopes or hygrometers. The simplest kind consists of a piece of very thin whalebone, which in contracting or expanding by moisture, gives motion to an index. The aptness of this substance for such purposes may be seen by placing some thin shavings in the warm hand, they will instantly bend or crumple up; a still more delicate material is a human hair, which has boiled in alkaline ley, a hygroscope of this description was employed by Saussure.

The method adopted by M. Le Roi and Dr. Dalton, was so simple that it deserves description. It depends on the property of vapour to condense on bodies of a lower temperature than its own.

" When a bottle of wine is brought from a cold cellar, or a glass on a summer's day is filled with water fresh drawn from a deep well, it becomes dewed upon the surface. By pouring such cold water into another glass, then carefully drying the surface of the first, and returning it, and repeating the operations as often as may be necessary, the water becomes slowly warmer, and Dr. Dalton carefully marked with a delicate thermometer the temperature at which the dew ceased to form, and this he appropriately denominated the *dew-point.* It is in fact the temperature of water which would yield vapour of the precise elasticity of that upon which the observation is made: and all the relations of such vapours being known, the observation is applicable, with certainty, to the determination of every question that can be proposed concerning it. Even in winter time, or in very dry situations, a sufficient reduction of temperature may be produced in the liquid, by the frigorific effects of the solution of salts, to produce the effect of precipitation. The observation is rendered more precise by using small bright metallic vessels, upon the cool surface of which the dew is most visible."—*Daniell's Introduction to Chemical Philosophy.*

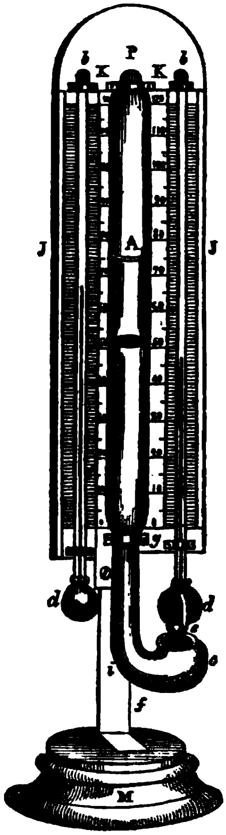
Fig. 20.



A very elegant and useful hygrometer was invented some years ago by Professor Daniell, and described in his Meteorological Essays: it has been very extensively used in all parts of the world. It is shown in *Fig.* 20: a glass tube terminating at either end by a bulb, is bent twice at right angles, and supported on a stand; *b*, contains a quantity of sulphuric ether, the air having been expelled by boiling, as in the cryophorus. It contains also a delicate thermometer, and a zone of the ball is gilt and burnished, so that the deposition of dew may be easily perceived. The other ball *a*, is covered with muslin. When about to be used, this ball is moistened with ether which by evaporation cools it, and enables it to condense the vapour of the included fluid, occasioning the vaporization of the ether in *b*. This ball consequently has its temperature gradually reduced, and the included thermometer shows precisely the degree at which dew begins to be deposited on the metallic part: and also by allowing it to get warmer, the degree at which the dew disappears; these points ought to be very near one another, and the mean between the two is the *true dew point*. The thermometer on the stem of the instrument, indicates the temperature of the air, at the time the experiment is made.

The instrument shown in *Fig.* 21, is a convenient contrivance of Dr. Mason, for estimating the opposite states of dryness and moisture, by measuring the degree of cold produced by evaporation, but mathematicians have not yet decided on the corrections to be applied for variations of pressure, tempera-

Fig. 21.



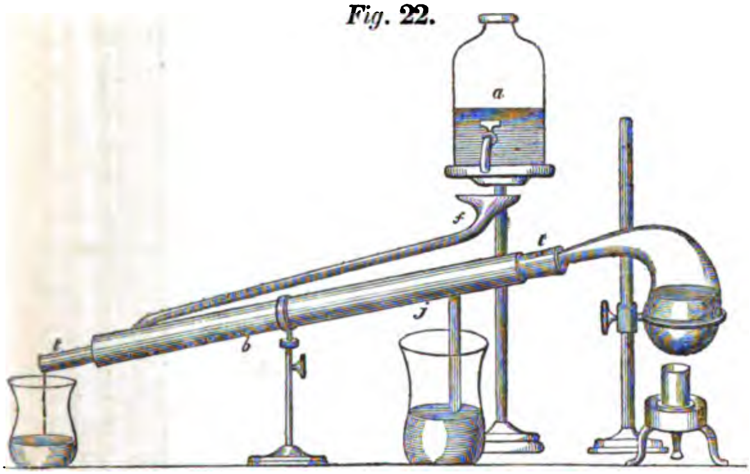
ture, &c., otherwise it would be decidedly superior to any other hygroscope. "An upright rod of brass *f*, is fixed on a stand M, and supports a scale JJ, in the middle of which a space is left for the glass tube A, formed on the principle of the bird fountain, having on each side of it a thermometer *b b*. The bulbs of these thermometers are covered with white silk, but round the stem of one, a thread of floss-silk, *e*, is attached, which terminates in the cup of the fountain, *c*. The bulb being thus in connection with a reservoir of water, is kept wet by capillary attraction: and as evaporation is constantly taking place, its temperature is rendered below that of the other bulb."

The process of condensing vapours into liquids is of perpetual occurrence to the Chemist, the principal objects to be attended to, are to keep the receivers as cool as possible, and to conduct the process in as steady a manner as possible, that the results may be uniform.

A most valuable apparatus has of late years been used by Professor Liebig, shown in *Fig.* 22, and called the condensing tube; of the merits of this simple contrivance, the Author can speak in the highest terms, as, since its introduction he has used it in his laboratory, to the exclusion of every other distillatory apparatus, for preparing nitric, and hydrochloric acids, rectifying alcohol, &c. &c. Its advantages are, first, its extreme cheapness; second, the small space which it occupies; third, the readiness of its application; and fourth and chiefly, its requiring little or no attention while at work.

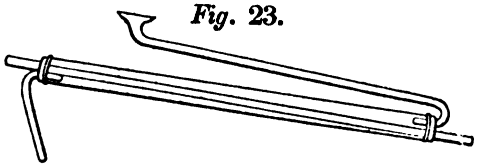
It consists of a plain glass tube *t t*, about eighteen inches in length, and two-thirds of an inch internal diameter, which is enclosed in a larger tube *b*, of brass or tin plate, about twelve inches long, and two inches in diameter, the ends of which are closed by perforated corks. A constant supply of cold water from a vessel *a*, (which may be a common gas holder) is introduced into the space between the tubes, being conveyed to the lower part of the instrument, by the funnel and tube *f*, and flowing out from the upper part by the tube *j*. The condensed liquid drops quite cool from the lower extremity of the glass tube, where a vessel is placed to receive it.

Fig. 22.



Both the outer and inner tube may be of glass, in the condensing apparatus, and the small tubes to bring and carry off the condensing water may be made to pass through openings in the corks which they fit, as shown in *Fig*. 23.

Fig. 23.



Let us now proceed to notice some other properties of heat; its communication by conduction and radiation. The manner in which heat is distributed through a liquid, as shown in *Fig.* 7, is altogether different from the manner in which it traverses solid bodies, in which the particles have not the same free and easy mobility amongst themselves. In liquids, the heated particles rise to the surface, displacing those which are colder and heavier; but in solids it appears that the relative position of the adjacent particles is not altered, and the heat is conveyed along them with a velocity differing considerably in different bodies, by a process called *conduction.* The best conductors of heat are the metals, next stones, next hard woods, and so on. The metals differ considerably from each other in conducting power as shown in the following table, in which some are compared with gold.

Gold	1000	Iron	374·3
Silver	973	Zinc	363
Copper	898·2	Tin	303·9
Platinum	381	Lead	179·6

Bodily sensation is a very imperfect method of estimating heat, almost every article we touch in a room, gives us a different idea of its temperature, though they are in reality all precisely the same: the carpet, woollen table cloth, and articles of this description feel warm, the wooden materials feel colder, the marble mantlepiece still more so, and the metallic fire-irons feel to the warm hand many degrees colder than either. These differences arise entirely from differences in the conducting power, those bodies in which this property resides most abundantly, abstract the heat most rapidly from our bodies, giving rise to a sensation of cold.

Some curious phenomena dependent on the property of conduction were observed by Mr. Trevelyan, and described in the third volume of the London and Edinburgh Philosophical Magazine. When certain metals having different temperatures, were placed in contact with each other, he noticed certain vibrations, occasioning particular sounds. Mr. Trevelyan made numerous experiments on the subject, and has given an illustrated description of the methods of operating to obtain the best results. The phenomenon was first noticed when he was about to spread with a plaster-iron some common pitch, when the iron being at too high a temperature, it was placed in a slanting direction against a block of lead, the handle resting on the table, a shrill high note was immediately heard, which continued some time.

The apparatus subsequently described by Mr. Trevelyan, in a paper read before the Royal Society of Edinburgh, are shown below. *Fig.* 24 is the block of lead, on the rounded surface of which the metallic bar to be tried rests; the block is screwed to a brass plate, having three small flat knobs to rest on. *Fig.* 25 is a ring, on which the bar may be placed. *Fig.* 26, is the bar as placed on the ring for producing the tone. *Fig.* 27, is the arrangement for exhibiting the vertical and lateral vibration. This vibration appears to depend on a certain repulsion existing between heated surfaces, increased in this case by the low conducting power of the lead, (see the last table) which allows its surface to be strongly heated by the brass.

Fig. 24.

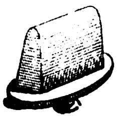


Fig. 25.

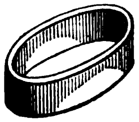
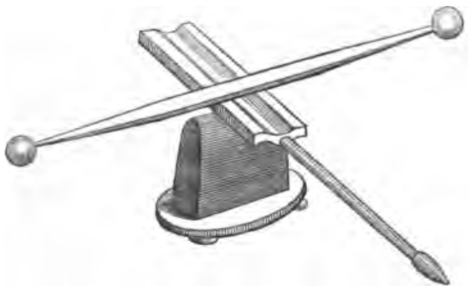


Fig. 26.

Fig. 27.



The subject has been very minutely examined by Professor Forbes, of Edinburgh. The fourth volume of the London and Edinburgh Philosophical Magazine contains his two papers, in which he has established the following general laws.

First. The vibrations never take place between bodies of the same nature.

Second. Both substances must be metallic.

Third. The vibrations take place with an intensity proportional (within certain limits) to the difference of the conducting powers of the metals for heat, (or electricity); the metal having the least conducting power, being necessarily the coldest.

Fourth. The time of contact of two points of the metals, must be longer than that of the intermediate portions.

Fifth. The impulse is received by a distinct and separate process, at each contact of the bar with the block, and in no case is the metallic connection of the bearing points on the bar, or those of the block, in any way essential.

Sixth. The intensity of the vibrations is (under certain exceptions) proportional to the difference of temperature of the metals.

It has been stated that the distribution of heat through a liquid, is effected by a process entirely different from its diffusion through a solid, it has indeed been doubted whether heat is ever conducted downwards through the former. Water contained in a glass tube may be boiled upon the surface, while the temperature of the lower part is hardly affected: aëriform fluids are still worse conductors, insomuch that a temperature of 300° may be endured without inconvenience; workmen are frequently obliged to enter stoves raised to this heat, which they do with impunity, provided they are careful to avoid touching anything of a metallic nature, by which they would be severely burned, indeed at so comparatively low a temperature as 120° metals cannot be handled comfortably, nor can the hand be held in water at 120° without pain. It is the same non-conducting property of gaseous bodies, that preserves the body in regions of excessive cold, at temperatures twelve or fourteen degrees below the freezing point of mercury. The following curious experiment will strikingly illustrate the same fact. Heat a bright silver or platinum capsule nearly to whiteness, then pour on it a small quantity of water: you will probably expect to see it boil violently away, it will not however do so, but, being protected by a stratum of vapour from actually touching the heated metal, it will roll about upon its axis, and slowly evaporate, without entering into ebullition at all, but if the temperature of the capsule be allowed to fall, the stratum of vapour will be removed, and the water will boil with almost explosive violence. Laundresses are perfectly acquainted with this fact, as appears from the methods which they adopt for ascertaining when their smoothing irons are sufficiently hot, though they are unacquainted with the cause.

If the hand be held above a red-hot iron, a sensation of heat will be felt, arising chiefly from the ascending stream of heated air, but not entirely from this cause, for if the hand be held below the iron, heat will be also experienced, though not in so great a degree. This arises from the emission of heat from the surface of the metal in the form of rays, which are found capable of passing through a vacuum, air, and certain other transparent media, with the velocity of light.

The Experiments of Sir John Leslie, published in 1804, completely prove the dissipation of heat by radiation from the surfaces of bodies even at low temperatures, though some important facts in relation to the subject were established many years ago by Scheele. Leslie filled a polished metallic vessel with hot water, and noted the time it took to cool a certain number of degrees; he then varied the surface of the vessel, by covering it with lamp black, &c. and showed in a striking and decisive manner, the *influence of surface* in the process. In one experiment the water in the polished vessel was one hundred and fifty six minutes in cooling half-way to the temperature of the apartment, and when coated with lamp black only eighty-one minutes, or little more than half the time. He afterwards found it convenient to employ metallic

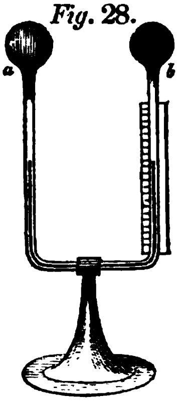


Fig. 28.

mirrors, to concentrate the heat by causing it to fall into a focus in which a differential thermometer, *Fig.* 28, was placed, by this means the slightest change in the temperature of the focal spot was immediately indicated, though no difference in the general temperature of the room was evinced.*

The following table shows some of the results at which he arrived with this apparatus.

	RADIATING POWER.		RADIATING POWER.
Lamp black.........	100	Tarnished lead......	45
Water by estimate...	100+	Clean lead..........	19
Writing paper.......	98	Iron polished........	15
Sealing wax........	95	Tin-plate, gold, silver, copper..........	12
Crown glass........	90		
Plumbago..........	75		

From this table we learn, that if we wish to retain the heat of a fluid as long as possible, we shall insure it, by confining it in bright metallic vessels, from which the heat is radiated at least eight times slower than if it were black; and again, that, when our object is to communicate heat to surrounding bodies, as apartments, through the medium of hot water, &c., the pipes conveying it should be roughened or coated with black pigment, such as lamp black. We also derive from the table an explanation of the fact, that tea is made so much better in bright silver tea-pots, than in those of porcelain or stone-ware,

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* The construction of the differential thermometer insures this. It consists of two bulbs *a* and *b*, the stem connecting which is bent twice at right angles; the bulbs contain air, and a small quantity of coloured sulphuric acid. When a hot body approaches one of the balls, the air is expanded, and forces the fluid towards the other ball; a scale is attached to the stem by which the degree of expansion may be measured. It is evident that when both balls are equally heated, no motion of the included liquid can take place.

and of the advantage of bright metallic covers at the dinner table.

In the above experiments it is absolutely necessary to employ reflecting mirrors of polished metal, those of glass being for these purposes entirely worthless, this arises from the absorbent power of glass, which, in consequence reflects but little heat, those surfaces which are the best radiators absorbing most and reflecting least, and vice versâ. It appears from the experiments of Dr. Bache, that the radiating power of any surface, is not affected by its colour, though its absorbent power is entirely so.

Some interesting experiments may be made with the Differential Thermometer, to prove the influence of surface in the absorption of radiant heat: if one of the balls be covered with gold leaf, and the other left naked, or covered with whitewash or lamp black; and a hot poker held midway between them, it will be found that by far the greatest effect is produced on the naked or coloured bulb, showing its superior receptive power: and again, to show the difference between solar and terrestrial radiant heat, and that the absorption of the former, depends, and is proportionate to, the intensity of the colour of the surface, let one of the balls be blackened, and the other whitened, and expose the instrument to the sunshine, the black ball will be most affected; so delicate is the thermometer in this state, and so susceptible is it of heat, that the mere impression of day-light affects it by slightly augmenting the temperature of the black ball, it has accordingly been employed by Pictet as a Photemeter or measurer of light; from experiments with it, he concluded that the light of the sun possessed twelve thousand times the intensity of a wax candle, so that a fragment of the sun, of the size of such a flame would possess the illuminating power of twelve thousand wax candles.

The difference supposed to exist between solar and terrestrial radiant heat, is probably apparent rather than real, arising in some degree from the immeasurable difference in the *quan-*

tity emanating from the sun, as compared with any thing that can be produced artificially.

The knowledge of the laws of radiant heat, suggests several useful practical applications; when the object is to absorb heat, rough unmetallic substances should be employed; fruit trees are trained against brick walls, because it is known that they are excellent radiators and absorbers of heat, giving out during the night, the heat which they had received from the sun's rays during the day. The only heat which we receive from the glowing coals in the common fire places, is communicated by radiation, as all the heated air ascends up the chimney, to the waste of a great quantity of fuel, the room is very unequally warmed, one part alone being comfortable, while all the rest is cold. The stoves lately brought into use, are, when properly constructed, very effective and œconomical; they contain an open fire as usual, and throw up a stream of warm air, heated by being made to pass from below, upwards, through a double casing surrounding all the heated parts of the grate. Of these new stoves, that invented by Mr. Richard Prosser, and sold by the Proprietors, Messrs. Rippon and Burton, 12, Well street, Oxford street, appears to be one of the most happy. It is called the Chunk stove, and its peculiar advantages are stated to be—its entire freedom from dust or smoke; its very great œconomy of fuel; and its perfect safety from fire. It has no door, and does not produce any of those unpleasant effects upon the atmosphere which have been experienced in the use of others. As there is no fire or heated substance in contact with the outer case of the stove, the surrounding air becomes warmed to a healthy degree, and from there being *no door*, the generated carbonic acid cannot pass into the apartment. It does not require much attention. The fuel (cinders or coke,) is conveyed to the stove in the bucket in which it is consumed, and all the ashes remain enclosed, until removed in it, without any raking and collecting, twenty-four hours afterwards—during which time it is not necessary to pay any attention whatever to the fire. It occupies very little space, being a cylinder of thirty three inches high and sixteen inches diameter. The cost of fuel will be about two pence for twenty four hours.

The proprietors have recently brought out another stove, which they call the Vesta; in principle it is the same as the Chunk stove, from which it differs merely in some mechanical arrangements, which the practical use of the latter suggested.

Within the last few years M. Melloni has acquainted us with several new and interesting facts relative to the transmission of heat through different media, his papers have been translated in the valuable " Scientific Memoirs," published by Mr. Richard Taylor.

It had been for some time known that whereas the heat of the Sun, passes without loss through any transparent body; the terrestrial radiant matter, emanating for instance, from a candle, or a lamp, or a fire, suffers, in such case, a kind of decomposition, a certain variable proportion only being allowed to pass, which increases as the temperature of the radiant body is elevated, the transparent medium becomes hot, while the temperature of the sun's rays makes it scarcely warm; the *light* however passes unimpeded in both cases, appearing to show, that in the case of terrestrial radiant matter the heat and light are very feebly combined.

Melloni, in his researches, made use of the thermo-electric pile* to detect changes of temperature; this delicate and beautiful instrument is shown in *Fig.* 29. It consists of an arrangement of thirty pairs of antimony and bismuth bars, contained in a brass cylinder, *t*, and having the wires from its poles connected with an extremely delicate magnetic Galvanometer, *n*. The extremities of the bars at *b*, being exposed to any source of radiant heat, such as the copper cylinder *d*, heated by the lamp *l*, while the temperature of the other extremity of the bars is not changed; a current of electricity passes through the wires from the poles of the pile, and causes the

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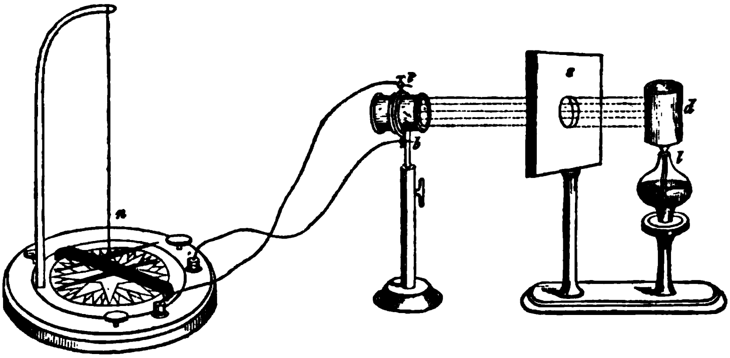
* See my Lectures on Electricity—Lecture Eighth.

magnetic needle of the Galvanometer to deflect. The quantity of electricity circulating increases in proportion to the difference of the temperatures of the two ends, that is, in proportion to the quantity of heat falling on *b*: and the effect of this current of electricity upon the needle, or the deviation produced, is proportional to the quantity of electricity circulating, and consequently to the heat itself,—at least, Melloni finds this correspondence to be exact through the whole arc, from zero to 20°, when the needle is truly astatic.—*Graham's Chemistry, page* 32.

Fig. 29.



With this apparatus, Melloni proved that at different temperatures, a body emits different species of rays of heat, which may be sifted or separated from each other by passing them through certain transparent media. They are all emitted simultaneously and in different proportions by flame: but in heat from sources of lower intensity, some of them are always absent. The calorific rays of the sun are chiefly of the kind which pass through glass, but Melloni shows that the other species are not altogether wanting. The rays of heat emitted by the sun, and other luminous bodies, are quite different rays from the rays of light with which they are accompanied.

Professor Forbes, of Edinburgh, has also greatly distinguished himself by his researches, on this part of the subject of heat, but I have no space to enter into even a brief analysis of his papers. They will be found in the Transactions of the Royal Society of Edinburgh. In February, 1836, the Keith medal was awarded to Mr. Forbes, by the Council of the Royal Society, for his Experiments, particularly those on the Refraction and Polarization of Heat.

The equilibrium of the temperature of the globe is brought about, in a great measure, by radiation. It is well known that a body however hot, will gradually cool down to the temperature of the surrounding objects; all bodies have a constant tendency to radiate heat, not only in a room, but from the surface of the earth towards the regions of space, and this radiation, as has been well remarked by Mr. Daniell, would, if it were not met and counteracted by the radiation from the sun, soon annihilate all organic beings by the rigour of an eternal frost. We are thus enabled to understand a remarkable experiment which may be made with reflecting mirrors. If a lump of ice be placed in the focus of one, and a delicate thermometer in the focus of the other, a diminution of temperature will be indicated, which was at first thought to prove the *radiation of cold.* But on the principle of radiation, the temperature of the thermometer is only stationary as long as it *receives* as much heat as it radiates, this it does not do, when placed opposite a lump of ice; in the focus of the second mirror, it radiates more heat than it receives, and thus its temperature falls.

The phœnomena attending the formation of dew, have been minutely examined by Dr. Wells, and he has shown in a beautiful and philosophical Essay, that they are referable to natural radiation. It must have been remarked by every person, that the most copious deposition of dew is during a clear, still, cloudless night, when the surface of the ground, in consequence of there being no counter-radiating source, has its temperature diminished many degrees (from ten to twenty) below that of the air above it; now as air is never free from aqueous vapour, and as the quantity which it can retain, depends on its temperature, the cold ground will condense a portion of the moisture contained in the warmer superincumbent air, and become covered with dew. It cannot fail likewise to have been remarked, that the grass-plat is far more copiously dewed than the gravel walk; now fibrous vegetable matters are much better radiators of heat than earth and stones, hence they become cooler during the night, as may be proved by laying a thermometer on each. If a piece of flannel, and a strip of tin-foil be exposed, the flannel will become quite wet, while the latter will be unaffected. So also the smooth varnished leaves of plants have no dew deposited on them, while the rough and downy leaves are covered, and hence more exposed to danger from frost. The effects of radiation from the earth's surface, during the night are well known to Gardeners, who frequently effectually protect young and delicate plants from cold during the night, by covering them loosely with matting: a thin cambric handkerchief, suspended by small sticks, some distance above the plant, will be found powerfully to retard the radiation of heat, and though any change of temperature arising from atmospheric causes could not, by this means be interfered with, nor the cold kept off, still, the escape of radiant heat from the surface, is prevented to a degree sufficient to protect the plant.

Dr. Wells appears to have been the first who remarked the influence of clouds in preventing radiation, and he found that, if the night, at first clear, becomes cloudy, the temperature of the grass always rises, independent of any changes of calmness, and nearly so of change of atmospheric temperature.

The method of making ice in hot countries, already referred to, depends probably more on radiation, than on evaporation, by which it is generally explained: the process succeeds best when the pans are placed in shallow trenches dug, in the ground, an arrangement which retards evaporation; and no ice forms in windy weather when evaporation is greatest.

Philosophers are now disposed to class conduction and radiation under the same natural law. Heat in its passage through a bar of iron is probably radiated from particle to particle, since it is known that the molecules of which it is composed are not absolutely in contact, but retained near each other by powerful attraction; thus, observes Professor Graham, "radiation as observed in air, or in a vacuum, may pass into conduction in the case of solids, without any breach of continuity in the natural law to which heat in motion is subject."

Lastly, with regard to the existence of a central heat in our globe, it has been demonstrated by Fourier, that though the crust of the globe were of cast iron, it would require myriads of years for the heat to be transmitted to the surface from a depth of one hundred and fifty miles; but the crust of the globe is composed of materials of far less conducting power than cast iron,—so that supposing it to be true, as is assumed, that for every mile beneath the earth's surface, an increase of heat to the amount of one hundred and sixteen degrees Fahrenheit is added, which would make the temperature at the depth of thirty miles and a half, equal to three thousand five hundred degrees, yet the surface of the earth would remain unaffected; there is every reason to believe that no material change in the quantity of heat it has received from the sun, has occurred during the historical epoch, and the temperature of the surface of the earth depends upon the amount of heat which it thus receives compared with the heat radiated away from its surface into free space.

I shall here conclude this short outline of our present knowledge of the laws and phenomena of heat, reserving the two last heads, Ignition and Combustion, for another lecture, after the gaseous substances concerned in their production have been described; in the mean time, let me request your particular attention to the next lecture, in which it will be attempted to give a popular account of the important laws of "Definite Proportions," and the Atomic Theory.

LECTURE FOURTH.

ON CHEMICAL AFFINITY; AND THE THEORY OF DEFINITE PROPORTIONS.

COHESION—DIVISIBILITY OF MATTER.—INSTANCES—IMPEDIMENTS AND AUXILIARIES TO CHEMICAL ACTION:—ASSISTED BY DIMINISHING COHESION, BUT ONLY TO A CERTAIN EXTENT.—IN GASEOUS BODIES REPULSION COUNTERACTS CHEMICAL ACTION:—IMPORTANCE OF COHESION IN CHEMICAL ACTIONS AND RE-ACTIONS.—BERTHOLLET'S VIEWS—EXAMINATION OF THEM—EXAMPLES—INVERSION OF AFFINITY SOMETIMES CAUSED BY COHESION—INSTANCES—BERTHOLLET'S THEORY NOT TENABLE.—INFLUENCE OF ELASTICITY ON CHEMICAL ACTION—INSTANCES—INFLUENCE OF QUANTITY OF MATTER—BERTHOLLET'S VIEWS DO NOT ACCORD WITH THE PRESENT STATE OF OUR KNOWLEDGE OF FACTS.—CIRCUMSTANCES CONTROL CHEMICAL ACTION:—CHEMICAL AFFINITY—PHŒNOMENA ATTENDING—EXAMPLES—SIMPLE AND COMPLEX ELECTIVE ATTRACTION—DECOMPOSITION—EXAMPLES—CORRECT TABLES OF AFFINITIES CANNOT BE CONSTRUCTED.—LAWS OF COMBINATION—TABLE OF ELEMENTS WITH THEIR SYMBOLS AND LEAST COMBINING PROPORTIONS:—CHEMICAL UNION OF TWO KINDS, UNLIMITED, AND LIMITED—THE LATTER THE MOST IMPORTANT—EXAMPLES—FIRST LAW OF COMBINATION—EXAMPLES—SECOND LAW—CHEMICAL EQUIVALENTS

—THE OXYGEN AND HYDROGEN SCALE—METHOD OF REDUCING NUMBERS OBTAINED IN ANALYSIS TO EITHER SCALE—EXAMPLES—TO THE UNION OF COMPOUND BODIES THE LAW OF COMBINATION ALSO APPLIES—INSTANCES—GREAT USE IN CASES OF MUTUAL DECOMPOSITION—EXAMPLE—METHOD OF DETERMINING EQUIVALENT NUMBERS—THIRD LAW OF COMBINATION—FIRST DETECTED BY WOLLASTON—EXAMPLES—THE USE OF SYMBOLS.—ILLUSTRATION.

The Science of Chemistry is now brought so completely under the dominion of *numbers*, that it would be useless for us to proceed further with our subject, before the important laws of definite combining proportions, and the beautiful Atomic Theory have been explained; and though the subject will require a little closer attention on the part of the general reader, it is hoped that its importance, and the facilities it will offer for the immediate comprehension of the remaining Lectures, will be considered a sufficient excuse for devoting a whole one to its elucidation.

We will first, however, direct our study to Chemical affinity, and the general results of Chemical action.

All the materials of which our globe is composed are held together by an invisible and mysterious power which philosophers have named cohesion. That this power differs considerably in different substances, we have abundant proof in the density and hardness of some, and the softness and porosity of others; it is most conspicuous amongst solids, less in liquids, whilst in gaseous bodies we have no evidence that it exists at all.

This power of attraction differs from the general and universal law of gravitation, in being exerted at insensible distances, it thus preserves the forms and modifies the textures of bodies, and it gives to liquids that spherical figure which we observe in drops.

By mechanical division we can diminish cohesion, but we cannot destroy it; the extent indeed to which this division may be carried in some substances is astonishing. It has been shown by Boyle, that an ounce of gold can be extended on silver to the length of one hundred and fifty five miles; and others have calculated that fourteen millions of films, such as exists on the wire would be required to make up the thickness of an inch, although an equal number of leaves of common printing paper would be nearly three quarters of a mile in thickness. Dr. Wollaston made a gold wire so thin that an ounce of it would extend fifty miles, and the metal itself is visible to the unassisted eye in so small a quantity as the hundred thousandth part of a grain; now although so remarkable and minute a mechanical division is here effected, we are far from having annihilated the cohesive power which retains the molecules of the metal in that state of close approximation from which solidity results, the hundred thousandth part of a grain consisting as essentially of an innumerable assemblage of molecules as the largest fragment, nor can we by any mechanical contrivances destroy that aggregation. Again, there is a substance produced by the action of sulphuric acid on indigo, which is called from its colour cerulin, when dry, this substance is copper coloured, but when wet intensely blue, one grain of this compound will communicate a blue tinge to five or six pints of water, it must therefore undergo a division which is almost incalculable without its cohesive power being destroyed.

Heat, as has been shown in a former lecture, is to be considered as the great antagonist to cohesion, as it never fails to overcome the barrier which that power presents to combination, especially when so regulated as to produce the state of liquidity.

In order that bodies should exert their chemical powers on each other, it is necessary that the particles should be brought into a close proximity, chemical action being like cohesion, exerted at insensible distances; hence it is, that Chemistry presents us with but comparatively few instances of intense action between solids; their chemical affinities may be very powerful, but combination cannot take place, because they cannot be brought within the sphere of their mutual attraction; when, however, either or both are in the state of liquid, the impediment to the exertion of affinity is removed, the cohesion of the particles of the substances concerned being so much diminished that the chemical forces prevail: thus, dry tartaric acid, and dry bi-carbonate of soda, however intimately they may be mixed by trituration will not combine; but if the acid be dissolved in a small quantity of water, and poured on the soda, it is well known that immediate action, accompanied by effervescence will take place, the acid and alkaline properties of the respective substances disappear, and a neutral salt, tartrate of soda is the result. It was formerly considered that it was absolutely necessary that one at least of the substances concerned should be in a liquid state before combination could take place; the researches in modern Chemistry have however revealed to us many instances which disprove this supposed general law: for examples:—when chlorate of potash and sulphur, or chlorate of potash and sulphuret of antimony are rubbed together, the mixture becomes rapidly decomposed and explosion ensues. When fulminate of silver or iodide of amidogen, are even slightly touched, detonation follows. In these cases, the original arrangement of particles must have been so unstable that the imperfect approach produced by mechanical mixture, or the slight change of position arising from a sudden shock is sufficient to cause a new mode of combination.

To insure the full exertion of the power of chemical affinity, *all* the substances concerned should, if possible, be reduced to liquidity; no impediment will then exist, and if, after intimate mixture, no action should ensue, it may with almost certainty be concluded, that no affinity exists between them.

Now it might be supposed that, since chemical affinity is so much assisted by diminishing cohesion, when that power is altogether wanting, as it seems to be in gaseous bodies, the action between substances disposed to combine ought to be immediate and intense; this is not however the case, and although instances are not wanting, in which the union of gases does take place, without any further influence than their own attractive powers, (chlorine and ammonia for example,) yet the contrary is most commonly the case; oxygen and hydrogen, and chlorine and hydrogen, elements amongst which there is the strongest affinity, the former giving rise to water, and the latter to hydrochloric acid, may be kept in contact for any length of time without combining, which evidently arises from the particles not being brought into sufficiently close contact. Indeed the tendency to assume the aëriform state, frequently offers great assistance to decomposition in compounds; this is particularly observable in those substances which have a powerful attraction for water; clay, for instance, from which that liquid can only be expelled by giving it the gaseous form by intense heat; chloride of nitrogen again, is remarkable for its facility of decomposition, being resolved into chlorine and nitrogen.

Although cohesion is thus shown to be an impediment to the exertion of chemical action in the general sense, it is of the highest importance to the Chemist, in many instances determining the result of chemical action, probably sometimes, in direct opposition to affinity, serving, on the principles of Berthollet, to explain the anomalous discordance between those experiments on which the tables of affinities of bodies for each other had been constructed.

To set this matter in a clear point of view, suppose a quantity of sulphate of soda and nitrate of potash to be dissolved in water, each acid is attracted at the same moment by both bases, and each base by both acids; so that there occurs a division of each acid between the two bases, and of each base between the two acids, and the solution contains the sulphates and nitrates of soda and potash. While the solution remains diluted, this distribution of acids and bases holds good, but if the liquor be much concentrated, the sulphate of potash being but sparingly soluble will separate in crystals and a fresh arrangement will be entered into, and thus finally all the sulphuric acid and all the potash will be removed and nothing left in solution but nitric acid and soda.

In this case, if we regard the chemical affinities of potash and soda, of sulphuric and nitric acids as exactly equal; the decomposition which actually occurs on concentration is determined entirely by the greater cohesion of the sulphate of potash and its consequent sparing solubility.

It is, however, a question, in the case of a mixture of various soluble salts, whether each acid is confined to one base, or whether each acid is divided between the various bases. When the relative forces of affinity are not very unequal, the latter arrangement seems the most probable, and the one which gives the most plausible theory of the constitution of mineral waters and of the products which they yield by evaporation. In accordance with this view, when two acids and two bases meet together in neutralizing proportion, each acid unites with both bases in a manner regulated by their respective forces of affinity and four salts are contained in solution. In like manner, the presence of three acids and three bases will give rise to nine salts; and when four of each are present, sixteen salts will be produced.—*Turner.*

The influence of cohesion in determining the result of chemical action will now appear. It is strikingly shown on mixing in solution sulphuric and nitric acids and baryta; at first this base may be supposed to be divided between the two acids, nitrate and sulphate of baryta being produced; but sulphate of baryta is absolutely insoluble in water, and is consequently instantly removed from the sphere of action: and the base becomes again divided between the two acids, a fresh quantity of sulphate of baryta is generated and removed, and this goes on till either the whole of the baryta, or the whole of the sulphuric acid is withdrawn; precisely the same phœnomena occur on mixing sulphate of soda in solution with nitrate of baryta, and indeed any soluble sulphate is instantly decomposed, on bringing into contact with it any solution of baryta, which substance becomes, in consequence, the most valuable test of the presence of sulphuric acid with which chemists are acquainted.

Other cases occur in which the separation of the least soluble ingredients takes place gradually; as for instance, during the evaporation of hard water, which generally contains soda, hydrochloric acid, lime, and sulphuric acid. The soda we know to be the stronger base, and the sulphuric the stronger acid, yet on evaporating the water, the salt which first crystallizes is sulphate of lime, and on continuing the evaporation, all the sulphuric acid may be removed in combination with the lime. But the acids and bases being divided among one another in solution, there coexist sulphate of lime, sulphate of soda, muriate of lime, and muriate of soda. But when the liquor is concentrated, the sulphate of lime is first deposited, and a new quantity being formed all its constituents are eliminated in combination.—*Kane.*

We have even instances, in which an actual *inversion* of affinity is occasioned by cohesion, both in double and single decompositions. As an instance of the former, on mixing solutions of carbonate of ammonia and nitrate of lime, there are formed nitrate of ammonia and carbonate of lime; and as an instance of the latter, on passing a stream of carbonic acid into a solution of acitate of potash in alcohol, the salt is decomposed, acetic acid being set free and carbonate of potash being formed: this is a very striking example, there being no doubt whatever that acetic acid is a much stronger acid than carbonic, since, on adding vinegar to carbonate of potash acetate of potash is formed, and carbonic acid set free in a gaseous form; the formation of carbonate of potash in the above experiment is evidently therefore entirely caused by its insolubility in alcohol. But we are in possession of facts which show that double decomposition sometimes occurs on mixing salts, although no *precipitation* supervenes. For instance:—sulphate of copper is well known to possess a beautiful blue colour, and to communicate the same to water in which it may be dissolved; now, on mixing a solution of this salt with a solution of chloride of sodium or common salt, the colour of the solution changes from blue to green, indicating the formation of chloride of copper, and consequently that of sulphate of soda also, but we know, in this case, that hydrochloric acid will displace sulphuric acid from sulphate of copper, at the temperature of the experiment, while sulphuric acid will, on the other hand displace hydrochloric acid from chloride of sodium; thus, those acids and bases which have the strongest affinity for each other are proved to enter into combination.

The opinion of Berthollet, however, that acids and bases when mixed togther in solution arrange themselves, so that each base shall be divided amongst all the acids, and each acid amongst all the bases, although in a great many cases true, and indeed one of the most fruitful sources of the decompositions which occur in our experiments, cannot be admitted as a true representation of the actual phœnomena of combination, since it makes decomposition, at all times dependent upon accidental circumstances, such as the volatility and insolubility of the product, and never resulting from the prevalence of certain affinities over others; in short, since it neglects the consideration of affinity altogether. It makes the resulting actions between bodies in contact to depend upon their relative quantities or masses, and the physical properties of the products of their combination, to the entire exclusion of the agency of the proper affinities between the bodies in contact.

According to Berthollet, no decomposition should be complete unless the product be volatile or insoluble; but one experiment will suffice to show that this is not necessarily the case, and that a body may be separated completely from a compound and supplanted by another body, although none of the products are removed by the operation of either of the causes specified, but all continue in solution and in contact with each other. The salt borax, which is a borate of soda, is entirely decomposed by the addition to its solution of a quantity of sulphuric acid, not more than equivalent to its soda, although the liberated boracic acid remains in solution; for the liquid imparts to the blue litmus paper, a purple or wine-red tint, which indicates free boracic acid, and not that characteristic red tint, resembling the red of the skin of the onion, which would inevitably be produced by the most minute quantity of the stronger acid, if free. But if the borax were only decomposed in part, in these circumstances, and its soda equally divided between the two acids, then free sulphuric as well as boracic acid should be found in the solution. The complete decomposition of the salt can be accounted for in no way but by ascribing it to the higher affinity of sulphuric acid for soda, than that of boracic acid for the same base.—*Graham.*

From the foregoing observations, we learn that cohesion is to be regarded by the chemist, in two different and opposite points of view. In a general sense, it operates as an *antagonist* to the exertion of chemical action, while in particular cases it favours and determines the operation and results of that force.

The power of repulsion, as exhibited in the elastic state of bodies, exerts an influence on chemical affinity analogous to that of cohesion, for as the formation of an insoluble substance in a liquid will enable lower degrees of affinity to preponderate by removing the body which is formed by its insolubility, so will elasticity determine the production of such substances, as by their volatility may be driven off, even though the affinities of their elements may be much feebler than those of other bodies.—*Kane.*

For examples:—If to a solution of sulphate of magnesia, ammonia be added, the magnesia will be precipitated, and the sulphuric acid, with which it was combined, will unite with the ammonia; but if sulphate of ammonia be mixed with *dry* magnesia and heated, the ammonia, yielding to its volatility, will be expelled, leaving the magnesia in exclusive possession of the sulphuric acid. If carbonate of ammonia be added to a solution of muriate of lime, the insoluble carbonate of lime will be determined, but if the salts resulting from this decomposition, namely, carbonate of lime and muriate of ammonia be mixed in a dry state and heated, the original salts will be gradually reproduced and the carbonate of ammonia volatilized.

The metal potassium is formed by the decomposition of potassa at a high temperature by iron; now the affinity of the latter metal for oxygen is certainly much inferior to that of potassium, yet the iron takes oxygen from the potassa which is to be explained by supposing that when the potassa is brought into contact with the iron at a *white* heat, the oxygen of the alkali becomes divided between the two metals and a portion of potassium is set at liberty. But the potassium being volatile is expelled at the moment of its reduction, and thus, by its influence being withdrawn, an opportunity is given for the decomposition of an additional quantity of potassa.

The boracic acid is remarkably inert, so much so that, as we have seen, it may be deprived of every particle of its base by sulphuric acid, forming a remarkable exception to the law of Berthollet; nevertheless, at a red heat boracic acid will completely decompose sulphate of soda, it being *fixed* in the fire, while sulphuric acid is volatile. Again: There is nothing in the general appearance or character of *powdered flints* which would induce a person to suppose it to be an acid, indeed it is only from analogy that it is recognised as such by chemists; nevertheless, silica at a bright red heat is capable of expelling the most powerful acids; a familiar instance of which, is the common process of glazing pottery, by throwing over it at a high temperature, handfuls of common salt, on doing which clouds of elastic vapour (muriatic acid gas,) are driven off, and the silica of the earthy materials of the vessels combine with the soda; this is perhaps one of the most instructive instances that could be brought forward, of the prevalence of the physical over the chemical force; here an acid, which when dissolved in water is the feeblest with which we are acquainted, removes the strongest, solely on account of its fixity at a high temperature.

Quantity of matter, there is no doubt, exerts an influence on chemical affinity, though by no means to the extent insisted on by Berthollet; we may observe this influence during the solutions of any soluble salt, added in successive portions, to a given quantity of water; the first portion disappearing more readily than the second, the second than the third, and so on, till a saturated solution is obtained. The chemist frequently takes advantage of this property of quantity of matter; when, for instance, he wishes completely to deprive a metallic salt of its acid by means of potassa, he uses rather more alkali than is absolutely required to saturate the acid, in order the more effectually to bring every particle of the substance to be decomposed in contact with the decomposing agent. The power ascribed by Berthollet to quantity of matter, was much greater and more important; he contended that it compensates for weaker affinity, and supposed that the affinity of different acids for the same alkali is in the inverse ratio of the ponderable quantity of each, which is necessary for neutralizing equal quantities of the alkali. Thus, if two parts of one acid, A, and one part of another acid, B, are required to neutralize equal quantities of the alkali, C, he inferred that the affinity of B for C, was twice as great as that of A; and further, he thought that as two parts of A, produce the same neutralizing effect as one part of B, the attraction exerted by any alkali towards two parts of A, ought to be precisely the same as for the one part of B; and he hence concluded, that there is no reason why the alkali should prefer the small quantity of the one, to the large quantity of the other; on this he founded the principle, that quantity of matter compensates for force of attraction.

Berthollet indeed, went so far as to declare, that what chemists call *elective affinity,* (which we shall inquire into presently,) had no real existence; that chemical union differed from mechanical cohesion, only in being exerted between the particles of different substances, and that in all cases where certain bodies combine in preference to others, the source was to be found in accidental and external circumstances. On his ideas, the force by which the particles of a fragment of sulphate of soda are united, differs from the force by which the sulphuric acid is united to the soda, only in the fact that the cohesion unites particles of the same kind, whilst affinity unites particles of different kinds. The solution of a salt in water must, on these principles, be looked upon as a chemical operation, and while the adhesion of two pieces of clean lead is regarded as mechanical, the adhesion of a piece of lead to a piece of tin, or a drop of water to a pane of glass, must be looked upon as the result of chemical affinity. Chemists however of the present day, require more substantial proofs of the existence of chemical affinity between bodies; they require that the individuality of the constituents should be parted with, and new properties acquired, neither of which conditions are, in the instances referred to, satisfied, and the views of this great chemist have been, for some time, given up.

The chemical action of two bodies does not, therefore, arise from their chemical affinities *alone,* for these forces are modified by the combined influences of heat, electricity, cohesion, and other physical agencies to a very considerable extent. By a change of temperature, an affinity, originally weak, may be made to preponderate over one previously much stronger. By electrical conditions, the strongest and most direct chemical affinities may be overcome: according as the cohesion of the acting bodies may prevail, decomposition, simple or compound, may be produced in opposite ways; and thus a chemical result depends on the resultant of a number of forces acting in different ways and with various intensities, of which affinity is one, though unquestionably the most important.

It is indeed (remarks Dr. Kane,) fortunate for the intellectual progress of mankind, that this is the case: for on the variability of the intensity with which chemical affinity may be exerted, depends the existence of the infinite variety of organized and inorganic beings which people and beautify this earth. Had mere affinity been omnipotent: Had those bodies which attract each other most powerfully, been in all cases able to combine, and that there had been no means of dissolving their connexion when once formed, immediately on the origin of our globe, those bodies which have the most powerful affinities would have satisfied them by entering into eternal union; those next in power would then have satisfied their tendency to combine, and long since, nature should have been arranged into some few chemical combinations, the breaking up of which could not be accomplished by any existing force. The complex changes of animal and vegetable digestion and respiration could not go on; the working of the metals; the chemical arts of civilized life could not have been invented, and the planet we inhabit should have revolved in space a barren and uninhabitable ball.—*Kane.*

Having thus explained, as fully as the popular character of our work will admit, the nature of the restrictions which contribute to modify the chemical force, we will proceed to the consideration of affinity alone, the basis of the science itself, the important instrument employed by the chemist in all his operations. Chemical affinity is a power which finds no parallel in any of the other forces in nature; its action is between the ultimate elements of matter, the individuality of which it destroys, and out of which it forms new bodies, possessed of new characters.

This intimate union of dissimilar elements, taking place between their ultimate molecules, cannot of course be witnessed by the eye of man; but the action is always attended by phœnomena, indicative of the change which is taking place, and from which the operation of affinity may at once be concluded. The following experiments may be made in proof of this.

Experiment 1. Mix four parts of strong sulphuric acid with one of water; or seventy-three parts of the acid with twenty-seven of water, a temperature equal to three hundred degrees will be produced; here the exertion of chemical affinity is proved by the great elevation of temperature.

Experiment 2. Mix in a glass flask sixteen parts of fragments of sulphur, with sixty-four parts of copper filings, and apply the heat of a lamp so as to fuse the lower stratum of sulphur; now remove the lamp, heat and light will be copiously evolved, the copper glowing and burning in the sulphur vapour: in a short time this phœnomenon will be at an end, and in the place of the copper filings and yellow sulphur, a black brittle substance will be found in the flask, viz:—sulphuret of copper. In this experiment we derive proof; First: That copper and sulphur have an affinity for each other, and that when presented in certain proportions and under certain conditions, they combine. Second: That sixteen of sulphur is the quantity requisite to satisfy sixty-four of copper. Third: That the conditions required is the diminution of the aggregation of the sulphur. Fourth: *That chemical action is sometimes attended by the* phœnomenon of combustion. Fifth: That the individuality of bodies, amongst which chemical affinity is exerted is destroyed. And Sixth: That a *new* product results.

Experiment 3. Introduce a coil of harpsichord wire, to the end of which is attached a piece of burning tow into a jar of pure oxygen gas; the wire will burn, throwing out brilliant sparks, and a substance, having none of the properties of pure iron will be the result.

Here chemical action is attended by the phœnomena of heat and light.

Experiment 4. Mix one hundred parts of strong sulphuric acid with one hundred parts of water; the result will not be two hundred measures, but considerably less.

Here we find chemical action attended by diminution of bulk, and consequently by an increase of specific gravity.

Experiment 5. Take a glass of water, and drop into it a small quantity of solution of corrosive sublimate, (bichloride of mercury,) and having stirred it well, introduce a few drops of solution of iodide of potassium; a beautiful brick-red precipitate which will gradually become of a cinnabar-red colour, will be determined. Or, into a similar glass of cold water, introduce a few drops of a solution of starch in hot water, then, as before, a small quantity of solution of iodide of potassium; no change will be perceptible till a drop of sulphuric acid is added, which will occasion the production of a beautiful blue colour.

In these experiments we find a change of colour attending chemical action, and by the last experiment we learn, that no action takes place between solution of starch and iodide of potassium till a strong acid is introduced.

Experiment 6. Dissolve some chalk (carbonate of lime,) in a small quantity of muriatic acid, till the acid is saturated; filter the solution, and when perfectly clear and liquid, add a few drops of sulphuric acid; fumes will be evolved, and a solid, sometimes quite dry, will remain.

Here we find a change of form; two liquids giving rise to a solid.

Experiment 7. Heat a small quantity of strong liquid ammonia in a flask, and allow the vapour to pass into a jar of chlorine; the sides of the jar will speedily become covered with a saline incrustation.

Here we have two aëriform bodies producing a solid.

Experiment 8. Rub in a mortar a few crystals of sulphate of soda, with an equal quantity of nitrate of ammonia; a liquid will gradually be formed.

In this experiment the change is from solidity to liquidity.

From these simple experiments, we find, that the external phœnomena are generally sufficiently marked to inform us when chemical action is going on between two or more bodies, and the second experiment shows that imperfection of contact completely prevents the exertion of very powerful affinities; the sulphur could not combine with the copper until it had been brought to a very fine state of division by the action of heat. A more satisfactory manner, perhaps, of making the experiment, would be to reduce both the copper and sulphur to a very fine state of division and then rub them together in a mortar; a sulphuret of copper would be formed, *with the evolution of much heat,* but *without* the application of external heat. The copper for this purpose is obtained by precipitating it from its combination with sulphuric acid (solution of blue vitriol,) by a plate of polished iron. That the state of aggregation of a solid may oppose an insuperable bar to the action of a very powerful affinity, is well shown by the metals, lead and iron. The affinity between lead and oxygen is very considerable, for the metal is rapidly converted into a white oxide when ground to powder and agitated with water in its usual äerated condition, and in the state of extreme division in which it is obtained by calcining its tartrate in a glass tube, it becomes a pyrophorus, and combines, even when cold, with so much avidity with oxygen, as to take fire and burn the moment it is exposed to the air. Iron also, in the spongy and divided state in which it is procured, by reducing the peroxide by means of hydrogen gas at a low red heat, absorbs oxygen with equal eagerness from the air at common temperatures, and takes fire and burns. But notwithstanding an affinity for oxygen of such intensity, these metals in mass oxidate very slowly in the air, particularly lead, which is quickly tarnished, certainly, but the thin coating of oxide formed does not penetrate to a sensible depth in the course of several years. The suspension of the oxidation may be partly due to the comparatively small surface which a compact body exposes to air, and which becomes covered by a coat of oxide and protected from further change; but partly also to the effect of the conducting power of a considerable mass of metal in preventing the elevation of temperature consequent upon the oxidation of its surface; for metals oxidate with increased facility at a high temperature, such as the lead pyrophorus quickly attains from the oxidation of the great surface which it exposes compared with its weight. The heat from the oxidation of the superficial particles of the compact metal, however, is not accumulated but carried off and dissipated by the conducting power of the contiguous particles, so that elevation of temperature is effectually repressed.—*Graham.*

The simplest instances of the exercise of Chemical attraction are afforded by the mixture of two substances:—water, for instance, combines readily with sulphuric acid or with spirits of wine, but it exhibits no disposition to unite with oil: camphor is very sparingly soluble in water, but it combines readily with alcohol; sugar, on the other hand, is soluble almost to any extent in water, but is dissolved only in a very small degree by alcohol. Instances of simple combination are furnished also by the neutralization of a pure alkali by an acid; or by the combustion of iron or phosphorus in oxygen gas. But chemists frequently speak of affinity under the term *elective attraction*, which they divide into *simple and complex.* Oil, as has just been mentioned, is not soluble in water, it combines however readily with solution of ammonia, forming a soapy substance; but if we add to this *liniment* an acid, the oil will re-appear, the alkali having a stronger attraction for the acid than for oil; again, the solution of camphor in alcohol is perfectly transparent, but on adding water, it instantly becomes milky, and in a short time the camphor is deposited; this arises from the alcohol having a stronger attraction for water than for camphor. To give another instance, lime and magnesia are both soluble in muriatic acid, but if we present a mixture of these two substances to liquid muriatic acid, the whole of the lime will be dissolved before any trace of magnesia is taken up; here we have then two substances both susceptible of combining with a third, and placed in the most favourable circumstances for uniting with it; but in consequence of one having a stronger affinity than the other, it combines with the third substance, to the total exclusion of the other. That the lime has a stronger affinity for muriatic acid than magnesia has, may be shown more immediately by adding lime to a solution of magnesia in muriatic acid; it will be found that the magnesia will be expelled, the lime taking its place; and instead of a solution of muriate of magnesia we shall have a solution of muriate of lime; if we now add soda, the lime will be expelled, and we shall have a solution of muriate of soda, and the soda again may be expelled by potash. But magnesia will also expel some substances from their combination with muriatic acid; oxide of iron, for instance; so that by observing the order of decomposition, a view of the relative affinities which these different bases exercise with the same acid may be formed.

It will stand thus:—

MURIATIC ACID.

Potash.
Soda.
Lime.
Magnesia.
Oxide of iron.

But there is very frequently involved a second phœnomenon, which is, equally with elective affinity, characteristic of chemical force; viz:—*decomposition.* For example:—On submitting iron to the action of nitric acid, deep red fumes are evolved with an appearance of boiling, and the metal disappears; the same takes place if a piece of copper be substituted for the iron; but if these two metals be together, and at the same time plunged into the acid; no action will be exerted on the copper till the iron is wholly dissolved: from this we learn that the acid has a stronger affinity for iron than for copper: but this is not all; the solution is not a silent one, as was the case in the former experiments; effervescence, evolution of red fumes, and considerable development of heat, are observed. These phœnomena are occasioned by the decomposition of a portion of the acid, which cannot dissolve an atom of either copper or iron till the metals have become oxides, and to bring them to this state a portion of the acid gives up a portion of its oxygen, and the acid thus deprived, becomes a new and gaseous substance, of which the red fumes are strikingly characteristic.

A less intricate example of decomposition, is furnished, by adding to sulphuretted hydrogen a portion of iodine, (a simple substance); the sulphur is immediately thrown down, the iodine at the same time disappearing and uniting with the displaced hydrogen. This latter element has, however, a still more powerful affinity for chlorine, consequently, on bringing the latter in contact with the iodide of hydrogen, the iodine will in its turn be expelled, and hydrochloric or muriatic acid formed.

In the same manner that a table was formed of the order of affinities of different bases for muriatic acid, a table of the order of affinities of the different acids for the same base may be arranged. Thus, if we expose to the air a strong solution of caustic soda, it will absorb carbonic acid, (which we shall hereafter show, is always present in the atmosphere,) and become carbonate of soda; from this salt the carbonic acid may be expelled with effervescence by acetic acid or vinegar; from the acetate of soda, the acetic acid may be expelled by the muriatic; from the muriate of soda, the muriatic acid may be expelled by nitric acid; and from the nitrate of soda the nitric acid may be expelled by sulphuric acid. The order of affinities of these acids therefore, for soda, may be written thus:—

SODA.

Carbonic acid.
Acetic acid.
Muriatic acid.
Nitric acid.
Sulphuric acid.

The same sort of list may be constructed for the metals, by observing their order of precipitation from their solutions. Thus, silver forms a soluble salt with nitric acid, the general phœnomena of its solution being the same as has been described in the cases of iron and copper. From this solution *metallic silver* is set free by mercury, which therefore deprives it of oxygen; from the nitrate of oxide of mercury the metal is separated by copper; from the copper salt, the metal is separated by lead; and from the nitrate of oxide of lead, the metallic lead is separated by zinc. The affinities of these different metals for oxygen may therefore be thus represented.

OXYGEN.

Zinc.
Lead.
Copper.
Mercury.
Silver.

One or two examples will serve to show the nature of *complex elective attraction*, or double decomposition. It must be premised, that it is probably from " the facility or absence of effort," with which double decomposition takes place, as, if the combinations were just balanced by the decompositions which occur at the same time, that the results are so much affected by circumstances, particularly by the insolubility of one of the compounds. The peculiarity of double decomposition is that, by means of it, re-actions may occur, which could not have been produced by simple affinity, and which, on the contrary, appear to have been produced in opposition to it. For example:—

Ammonia cannot decompose nitrate of lime; on the contrary, lime will take nitric acid from ammonia, yet, if solutions of nitrate of lime and carbonate of ammonia are mixed, they decompose each other, and by double elective affinity there are formed nitrate of ammonia and carbonate of lime. A diagram will conveniently explain this: the figures attached to the different salts will find an explanation presently.

Nitrate of Ammonia.
891.5.

Nitrate of Lime.
1033.

Nitric Acid.
677.

Ammonia.
214·5.

Lime.
356.

Carbonic Acid.
276.

Carbonate of Ammonia.
490·5.

Carbonate of Lime.
632.

In this diagram, the salts before mixture, are placed upon the outside of the perpendicular lines; their component parts are shown within them; and the new results are shown on the outside of the horizontal lines.

In order to understand the cause of such *double decomposition*, we must take into account not merely the affinity of the ammonia for the nitric acid, but that of the lime for the carbonic acid. Thus, if the affinity of lime for nitric acid be represented by 80, and that of ammonia for nitric acid by 70, the lime will be the stronger, and can when by itself, expel ammonia: but if the carbonic acid intervene, and the affinity of lime for carbonic acid be 50, and of ammonia for the same acid 30, then decomposition must occur; for the forces preventing decomposition are the affinities of nitric acid for lime, and of carbonic acid for ammonia, that is $80+30=110$, whilst those tending to cause decomposition are the affinities of nitric acid for ammonia, and of carbonic acid for lime, viz: $70+50=120$; the latter are the more powerful, and the constituents of the two salts consequently change places.

The former affinities are termed the *quiescent*, the latter the *divellent* affinities, and whenever the sum of the divellent is greater than that of the quiescent affinities, decomposition must occur.

We will give one more example:—The affinity of hydrogen for sulphur is greater than that of mercury for the same element; and the affinity of mercury for chlorine is much greater than its affinity for sulphur, nevertheless, on bringing chloride of mercury into contact with sulphuret of hydrogen, complete decomposition ensues, chloride of hydrogen (muriatic acid,) and sulphuret of mercury being produced. By representing the different forces by numbers we shall see how this is brought about. Let the affinity of mercury for chlorine be $=20$, and for sulphur $=10$, and let the affinity of hydrogen for chlorine be $=30$, and for sulphur $=15$. Then the quiescent affinities are $20+15=35$, and the divellent affinities $30+10=40$.

We will bring this part of the subject to a close by inserting two lists; one, of the affinities of different bases for sulphuric acid, and the other of the affinities of the same bases for muriatic acid; they will serve to show how complicated the circumstances which embarrass our explanations of affinity are, and how impossible it is to construct correct tables of the scale of affinities in which all existing substances should find a place, and which at first may seem no very difficult matter.

No. 1. Muriatic Acid.	No. 2. Sulphuric Acid.
OXIDE OF SILVER.	BARYTES.
POTASH.	STRONTIA.
SODA.	POTASH.
BARYTES.	SODA.
STRONTIA.	LIME.
LIME.	MAGNESIA.
MAGNESIA.	OXIDE OF SILVER.

Here we find oxide of silver occupying the highest point in one scale and the lowest in the other, and none of the bases in the same position in both; and the inference we must draw, is, that neither scale is correct, and that such tables though exceedingly useful as showing the results of careful experiments, are not to be regarded as exact representations of the order of affinities, but that it is necessary to apply to them a number of corrections, arising from some of the causes that have been dwelt upon in the early part of this lecture.

To those who would wish to study the Electro-Chemical Theory, and the relations of electricity and affinity, I would particularly recommend the recent works of Graham and Kane, the popular nature of our Lectures will not, however, allow of our entering into a part of the subject so exclusively theoretical, and involving so much hypothesis.

Laws of Combination. The following table representing the names of those substances which, having as yet resisted every attempt to resolve them into simpler bodies, are termed "Elements" with their Symbols and *least* combining proportions, is extracted from the valuable Elements of Chemistry, by Professor Graham.

NAMES OF ELEMENTS:

WITH THEIR SYMBOLS, AND LEAST COMBINING PROPORTIONS.

Names of Elements.	Symbols.	Equivalents.		Names of Elements.	Symbols.	Equivalents.	
		O as 100	H as 1			O as 100	H as 1
Oxygen...........	O	100·00	8·01	Aluminum........	Al	171·17	13·72
Hydrogen.........	H	12·4795	1·00	Glucinum.........	G	331·26	26·54
Nitrogen..........	N	177·4	14·19	Zirconium.........	Zr	420·2	33·67
Carbon............	C	76·44	6·13	Thorium..........	Th	744·90	59.83
Sulphur...........	S	201·17	16·12	Yttrium..........	Y	402·51	32·25
Selenium..........	Se	494·58	39·63	Manganese........	Ma	345·89	27·72
Phosphorus........	P	392·28	31·44	Iron (Ferrum).....	Fe	339·21	27·18
Boron.............	B	136·25	10·91	Zinc..............	Zn	403·23	32·31
Silicon............	Si	277·31	22·22	Cadmium..........	Cd	696·77	55·83
Chlorine..........	Cl	442·65	35·47	Cobalt............	Co	368·99	29·57
Iodine............	I	1579·50	126·57	Nickel............	Ni	369·68	29·62
Bromine..........	Br	978·31	78·39	Copper (Cuprum)..	Cu	395·70	31·71
Fluorine..........	F	233·8	18·74	Bismuth..........	Bi	886·92	71·07
Potassium (Kalium)	K	489·92	39·26	Lead (Plumbum)..	Pb	1294·50	103·73
Sodium (Natronium)	Na	290·90	23·31	Tin (Stannum)....	Sn	735·29	58·92
Lithium...........	L	80·33	6.44	Cerium...........	Ce	574·70	46 05
Barium.	Ba	856·88	68·66	Uranium..........	U	2711·36	217·26
Strontium.........	Sr	547·29	43·85	Arsenic...........	As	940·08	75·34
Calcium..........	Ca	256·02	20·52	Antimony (Stibium)	Sb	1612·90	129·24
Magnesium........	Mg	158·35	12·69	Chromium........	Cr	351·82	28·19

Names of Elements.	Symbols.	Equivalents.		Names of Elements.	Symbols.	Equivalents.	
		O as 100	H as 1			O as 100	H as 1
Vanadium.........	V	856·89	68·66	Mercury (Hydrargyrum.........	Hg	1265·82	101·43
Molybdenum......	Mo	598·52	47·96	Silver (Argentum).	Ag	1351·61	108·30
Tungsten (Wolfram)	W	1183·00	94·80	Gold (Aurum).....	Au	2486·03	199·21
Columbium (Tantalum)...........	Ta	2307·43	184·90	Platinum..........	Pl	1233·50	98·84
Tellurium.........	Te	801·76	64·25	Palladium.........	Pd	665·90	53·36
Titanium..........	Ti	303·66	24·33	Rhodium..........	R	651·39	52·20
Osmium..........	Os	1244·49	99·72	Iridium...........	Ir	1233·50	98·84

It is well known that alcohol, sulphuric, muriatic, or nitric acids may be mixed with water in any proportion: a drop of acid may be diffused through a whole gallon of water, or a drop of water through a gallon of acid, or they may be mixed in any intermediate proportions, and nevertheless appear to unite perfectly with each other. In the same way one hundred grains of water will dissolve any quantity of sea-salt up to forty grains, but here its solvent power ceases, because the cohesive force of the particles of the solid at this point exactly balances the force of affinity.

Substances united in this manner preserve, more or less, the properties which they possessed when separate, and the affinity which unites them is comparatively feeble.

But bodies also enter into combination with each other in a different and much more important manner. The peculiarity of this second sort of union being that the proportions in which the bodies combine are *limited* on both sides, and the composition of the compounds produced, ***fixed and invariable:*** for example:—it has been mentioned that one hundred grains of water can freely dissolve any quantity of salt (chloride of sodium,) up to forty grains, but the chlorine and the sodium which constitute the salt, form it only in certain proportions, and whether we examine chloride of sodium as it exists in nature, or whether we form it artificially in the laboratory, we shall find that one hundred parts always contain 39·66 of sodium and 60·34 of chlorine; and moreover, we shall find it wholly impossible to give it the smallest particle more of either of its elements without altering its character. Again: if we examine water, either as it falls from the clouds in rain, or as we procure it by allowing a stream of hydrogen gas to burn in an atmosphere of oxygen, or as it is condensed from steam in the still, we shall find its composition uniform, and that one hundred parts contain by weight 11·1 parts of hydrogen and 88·9 parts of oxygen. It may indeed contain impurities which are foreign to it, but in all circumstances, its *necessary* component parts remain the same. It is this constancy of proportion which has raised the Science of Chemistry to the exalted station which it occupies amongst the sciences, and which gives to analyses their value; for had it been otherwise, had chlorine and sodium, or oxygen and hydrogen for instance, combined also in intermediate proportions, we should never have acquired accurate ideas regarding the constitution of bodies, and none of the benefits derivable from experience or experiment could have been attained.

We have in the early part of this Lecture stated fully, the reasons which induced the celebrated French Chemist, Berthollet, to dissent from this first great law of definite proportions; viz:—*That the composition and properties of any given substance are always the same.* His opinions were ably and successfully combated by Proust, and are now entirely abandoned; the great accumulation of facts similar to those observed and advanced by Proust, having proved beyond a doubt that the leading principle of Berthollet is erroneous.

If we examine the composition of some of the compounds of oxygen, or *oxides* as they are called, we shall find that different elements unite with it in very different proportions; thus:—

Water.	Oxide of Copper.	Oxide of Zinc.	Oxide of Lead.	Oxide of Silver.
Oxygen.. 100	Oxygen.. 100	Oxygen.. 100	Oxygen... 100	Oxygen... 100
Hydrogen 12·5	Copper .. 396	Zinc..... 403	Lead...... 1294	Silver..... 1352
112·5	496	503	1394	1452

If we now examine the composition of the compounds of the same elements with sulphur, (sulphurets,) we shall find that the quantities combining with the sulphur, have precisely the same proportion to each other as the above table shows in the case of oxygen, though the quantity of sulphur is not one hundred, but two hundred and one. Thus:—

Hydro-sulphuric acid.	Sulphuret of Copper.	Sulphuret of Zinc.	Sulphuret of Lead.	Sulphuret of Silver.
Sulphur.. 201	Sulphur.. 201	Sulphur.. 201	Sulphur... 201	Sulphur... 201
Hydrogen 12·5	Copper... 396	Zinc..... 403	Lead...... 1294	Silver..... 1352
213·5	597	604	1495	1553

If we now examine the compounds of the same elements with chlorine, we shall find that the same quantities of hydrogen, copper, &c. combine with 443 parts of chlorine; an examination of their compounds with bromine, will show 978 to be the proportion of that element; and with iodine, 1579. From the consideration of these facts, we derive the *Second Law of Combination*; viz— "That the relative quantities in which bodies unite, may be expressed by proportional numbers." The figures attached to the oxygen, hydrogen, copper, &c. in the foregoing tables, represent the *equivalents* of those substances, and will be found to correspond with the numbers attached to them in the Table of Elements, under the *oxygen scale.* It will be readily understood that any series of numbers may be taken, provided the proper relation between them is preserved. In the oxygen scale *the quantity of each substance which combines with one hundred parts of oxygen, to form a protoxide,* is represented.—*Graham.* The second series of numbers, under the hydrogen scale, are all twelve and a half times *less* than the first, and express particularly the proportional quantity of each of the elements which unites with *one* part of hydrogen, the element the combining proportion of which is smallest, and is, on that account taken as unity.

It is difficult to decide which of these two scales deserves preference: the hydrogen scale has been, by the authority of

Davy, so long prevalent in this country, that it is difficult to supersede it, and it certainly possesses the advantage that hydrogen has the smallest equivalent of all bodies, and did it so happen that the equivalents of bodies could be correctly expressed by *whole* numbers, there is no doubt that preference would be given to it; but this is not the case, and increasing experience confirms that it is not. Chemists, therefore, have almost universally decided that the standard of oxygen is most convenient, the calculations being much simplified by its number being 100; and there are but two or three bodies which on that scale require to be expressed fractionally, and even these may be neglected; to this must be added the great preponderance of bodies in which oxygen exists

The number of any substance, correctly obtained in experiment may be reduced to the standard scale by the rule of simple proportions; for example:—if we heat 496 parts of oxide of copper in a glass tube, and pass over it at the same time a stream of dry hydrogen gas, it will become reduced to the metallic state, the hydrogen uniting with the oxygen it contained, forming *water;* now it has been shown that 496 parts of oxide of copper contain 396 parts of copper and 100 of oxygen, and this latter entering into combination with 12·5 parts of hydrogen, produces 112·5 parts of water.

In this instance it is clear that 12·5 parts of hydrogen produce the same result of satisfying the combining power of 100 of oxygen as the 396 of copper, and hence these quantities of hydrogen and copper are *equivalent* to each other. But the experiment may be carried further; instead of reducing the oxide of copper by hydrogen gas, we may act upon it by muriatic (hydrochloric) acid; as before, the hydrogen would unite with the oxygen of the oxide, forming water; but another element is present, namely, *chlorine,* which though eliminated from its union with the hydrogen, would not be set free, it would unite with the copper, and the reaction would be so proportioned that the quantity of copper reduced by the hydrogen of the hydrochloric acid, would be exactly sufficient to unite with all the chlorine which was therein contained, and form with it *chloride of copper*.

In this case the 496 parts of oxide of copper would require 455 parts of hydrochloric acid to effect its complete decomposition, and there would be formed 839 parts of chloride of copper, and 112·5 parts of water. From this experiment, besides the additional proof of the equivalency of 12·5 parts of hydrogen, to 396 parts of copper, we learn that 12·5 parts of hydrogen, and 396 parts of copper, unite equally with 443 of chlorine, and hence, that that quantity of chlorine corresponds and is equivalent to 100 parts of oxygen. It is in this way that the equivalents of most of the metals have been obtained. In these examples the exact *equivalents of the elements* on the oxygen scale have been taken, but as has been already observed, these numbers are quite arbitrary and only used as a matter of convenience. Had one hundred parts of oxide of copper been taken, 2·52 of hydrogen would have been required; for 79·83 of copper, and 20·17 of oxygen enter into the composition of 100 parts of the oxide, and the water produced by the decomposition would have been 22·69. Again, to effect the decomposition of the oxide by hydrochloric acid, 91·73 of acid would have been required, and there would have been produced as before 22·69 parts of water, and 166·04 of chloride of copper, consisting of 89·21 of chlorine, and 79·83 of copper; then, to reduce these numbers to the equivalents of the respective substances on the *oxygen scale*, the operation is simply

as 20·17 : 79·83 :: 100 : 395·70 = equivalent of copper.
79·83 : 89·21 :: 395·7 : 442·65 = equivalent of chlorine.
20·17 : 2·52 :: 100 : 12·4795 = equivalent of hydrogen.

and on the hydrogen scale,

as 2·52 : 79·83 :: 1 : 31·71 = equivalent of copper.
79·83 : 89·21 :: 31·71 : 35·47 = equivalent of chlorine.
2·52 : 20·17 :: 1 : 8 = equivalent of oxygen.

It is not only to elementary substances that this law of combination applies, since compound bodies have their combining proportions or equivalents, which may likewise be expressed in numbers. Thus, since water is composed of one equivalent of oxygen, 100 or 8, and one equivalent of hydrogen, 12·5, or 1, its combining proportion or equivalent is 112·5 or 9. (Here we may state that, having explained the manner in which the equivalents of substances are calculated, for either scale, in future we shall refer to the oxygen scale *alone*, and give the whole numbers, except in the case of water, which will always be represented by the number 112·5, and those compounds containing hydrogen, whose equivalent numbers are small.) The equivalent of sulphuric acid is 501, because it is a compound of one equivalent, or 201 parts of sulphur, and three equivalents, or 300 parts of oxygen; but the strongest oil of vitriol which can be made contains water, and consists of sulphuric acid 501 + water 112·5; here the water is in its *exact combining proportion*, and we may consider oil of vitriol as composed of one equivalent of sulphuric acid, and one equivalent of water.

The equivalent of zinc is 403, and of oxide of zinc 503, consequently the combining proportion of sulphate of oxide of zinc is 1004, its composition being oxide of zinc 503+501 sulphuric acid. The equivalent of sulphate of potash is 1091, those of the elements concerned in its composition being as follows:—

Potassium..	490		Sulphur..	201		
Oxygen....	100		Oxygen..	300		
	590	+		501	=	1091

but these two salts, sulphate of zinc and sulphate of potash enter into combination, forming a double salt, the equivalent composition of which can be beforehand determined.

Sulphate of zinc. .	1004	one equivalent.
Sulphate of potash..	1091	one equivalent.
Double sulphate of zinc and potash	2095	one equivalent.

It is however in relation to the mutual decomposition of saline bodies that the principle of equivalent proportions becomes of most interest, and by which it is best illustrated. Thus, if to a solution of nitrate of lime, we add a solution of carbonate of ammonia, there is immediate decomposition by the mutual interchange of acids and bases, as represented in the diagram, page 116, and *the neutrality of the solution remains completely undisturbed;* the salts which exist after mixture are equally neutral with those which had existed previously, and the quantities of acids and bases which are involved in the decomposition are hence equivalent to each other. This curious fact, which was first noticed by the Saxon chemist, Wenzel, is now readily explained. Thus, in the decomposition referred to, if we take 1033 grains of nitrate of lime, we find that they require for their decomposition exactly 490·5 grains of carbonate of ammonia, and that there are formed 891·5 grains of nitrate of ammonia, and 632 grains of carbonate of lime.

The composition of these four salts is:—

NITRATE OF LIME.	
Nitric acid......	677
Lime	356
	1033

CARBONATE OF AMMONIA.	
Carbonic acid....	276
Ammonia........	214·5
	490·5

NITRATE OF AMMONIA.	
Nitric acid......	677
Ammonia	214·5
	891·5

CARBONATE OF LIME.	
Carbonic acid ...	276
Lime............	356
	632

All four of these salts are neutral. The acids and bases are in all equally neutralized, and hence the 677 of nitric acid, and 276 of carbonic acid being capable of saturating the same quantity of base, whether it be lime or ammonia, are equivalent quantities, and represent the combining proportions of these acids; and the 356 of lime and the 214·5 of ammonia being likewise shown to possess equal powers of neutralizing the acid, whether nitric or carbonic are the numerical equivalents of those bases. It matters not whether more or less than 490·5 grains of carbonate of ammonia are added to the nitrate of lime, for if more, a small quantity will remain in solution, if less, the nitrate of lime will be in excess, but in neither case will the neutrality be in the least affected.

The method of determining equivalent numbers will now be obvious. If the substance be an acid, it is to be combined with some base of which the equivalent is known: if it be a base, it must be united with an acid. If it be a metal, it must be united with chlorine or oxygen. If it be a simple non-metallic body, it may be united with a metal. In any case, a well-defined compound of the new body, with one whose equivalent number is already known must be obtained and accurately analyzed. The equivalent numbers of the two bodies are proportional to the quantities in which they were combined, *provided we have reason to consider that the compound examined contained an equivalent of each.* Thus, if the new body form with sulphuric acid a perfectly neutral and soluble salt, and on analysis this yields 37·3 sulphuric acid, and 62·7 of the new base in 100, the equivalent is found by the proportion, as 37·3 : 62·7 :: 501 : X = 842, which is the equivalent of the body, 501 being that of sulphuric acid, and 100 that of oxygen.—*Kane.*

This calculation must however be checked by applying to it the law of *multiple proportions,* which constitutes the Third important Law of Combination. It is, that when one body, A, unites with another body, B, in two or more proportions, the quantities of the latter united with the same quantities of the former, bear to each other a very simple ratio. This is well shown in the compounds of manganese and nitrogen, each with oxygen, which are as follows:—

ONE EQUIVALENT.

346 of manganese, unite with 100 of oxygen, forming protoxide.
346.. .... 150 .... sesquioxide.
346...................... 200 .... peroxide.
346...................... 250 .... manganous acid.
346...................... 300 .... manganic acid.
346...................... 350 .... permanganic acid.

Here it will be perceived, that the quantities of oxygen taken by the manganese, are multiplies of *one half* the quantity contained in the protoxide, and are as the numbers 2, 3, 4, 5, 6, 7; analogy however renders it probable that there is an undiscovered compound of 346 manganese with 50 oxygen, which would constitute the first term of the series.

177 of hydrogen unite with 100 of oxygen, forming nitrous oxide.
177.................... 200................. nitric oxide.
177.................... 300............ hyponitrous acid.
177.................... 400................. nitrous acid.
177.................... 500................... nitric acid.

Here the first compound consists of a single combining proportion of each of its constituents; but in the other compounds a single proportion of nitrogen is united with quantities of oxygen, which correspond exactly with 2, 3, 4, and 5, combining proportions of that element.

Compound bodies likewise unite among themselves in multiplies of their combining proportions, as well as in single equivalents.

Thus, in the compounds of potash and chromic acid,

590 potash, combine with 652, one equiv: chromic acid, to form yellow chromate of potash.

590 potash, combine with 1304, two equiv: chromic acid, to form red chromate of potash.

In the compounds of sulphuric acid and potash,

590 potash, combine with 501 sulphuric acid, forming the neutral sulphate.

590 potash, combine with 1002 sulphuric acid, forming bisulphate.

In the carbonates and oxalates of potash,
276, or one equiv: of carbonic acid, combine with
590, or one equiv: of potash, to form carbonate of potash.
552, or two equiv: of carbonic acid, combine with
590, or one equiv: *of potash*, to form bicarbonate of potash.
452, or one equiv: of oxalic acid, combine with
590, or one equiv: of potash, to form oxalate of potash.
904, or two equiv: of oxalic acid, combine with
590, or one equiv: of potash, to form binoxalate of potash.
1180, or four equiv: of oxalic acid, combine with
590, or one equiv: of potash, to form quadroxalate of potash.

It was by the verification of this law, by Wollaston, in the carbonates and oxalates of potash, that it gained universal acceptation. He took a quantity of bicarbonate of potash, and dividing it into two equal parts, he exposed one half to a red heat, by the effect of which the salt lost some carbonic acid and became neutral carbonate, and both portions being afterwards decomposed by an acid, the salt in its original condition was found to afford a measure of carbonic acid gas, exactly *the double* of that yielded by the portion exposed to the high temperature.

In salts with excess of base, the same principle holds, as Kane has shown in the sulphates of copper; thus:—

496 oxide of copper + 501 sulph: acid, form neutral sulphate.
992.............. + 501 ....bibasic sulphate.
1684.............. + 501 .... quadribasic sulphate.
3968.............. + 501 ....octobasic sulphate.

We will not pursue this any further at present, since, during the remaining Eight Lectures numerous opportunities will occur, to show the universality of this beautiful law. One word however on the *Symbols* placed before the equivalent numbers in the second column in the Table of Elements; their great use consists in supplying an exact expression of this law of multiple proportions. The ordinary symbol of a body indicating an equivalent of it; the number by which that symbol is multiplied, in the formula of each compound body, represents the number of equivalents therein contained. Thus, in the instances just given, the symbolical expressions for nitrogen and its compounds with oxygen, are

N	Nitrogen.	NO_3	Hydronitrous acid.
NO	Nitrous oxide.	NO_4	Nitrous acid.
NO_2	Nitric oxide.	NO_5	Nitric acid.

For manganese and its compounds with oxygen.

Mn	Manganese.	$Mn.O_2$	Peroxide.
MnO	Protoxide of manganese.	MnO_3	Manganic acid.
Mn_2O_3	Sesquioxide.	Mn_2O_7	Permanganic acid.

The expression for the yellow chromate of potash, is $KO+CrO_3$.
For the red chromate, $KO+2CrO_3$.
The expression for the neutral sulphate of potash, is $KO+SO_3$.
For the bisulphate, $KO+2SO_3$.
The expression for the carbonate of potash, is $KO+CO_2$.
For the bicarbonate, $KO+2CO_2$.
The expression for oxalate of potash, is $KO+C_2O_3$.
For the binoxalate, $KO+2C_2O_3$.
For the quadroxalate, $KO+4C_2O_3$.
The expression for the neutral sulphate copper, is $CuO+SO_3$,
For the bibasic sulphate, $2\ Cu\ O+SO_3$.
For the quadribasic sulphate, $4\ Cu\ O+SO_3$.
And for the octobasic sulphate, $8\ CuO+SO_3$.

The great use of these symbols will, on a little consideration, become obvious, though at first, to the beginner in Chemistry they may seem unnecessarily embarrassing. All that is required, is to learn the expression for each of the Elementary Substances, which may very soon be done, and then their utility will appear: we see at once the composition of any compound, and express by a few letters what, if written at length, would occupy many lines:—an instance, taken from the organic kingdom will show this without further explanation.

The expression for spermaceti, is

$2\,(C_{70}H_{64}O_{6}) + 2\,(C_{70}H_{60}O_{5}) + 3\,(C_{16}H_{16}) + 3\,(HO)$
representing
2 equivalents of margaric acid.
2 equivalents of oleic acid.
3 equivalents of cetene.
3 equivalents of water.

By this formula we see at a glance, not only the composition of spermaceti, but that of the margaric and oleic acids and cetene, and we learn also, that two equivalents of each of these acids, added to three of cetene and three of water 3(HO) together, make up precisely the sum of the elements concerned in the formation of spermaceti.

By the formula $KO + C_2O_3$, representing oxalates of potash, we learn not only that that salt is composed of an equivalent of each of its constituents, but we are informed also that potash is a *protoxide* of potassium or kalium, and that oxalic acid is composed of two equivalents of carbon, united to three equivalents of oxygen.

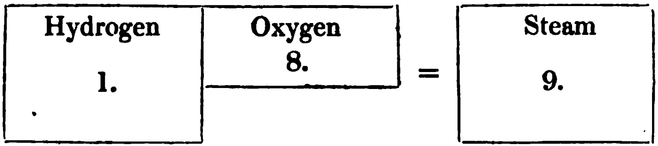
We shall proceed in the next Lecture to the consideration of the remarkable relation between the equivalents of gases and their *volumes*; after which we shall say a few words on the Atomic Theory, and then proceed with the Undecompounded Substances, commencing with oxygen.

LECTURE FIFTH.

THEORY OF VOLUMES:—THE SPECIFIC GRAVITIES AND ATOMIC WEIGHTS OF GASES BEAR A SIMPLE RELATION TO EACH OTHER—EXAMPLES—TABLE OF THE EQUIVALENT VOLUMES OF SEVERAL GASES AND VAPOURS—HYPOTHETICAL REPRESENTATION OF THE FORMATION OF STEAM AND HYDROCHLORIC ACID:—THE RELATION BETWEEN THE VOLUMES OF THE CONSTITUENT AND COMPOUND VAPOUR FURNISHES US WITH A METHOD OF CALCULATING THE SPECIFIC GRAVITY OF A VAPOUR—EXAMPLE—THE ATOMIC THEORY—HYPOTHESIS OF DALTON—HIS SYMBOLS—THE WORD "ATOM" MAY BE SUBSTITUTED FOR "EQUIVALENT."—VIEWS OF DUMAS AND KANE RESPECTING THE ATOMIC THEORY.—THE NON-METALLIC UNDECOMPOUNDED BODIES—THE GASES—OXYGEN GAS—ITS ABUNDANCE—PREPARATION FROM PEROXIDE OF MANGANESE—PARTICULARS OF THE PROCESS—METHOD OF COLLECTING LARGE QUANTITIES OF GASES—RATIONALE OF THE PROCESS OF PROCURING OXYGEN GAS FROM PEROXIDE OF MANGANESE—QUANTITY OF GAS OBTAINABLE FROM A GIVEN WEIGHT—PREPARATION OF THE GAS FROM CHLORATE OF POTASH—RATIONALE—METHOD OF MANIPULATING WITH THE GASES—THE HYDRO-PNEUMATIC AND MERCURIO-PNEUMATIC TROUGHS.—PREPARATION OF OXYGEN GAS FROM RED-OXIDE OF MERCURY—RATIONALE OF THE PROCESS—PROPERTIES OF OXYGEN GAS—ILLUSTRATIVE EXPERIMENTS—OXYGEN GAS ESSENTIAL TO ANIMAL LIFE—CHANGE IT PRODUCES IN THE BLOOD:—OXYGEN IS ABSORBED IN ALL CASES OF ORDINARY COMBUSTION—CONSIDERATION OF THE PROCESS

OF COMBUSTION—THE HEAT DEVELOPED DURING COMBUSTION DEPENDS ENTIRELY ON THE QUANTITY OF OXYGEN CONSUMED.—HEAT IS ALWAYS EVOLVED DURING THE ABSORPTION OF OXYGEN—EXAMPLES—PRODUCTS OF COMBUSTION—NOTHING LOST BY THE PROCESS—EXAMPLE —ILLUSTRATION OF THE PROCESS OF COMBUSTION—THE EVOLUTION OF HEAT NOT ACCOUNTED FOR.

Soon after the publication of Dr. Dalton's views of the atomic constitution of bodies, it was shown by M. M. Gay Lussac and Humboldt, that gases unite together *by volume* in very simple and definite proportions. If we take oxygen and hydrogen gases in the proportion in which they enter into the composition of water, which we have already stated to be 100 parts of oxygen to 12·5 of hydrogen, we shall find that the volume or space occupied by the latter will be precisely double that occupied by the former: in other words, we shall find that water consists of 100 measures of oxygen united to 200 measures of hydrogen, and on submitting water to the action of voltaic electricity, and collecting the evolved gases in separate graduated vessels, we shall invariably find that the hydrogen will occupy exactly double the space of the oxygen. Now oxygen is sixteen times heavier than hydrogen, and as the proportion by weight of these two gases in water is as eight to one, we may consider that one volume of hydrogen is combined with half a volume of oxygen, to form one volume of vapour of water or steam, for the specific weight of steam is to that of hydrogen as nine to one, and the combining weights and volumes of the elements of water and of its vapour may be thus represented.



Gay Lussac then proceeded to examine other gaseous compounds, in which he found the same simple relations; thus he found that 100 volumes of ammonia combine with precisely 100 volumes of hydrochloric acid gas; ammonia was found to consist of 100 volumes of nitrogen and 300 volumes of hydrogen; carbonic acid, of 100 volumes of carbonic oxide, and 50 volumes of oxygen; and sulphuric acid, of 100 volumes of sulphurous acid and 50 of oxygen. He likewise observed, that the product of the union of two gases, if itself a gas, sometimes retains the original volume of its constituents, no contraction or change of volume resulting from their combination; thus, one volume of nitrogen and one volume of oxygen form two volumes of deutoxide of nitrogen; one volume of chlorine and one volume of hydrogen form two volumes of hydrochloric acid gas: and that when contraction takes place, which generally is the case, the volume of the compound gas bears a simple ratio to the volumes of its elements.

Thus, two volumes of hydrogen and one volume of oxygen form *two* volumes of steam; one volume of nitrogen and three of hydrogen form two volumes of ammoniacal gas; one volume of hydrogen and one-sixth of a volume of sulphur vapour, form one volume of sulphuretted hydrogen gas.

This relation by measure which is found to subsist between gases, arises from the circumstance that their specific gravities correspond either exactly with their *atomic weights*, or bear a simple relation to them. Thus, the atom of chlorine gas is 35·5 times heavier than that of hydrogen gas, so that the combining measures of these two gases, which correspond with single equivalents, are necessarily equal. The atom of nitrogen and its weight as a gas being both 14·2 times greater than the atom and weight of hydrogen gas, their combining volumes must be the same.—*Graham.*

If we submit to heat those quantities of iodine and bromine which are expressed by their equivalent numbers, they become converted into vapour, *and occupy precisely the same* *volume as the equivalent of hydrogen gas at the same temperature and pressure.* Arsenic and phosphorus yield, under similar conditions, quantities of vapour equivalent to oxygen gas; sulphur yields vapour equal to *one-third* of the equivalent of oxygen; and mercury yields vapour equal to *four* times the equivalent of oxygen, and double that of hydrogen gas.

The following table will therefore represent the equivalent volumes of the substances which have been mentioned in gas or vapour, taking the equivalent of oxygen as 100, and its equivalent volume as 1, which is found more convenient than assuming hydrogen as unity.

Name.	Equivalent Weight.	Equivalent Volume.	Specific gravity of Vapour, Air being = 1000
Oxygen.......	100·0	1	1102·6
Hydrogen.....	12·5	2	68·8
Chlorine......	442·6	2	2470
Iodine.........	1580	2	8701
Bromine......	978	2	5393
Nitrogen......	177	2	976
Sulphur......	201	⅓	6648
Phosphorus...	392	1	4327
Arsenic.......	940	1	10362
Mercury......	1266	4	6969

This table assumes that the atom of oxygen gives *one*, and the atom of hydrogen *two* volumes of gas, so that the composition of steam may be represented as underneath.

Combining measure, or one vol: of oxygen.	Combining measure, or two vols: of hydrogen.	Combining measure, or two vols: of steam.

$$\begin{array}{ccccc} \boxed{1102{\cdot}6} & + & \boxed{\begin{array}{c}69\\ \cdots\cdots\\ 69\end{array}} & = & \boxed{\begin{array}{c}620{\cdot}3\\ \cdots\cdots\\ 620{\cdot}3\end{array}} \\ \hline & 1240{\cdot}6 & & & 1240{\cdot}6 \end{array}$$

and that of hydrochloric acid gas, as

Combining measure, or two vols: of hydrogen.	Combining measure, or two vols: of chlorine.	Combining measure, or four vols: of hydrochloric acid.

$$\underbrace{\boxed{\begin{array}{c}69\\ \hdashline 69\end{array}} + \boxed{\begin{array}{c}2470\\ \hdashline 2470\end{array}}}_{5078} = \underbrace{\boxed{\begin{array}{c:c}1269{\cdot}5 & 1269{\cdot}5\\ \hdashline 1269{\cdot}5 & 1269{\cdot}5\end{array}}}_{5078}$$

Volumes of the gases may be represented by equal squares, with their relative weights inscribed, having relation to the oxygen volume, 100, or 1102·6, which is found more convenient, since it represents the weight of a volume of oxygen, the volume of *atmospheric air being* 1000.

The double squares, representing hydrogen, chlorine, &c. are divided into *imaginary* squares by dotted lines, the *actual* division being of course as impossible as the division of an *atom;* in these squares are inscribed *one half* the equivalent number of the substance; in the case of hydrogen, the whole number is *twice* 69=138, which bears the same relation to the assumed number of oxygen, 1102·6, as 12·5 the equivalent number of hydrogen on the oxygen scale does to 100.

In hydrochloric acid gas, where *no* condensation takes place on the union of its elements, there is an imaginary division into four volumes, in each of which is inscribed *one fourth of* the number representing the combining measure of the gas.

Lastly, it must be observed, that the discovery of this simple relation between the volumes of the constituent and compound vapour has furnished us with a very convenient method of calculating the specific gravity of a vapour. Thus, to calculate the specific gravity of ammonia, we know that it is formed by the union of three volumes of hydrogen and one of nitrogen, and the weights of these volumes being as their specific gravities, if the four volumes *were* condensed into one volume, the specific gravity of ammonia would be 976, combining equivalent volume of nitrogen + (3 × 69), three times the combining equivalent of hydrogen = 1183; but as the four volumes are condensed into *two* volumes, the specific gravity is $\frac{1183}{2} = 591{\cdot}5$, *which agrees very closely* with the specific gravity of ammonia, as determined by actually weighing it.

Atomic Theory. In the laws of combination which we have now been endeavouring to set before our readers in a clear and intelligible manner, no theory or speculation is involved, they are founded on experiment alone, and may be considered as a mere expression of facts.

The Atomic Theory of Dalton, on the other hand, "The most beautiful, as well as the most comprehensive principle that has been conferred on Chemistry since the epoch of Lavoisier,*" is *founded* on hypothesis, it adopts unreservedly an opinion which from the earliest ages has divided philosophers, namely, that matter is *not* infinitely divisible, although in many instances comminuted to an extent beyond our powers of conception. All substances are supposed to be constituted of particles perfectly indivisible, and hence truly *atoms* possessing a certain absolute, and possibly appreciable weight. It further supposes that in different kinds of matter, the atoms are of different weights and magnitudes, the latter however being of no material interest: now if we imagine the *atomic weights* of the different elementary substances to be in the proportion of their *equivalent numbers,* the whole laws of combination will follow by the simplest reasoning, and the atoms of elementary bodies may be represented by spheres in which may be inserted their symbols and relative weights, thus —

Name.	Atom.	Weight of Atom.
Oxygen	O	100
Hydrogen	H	12·5
Nitrogen	N	177

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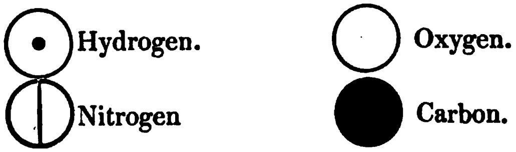
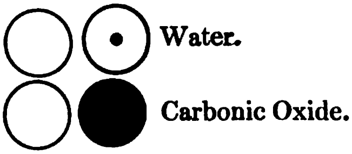
* See Introductory Lecture.

Name.	Atom.	Weight of Atom.
Carbon	C	76·4
Sulphur	S	201
Lead	Pb	1294·5

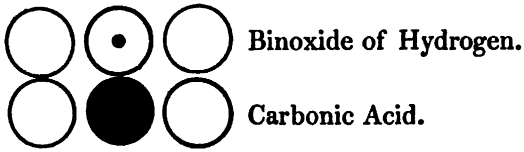
A different set of symbols was proposed by Dalton, to represent the mode in which he conceived bodies may combine together, thus:—



BINARY COMPOUNDS.



TERNARY COMPOUNDS.



Substances containing only two atoms, he called *binary* compounds; those composed of three atoms, *ternary* compounds; of four, *quaternary*, and so on.

Now, it must be observed, that we are utterly ignorant of the nature, size, form, or actual weight of the atoms of elementary bodies, and of the mode in which they are grouped or arranged; all we know is their actual weight. We know perfectly well that whatever the atom of oxygen may actually weigh, it is *eight* times heavier than the atom of hydrogen, or they are to each other as 100 to 12·5.

The word atom signifies *indivisible*, hence it follows, that bodies can only combine in the quantities which the atoms represent, or in multiples of them. Thus in the compounds of manganese and nitrogen with oxygen, referred to in page 127, if we substitute the word *atom* for that of *equivalent*, we shall have a highly probable representation of the laws of combination, and the substitution of ponderable masses for the abstract idea of equivalents, rendering the whole changes most readily conceivable.—*Graham.*

The terms atom and atomic weight, may therefore be used as synonymous with equivalent quantity, and combining proportion.

Some chemists, (Dumas and Kane,) do not adopt the atomic theory, but a modification of it, founded on the assumed existence of a similarity between atoms in their capacity for heat and in their volume, while in the gaseous state. They consider that it is possible, and indeed more consonant to experiment to explain all the laws of chemical combination, quite independent of all considerations as to whether the masses that combine are indivisible or the reverse. They regard the word *atom*, if interpreted in its strict and proper sense, to be unnecessary, and consider that it may be injurious, if employed with any vague or undefined meaning.

With a quotation from the admirable work of Dr. Kane, explanatory of the manner in which the Atomic Theory is to be regarded under this point of view, I shall take leave of the subject, begging to refer those of my readers who may wish for more ample information on the subject of the Atomic Theory, to the elegant Essay and Supplement of Professor Daubeny.*

" I consider," says Dr. Kane, " that sensible masses of mat-

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* An Introduction to the Atomic Theory, comprising a sketch of the opinions entertained by the most distinguished ancient and modern philosophers with respect to the constitution of matter, by Charles Daubeny, M. D. F. R. S. Professor of Chemistry in the University of Oxford. Price 6*s*., and a Supplement to the same. Price 2*s*.

ter are constituted of a number of lesser masses, which again may be made up of similar constituent groups, proceeding downwards to any extent, but still without involving the question of a limit to the degree of possible division. One class of these groups of particles, I consider to be represented by the equivalent numbers: and it is possible that these numbers may indicate the manner in which the chemically combined groups may be disposed to subdivide themselves: in order to generate a set of groups of an inferior class. The specific heats of bodies may be considered to have reference to an order of groups of particles often, but not necessarily coincident with those that combine to produce chemical compounds; and the third, probably the most remote, engaged in the ordinary properties of matter, may be such as being uniformly distributed in the gaseous form, confers upon those bodies the properties which characterize mechanically that condition, and are independent alike of the chemical properties and specific heats which appertain to, and are exhibited by groups of a more complex structure and superior order. From this point of view I contemplate the Atomic Theory."

The electrical agency appears to be so intimately connected with chemical action, becoming sensible in all cases of union or decomposition, and being developed in a degree proportional to the amount of the same, that the opinion of their identity is held by many of the most distinguished philosophers. I shall not however enter upon the subject of Electricity here, having some little time since submitted to the public, a short course of Eight popular Lectures, on the sciences of Electricity, Galvanism, Magnetism, and Magneto and Thermo Electricity, which little work I can confidently recommend to the notice of the general reader.

I proceed now with the non-metallic undecompounded bodies.

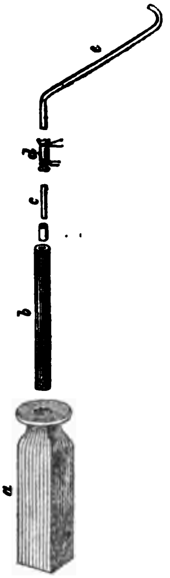
OXYGEN.

This is the most extensively diffused body in nature. It constitutes more than one-fifth of the air which we breathe, and eight-ninths of the whole quantity of water on the surface of the earth. It enters into the composition of most animal and vegetable substances; and into nearly all the earths and rocks of which the crust of our globe is composed, of which indeed, it may be considered as forming one-third of the total weight. It is consumed in immense quantities in the processes of respiration and combustion, and the functions of organized existence are connected and sustained through its agency.

Every human being on the face of the earth consumes nearly twenty-five cubic feet of oxygen every twenty-four hours, (45000 cubic inches daily, according to Lavoisier, Seguin, and Davy), and one hundred weight of charcoal requires for its combustion thirty-two cubic feet, yet notwithstanding this immense hourly consumption, the quantity of this essential principle is not diminished in the atmosphere, but bears the same proportion to the nitrogen the other ingredient, *now*, as it did centuries ago, for which an explanation will be given hereafter.

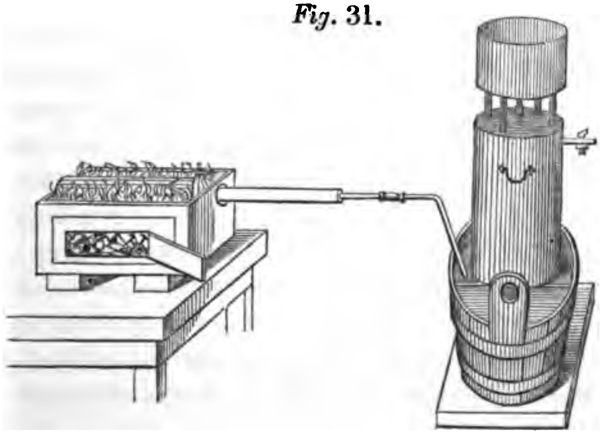
Preparation. We are acquainted with several methods of procuring this gas for examination; the one most commonly resorted to is the partial decomposition of the peroxide of manganese ($Mn\ O_2$) by means of heat; to effect this we proceed as follows. A pound of good Exeter manganese is first washed with diluted hydrochloric acid, to decompose any carbonates which may be present, and then repeatedly with clean water; it is afterwards made thoroughly dry by a moderate heat. This purified material is then introduced into a stout iron bottle, *a*, *Fig.* 30, to which is fitted by grinding, a connecting tube, *b*, which may be a piece of sound gun-barrel, to this again is attached a smaller tube, *c*, by means of a cork, and to give freedom of motion, the delivery tube, *e*, is connected with *c*, by means of a caoutchouc connector *d*. These caoutchouc connectors are invaluable in the chemical laboratory for uniting with ease and expedition various pieces of apparatus. They are very readily made by taking a piece of sheet India rubber, (which may be procured of any Philosophical instrument maker, at a very moderate price,) about an inch square, and having warmed it at the fire, wrapping it round a piece of glass rod or tube rather smaller than the connectors are required, then, on cutting the edges of the caoutchouc with a sharp pair of scissars, the clear surfaces will be found to adhere very readily, and by pressing them together with the thumb-nails, a strong and perfect joint is obtained. If a thin glass tube be employed, it may be removed from the interior of the caoutchouc tube by crushing it in pieces, but if a glass rod be used, it is advisable to rub it over with a little chalk previous to wrapping the India rubber over it, as by this means adhesion is prevented.

Fig. 30.



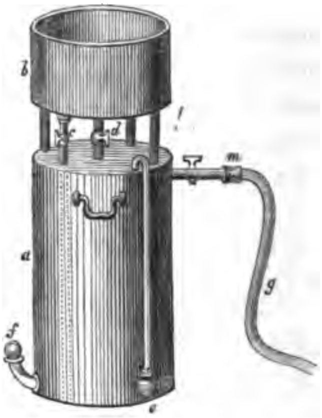
The iron bottle may be about two-thirds filled with the peroxide, and the tubes being securely united, it may be placed in any convenient furnace or fire-place, it soon becomes red hot, vapour of water first passes off, but when a piece of

Fig. 31.



glowing stick bursts into a flame and burns vehemently on being presented to the mouth of the delivery tube, the gas may be collected, and if required in considerable quantities, it is best done so in a gasometer. The whole arrangement is shown in *Fig.* 31.

Fig. 32.



The construction of the gas holder is as follows:— *a*, *Fig.* 32, is a japanned cylindrical copper vessel, of the capacity of four or five gallons, furnished with two handles; on this is secured by five props of copper, another vessel, *b*; two of these props are hollow tubes with stop cocks; one of them, *c*, passes down nearly to the bottom of the vessel, the other, *d*, only extends to the upper surface; when the gasometer is about to be filled with gas, it is first filled with water, by pouring it into the upper vessel and opening both stop-cocks; the water runs in through *c*, and the atmospheric air escapes through *d*; the height of the water in the vessel is shown by the guage-pipe, *e*. The vessel being full of water, the cocks are closed, and then the plug, *f*, may be removed, when it is obvious that no water can escape, because no air can enter to supply its place; but if air be introduced at this aperture, then, of course the water will flow out, the air occupying its place. The method therefore of filling the gasometer with any required gas, will be easily understood by referring to *Fig.* 31, in which the iron oxygen bottle is represented in a furnace with its delivery tube inserted in the lower aperture of the gas-holder placed over a tub; the heat expels oxygen from the peroxide, a pound of which, if good, will be found quite sufficient to fill a gas-holder of the capacity of four gallons. In order to obtain the gas from the vessel from time to time, as it may be required for experiment, the upper vessel being filled with water, we may either collect the gas in an air jar inverted over *d*, both cocks being opened, or, which is much more convenient, we may conduct it to any vessel standing over the pneumatic trough, by means of the flexible tube, *g*.

In the process just described for procuring oxygen gas, not more than one-third of the oxygen is expelled from the peroxide of manganese. This metal, as has been already stated, is capable of uniting with oxygen in several proportions, as 346 parts of manganese or one equivalent, with 100, and 200 parts of oxygen and two equivalents of manganese, with 300 of oxygen.

These compounds are

	SYMBOL.	EQUIV:
Protoxide of manganese.	MnO	446.
Deutoxide.	$2MnO_3$	992.
Peroxide, or native black oxide	MnO_2	546.

When the peroxide is submitted to a red heat, the change which takes place in it may be thus expressed:—

$$3\,MnO_2\ 1638 = \left\{ \begin{array}{l} 2O\,..\,200 \\ Mn_2O_3\ 992 + MnO\ 446 \end{array} \right\} = 1638$$

Or,

1638 grains of peroxide of manganese, yield 200 grains of oxygen gas, and 1438 grains of a mixture of 992 grains of deutoxide and 446 grains of protoxide of manganese.

We are here supposing the peroxide to be pure, which it never is, as met with in commerce; we may consider four gallons of gas from one pound, to be about the maximum obtainable quantity.

By treating the peroxide of manganese with oil of vitriol, a larger quantity of oxygen gas ought theoretically to be obtained, one half of that principle becoming free, and sulphate of *protoxide* of manganese being formed; we rarely however obtain this increased quantity, and the operation is not convenient in practice.

The oxygen gas obtained by the partial decomposition of peroxide of manganese, is not quite pure, though sufficiently so for many practical purposes: if not previously washed with a dilute acid, the peroxide invariably yields a greater or less quantity of carbonic acid gas; and however carefully it may be purified, nitrogen is always mixed with the oxygen, though in so small a proportion as not to be worth notice, except in delicate analytical experiments. When the gas is required perfectly pure it is prepared by heating in a glass tube, to which another bent tube is attached, a small quantity of ***chlorate of potash.*** This salt is a compound of chloric acid (ClO_5), and potash, (KO), of two substances containing oxygen; and it so happens that the other elements, namely, chlorine and potassium, (potash is an oxide of the metal potassium,) are capable of entering into combination, giving rise to a distinct salt, the chloride of potassium containing no oxygen at all; now this change from chlorate of potash, ($ClO_5 + KO$) to chloride of potassium, ($K\,Cl$) is brought about by the action of heat; the salt first melts, though it contains no water of crystallization, and when nearly red hot, emits abundance of oxygen gas almost pure:* care must be taken not to raise the temperature above a dull red heat, otherwise the effervescence may become so violent as to burst the tube. Let us see how much oxygen gas we ought theoretically to obtain from a given portion of salt.

$$(KO + ClO_5)\ 1532 = \left\{ \begin{array}{l} (6\,O)\ldots 600 \\ (KCl)\ldots 932 \end{array} \right.$$

Or,

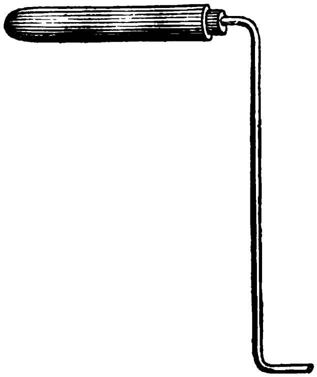
1532 grains of chlorate of potash, yield 600 grains of oxygen gas, and 932 grains of chloride of potassium: practically, half an ounce of chlorate of potash should yield 270 cubic inches, or nearly a gallon of pure oxygen gas. Of these two processes for procuring oxygen, the student is recommended to adopt the latter; the chlorate of potassa may be procured of any respectable Chemist, at about 9*d.* per ounce, so that two gallons of gas, almost pure, may be obtained for that sum; the process is more elegant, and more readily put in operation

---

* I find that the best chlorate of potash yields from 96 to 98 per cent. of pure oxygen.

than the other, and by introducing a small quantity of the salt into a glass tube, to which a conducting tube is attached by means of a cork, then heating it over a lamp till gas begins to be disengaged, we can have a supply of oxygen at a minute's notice: two or three of these tubes may be prepared and laid by for use; the termination of the delivery tubes being hermetically sealed by the blow-pipe before they are laid by, so that when we want a quantity of pure oxygen for an immediate experiment, we have only to file off the end of the delivery tube, apply heat to the salt and collect the gas over the water trough, and the first bubble that passes over may be preserved, the atmospheric air having been removed from the tube, and its place supplied by oxygen by the previous heating of the tube. *Fig.* 33 represents the simple little apparatus that may be used for this purpose.

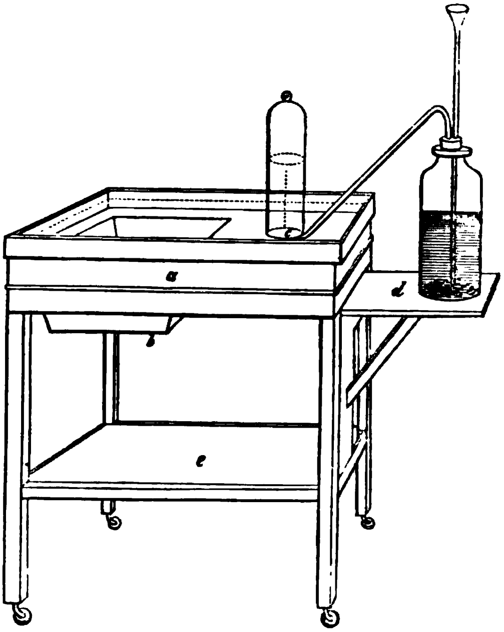
Fig. 33.



Before we proceed further with manipulation with the gases, the method of collecting and preserving them must be described. Many of the gases, such as oxygen, hydrogen, and nitrogen, may be collected and preserved over water, and we are indebted to Dr. Priestley for a convenient apparatus for effecting this, as also for numerous other instruments employed in pneumatic chemistry.

The most convenient form of the hydro-pneumatic trough, is that represented in *Fig.* 34. It consists of a copper trough placed in a wooden frame or stand; this trough may be made of japanned copper, twenty-eight inches long and fourteen inches wide; the well, *b*, may be fourteen inches deep, and in the shelf, *c*, two grooves are made six inches long and two inches wide, over which the vessels to be filled with gas are

Fig. 34.



placed, having been previously filled with water in the well, *b*. The retort or vessel in which the gas is generated is placed on the shelf *d*; the delivery tube being passed under the receiver standing over the groove, the lower shelf *e*, is very convenient for the reception of jars, &c. and the legs of the stand may be furnished with castors, by means of which the apparatus may be easily moved to different parts of the laboratory as occasions may require. Common confectioners' jars, and apothecaries' phials will answer exceedingly well for receiving and retaining gases over the hydro-pneumatic trough; but jars are sold of various sizes and shapes for the purpose, by the Philosophical instrument makers. It is convenient to have a few of these graduated into cubic inches and supplied with a stop-cock, as in *Fig*. 35; and for measuring small quantities of gas, tubes, graduated into 10ths and 100ths of a cubic

Fig. 35.

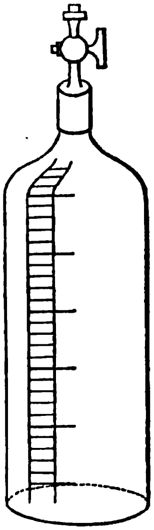
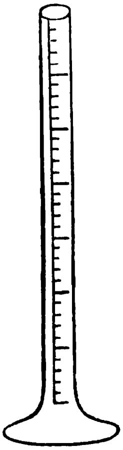
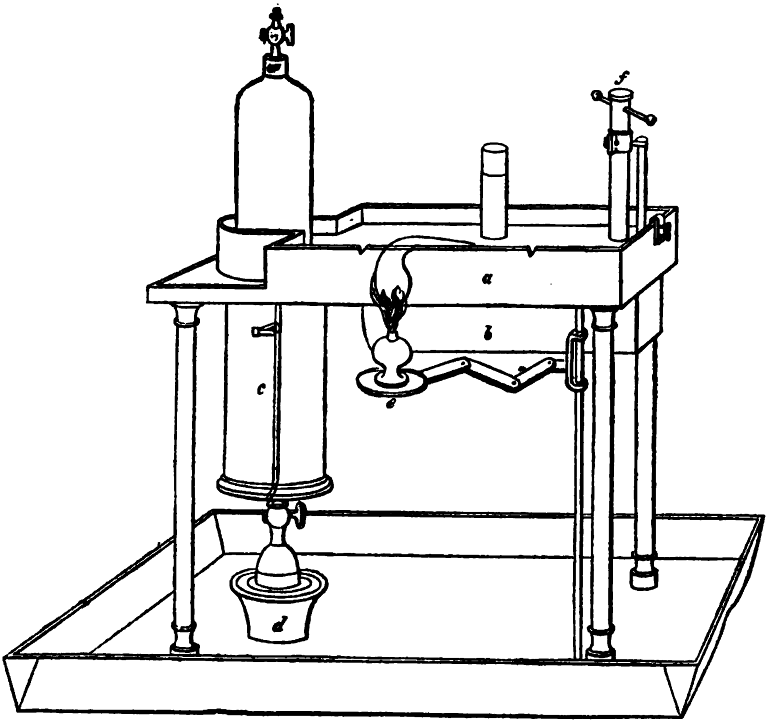


Fig. 36.



inch, as in *Fig.* 36, may be employed. It is convenient also to have a few jars open at the top and bottom and carefully ground, so that they may be covered with ground-glass plates; they may be had of Mr. J. Ward, 79, Bishopsgate Street Within, of half pint, pint, two pints, three pints, and four pints capacity, at 1*s.* 6*d.*, 2*s.* 6*d.*, 4*s.*, 4*s.* 6*d.*, and 5*s.* each.

There are some gases however, as cyanogen, sulphuric, and muriatic acid gases, ammonia, &c., which cannot be collected or preserved over water, in consequence of their solubility in that fluid, for these we employ mercury, and in consequence of the great expense of that metal, various plans have been devised for economising it in the construction of the mercurio-pneumatic apparatus: the best and most complete arrangement is that contrived by Newman, (Quarterly Journal, vol. 1, page 185,) and represented in *Fig.* 37. It consists of a trough



of cast-iron, supported by brass or iron legs, and having a small gasometer at one end. It is placed in a japanned iron tray to collect the scattered mercury; in the figure, *a*, is the shallow, *b*, the deeper part of the trough; *e*, is a sliding stand for a lamp; *f*, a detonating tube screwed into a spring support; *c*, the gasometer which is filled from the bottom, through the small basin of mercury at *d*. This is a very expensive apparatus, and requires a considerable quantity of mercury, at least 40 lbs. to work it with. It is, however, by no means necessary for the beginner in pneumatic chemistry, though indispensable in the laboratory of research; a much simpler and cheaper trough has been devised by Ollerenshaw, it is shown in *Fig.* 38; it is made of cast-iron, and is applicable with only 7lbs. of mercury; it may be had of Messrs. Knight, of Foster lane, for 18*s*., or mounted on iron legs, with a well, for £1. 17*s*. and the mercury will cost about 30*s*. more. A set of small thick jars are made to use with this trough, as represented in the figure, and may be had of the same makers.

Fig. 38.

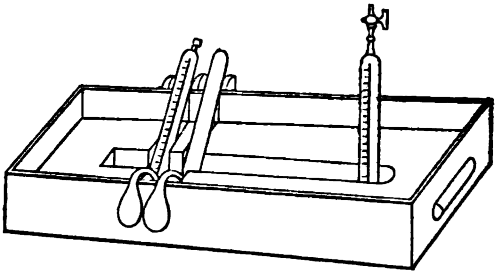
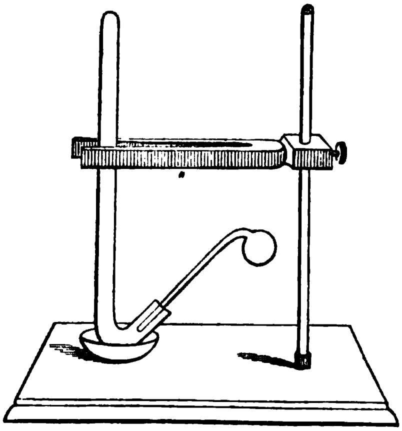


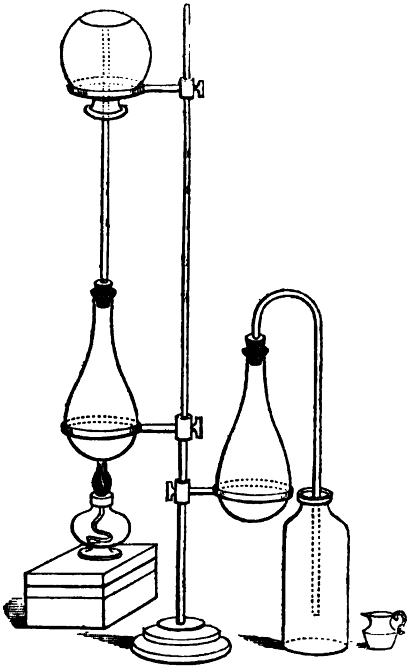
Fig. 39.



The student may even dispense with a trough altogether, by employing a little apparatus devised by Cooper, and shown in *Fig.* 39, it consists simply of a bent tube, supported by a forceps over a small evaporating dish; it is filled with the gas to be experimented upon from a little retort, in the manner shown in the figure, and will be found to answer the purpose exceedingly well when the general characters of the gas are only desired to be ascertained.

Indeed when no great precision is required, many of the gases absorbable by water, may be collected and examined by *displacement*. If the gas be lighter than atmospheric air, it may be generated in the flask B, *Fig.* 40, and collected in the inverted vessel, *c*, if heavier than atmospheric air it may be generated in D, and collected in A; by the former method ammonia may be collected and examined; the latter furnishes a good method of collecting and examining the protoxide of chlorine.

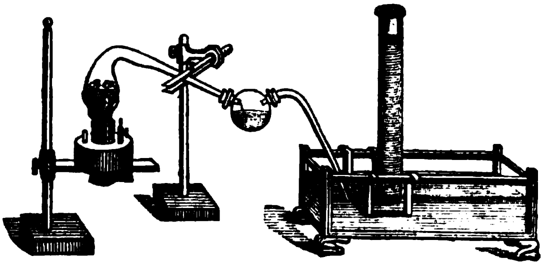
Fig. 40.



A little practice will soon enable the student to become expert in manipulating with the gases over the hydro-pneumatic trough. Air is transferred from one vessel to another by an *inverted pouring;* when we pour water into a jar we displace the air, the water being heavier, and conversely if we first fill the jar with water and invert it over that fluid, we may substitute any kind of air (not absorbable by water) for that water by passing it under the mouth of the inverted vessel, when, from its superior levity it will remove the water and occupy its place in the jar; it is not difficult to transfer air from a wide vessel, such as a tumbler, into a narrow tube, and by employing a funnel, a little practice with common air will enable the the operator to effect this without the loss of a single bubble. The manipulation is not so easy with mercury on account of the great weight of that fluid metal, but it is conducted in precisely the same manner. The student will also find that in filling jars over mercury greater care is required, in consequence of the absence of that adhesion which appears to take place between the particles of water and those of gas, and which causes the bubbles to become divided and to pass up in a quiet and uniform stream; in mercury on the other hand the gas passes up by jumps, frequently filling the jar at once: all these little particulars will however soon become familiar—and be guarded against by the operator. In estimating the volume of gas in a jar standing over mercury or water, due regard must be paid to the temperature of the room, and to the pressure of the atmosphere as indicated by the barometer; simple rules have been given for this in our second lecture.

To return to oxygen:—*Fig.* 41 represents a little apparatus for obtaining oxygen gas by the decomposition of red oxide of

Fig. 41.



mercury; the process is not practically useful, but the student is recommended to make the experiment, which is exceedingly instructive and interesting, as demonstrating the true constitution of metallic oxides.

Into the little retort, which must be of hard glass, there is introduced some red oxide of mercury, (known in pharmacy as red precipitate,) say an equivalent (HgO) 1366 grains; the retort is then attached to a receiver, provided with a tube, passing to the pneumatic trough. On applying the heat of an argand lamp to the oxide of mercury, it is entirely decomposed; the oxygen is given off in the form of gas, and the mercury distills over into the receiver. From one equivalent of the oxide we get 100 grains or nearly 300 cubic inches of oxygen gas, and 1266 grains of mercury are found in the receiver.

Properties of oxygen gas:—It is colourless and destitute of taste and smell: when however it is obtained by the voltaic decomposition of water, it always has a very peculiar, and in large quantities quite a *pungent* smell; the odour is precisely similar to that which accompanies the electricity of the electrical machine, and which every person who has witnessed the working of a large one cannot fail to have noticed. It is worthy of remark, that the hydrogen of the decomposed water has not the slightest odour, and there is no doubt that its presence in oxygen is occasioned by the presence of some, as yet uninsulated substance, to which Dr. Schoenbein has provisionally proposed the name of ozone, Ὄζω Greek, to smell.

Oxygen gas is heavier than atmospheric air in the proportion of 1102·6 to 1000, *(Dulong and Berzelius,)* and if 100 cubic inches of common air, at the temperature of 60°, and with the barometer at 30 inches, are taken to weigh 31 grains, 100 cubic inches of oxygen will weigh 34·18 grains, and one cubic inch will weigh 0·3418, or nearly one-third of a grain.

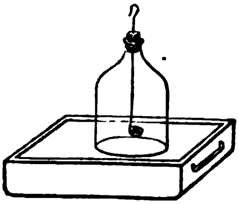
The most remarkable property of this gas is the energy with which it supports combustion.

Experiment 1. Light a green wax taper, then blow it out, so that the wick continues glowing; in this state introduce it by means of a bent copper wire, into a jar of oxygen gas; it will become re-ignited with a sort of explosion, and this may be repeated several times in the same quantity of gas.

Experiment 2. Place a piece of phosphorus, about the size of a pea, on a small copper stand on the shelf of the hydro-pneumatic trough; have a large wide-mouthed jar of oxygen close at hand, and having touched the phosphorus with a hot wire, so that it becomes ignited, quickly place the jar of oxygen gas over it, the phosphorus will burn with a degree of splendour insupportable to the eye. In this experiment care must be taken to dry the phosphorus thoroughly with blotting paper, otherwise it is apt to spirt and throw out ignited fragments against the sides of the jar. When the phosphorus is consumed the jar will be observed to be filled with dense white vapours, and the rise of water in the vessel will show that these vapours are absorbable by that fluid. By allowing it to stand for about half an hour the white fumes will disappear, and the water will have risen nearly to the top of the jar. If a drop of this water be now tasted, it will be found to be quite sour, from which we learn that the combustion of phosphorus in oxygen gas has given rise to the formation of an acid. It was from this circumstance, from the fact, that many combustibles by uniting with oxygen, give rise to *acids*, that this principle obtained its name; the word *oxygen* being derived from two Greek words οξυς, acid, and γεννειν, to generate. It was supposed by the French nomenclaturists, that oxygen was indispensable to acidity, and though we have now abundance of evidence that this is not necessarily the case, still the name is retained, because we have no better, and it is certain that in several of the most powerful acids, as the sulphuric and nitric, oxygen *is* the acidifying principle, and that the bases, as sulphur and nitrogen, have, to a certain point their acid powers increased, by an increase in the quantity of oxygen, with which they are caused to combine.

Experiment 3. Light a small quantity of sulphur in a copper spoon, and introduce it into a jar of oxygen gas, as represented in *Fig.* 42, it will burn with a beautiful blue flame, and sulphurous acid gas will be produced, strongly acidifying the water, which, at the conclusion of the experiment will rise in the jar.

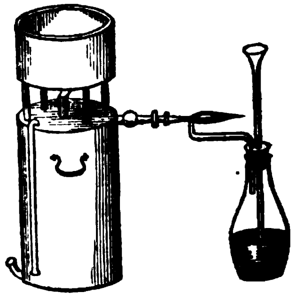
Fig. 42.



Experiment 4. Ignite a piece of charcoal, made from some light wood, and covered (if such can be procured,) with portions of the bark; introduce it into a jar of oxygen gas, as in the last experiment; it will burn vividly and throw off jets of brilliant sparks, the oxygen gas being converted into carbonic acid gas; if the charcoal be well burned and made of dense wood, it will not throw off sparks, but glow with intense heat, and gradually disappear.

Experiment 5. Coil some harpsichord wire in a spiral form round a cylindrical rod, to the end attach a piece of waxed cotton wick, or dip it into melted sulphur; then light it, and immerse it in a jar of pure oxygen gas; the combustion will extend from the sulphur or wick, to the iron, which will burn with an intense white light, throwing out a number of brilliant sparks, occasionally allowing a globule of fused oxide to fall, emitting a most intense light, and the wire continues to fuse and burn till it is entirely consumed, or till the oxygen is exhausted. The heat evolved by this rapid combination of iron and oxygen is so great, that the melted oxide flowing down in drops from the extremity of the wire, fuses itself into the substance of the stone-ware plate on which it falls, even after passing through a layer of water; and if any of the drops happen to be projected against the sides of the jar, they will melt their way into its substance, or even, if the glass is not very thick, pass completely through. Another very convenient method of exhibiting the combustion of steel spring, is to screw a jet on the cock, *m*, of the gasometer, *Fig.* 43, and having opened the cock, *c*, allow a stream of gas to play on

Fig. 43.



the steel spring placed before it, and heated to redness, or ignited by passing the stream of oxygen through a spirit lamp, which is afterwards removed: indeed, by this means, the most refractory substances may be fused. If the tube or jet be curved downwards, it may be brought to bear on a little cup of red-hot charcoal, in which the body to be fused may be laid, and thus, upon a small scale, the construction and effect of the most powerful wind furnaces may be imitated. In this experiment there is produced, not as in the last, an acid gas, but an oxide; the metallic iron becomes *protoxide of iron*, its weight is increased, and this increase is precisely equal to the weight of the oxygen consumed.

Experiment 6. Take some turnings of zinc, make them into a little ball, in which insert a small piece of phosphorus, set fire to it and introduce it quickly into a jar of oxygen gas; the zinc will take fire and burn with a beautiful green flame surrounded by a white one.

Experiment 7. Introduce into a jar of oxygen gas a mixture of equal parts of nitrate of strontia, and charcoal powder previously ignited: it will burn with a *rose-coloured* flame.

Experiment 8. Introduce a mixture of one part of boracic acid, and three of charcoal powder; the colour of the flame will be *green.*

Experiment 9. Introduce a mixture of one part of nitrate of barytes, and four of charcoal powder; the colour of the flame will be *yellow.*

Experiment 10. Introduce a mixture of equal parts of nitrate of lime, and charcoal powder; the colour of the flame will be *orange red.*

Experiment 11. Take a small piece of the metal potassium, and having carefully wiped off the naptha adhering to its surface, heat it in a deflagrating spoon over a spirit lamp, and when a purple flame appears plunge it into a jar of oxygen, it will burn vividly; wash out the spoon with a little water, and dip into the washing a slip of *yellow turmeric* paper, it will instantly become brown indicating the presence of the alkali potassa or oxide of potassium.

From this experiment we learn, that a class of bodies entirely opposed to acids is formed through the agency of oxygen, and it will hereafter be shown that all the alkalies, alkaline earths, and earths proper, are oxides of peculiar bases, and that those bases are metals. The nature of the compound formed with oxygen depends entirely on the nature of the base; for instance, when arsenic is burnt in oxygen gas, an acid is formed; when potassium is burnt, an alkali is formed; and the union of the metal calcium with oxygen gives rise to an earth, viz: *lime.*

Oxygen gas is essential to animal life, and it is its presence in the atmospheric air which fits that compound for its uses in the œconomy of nature. The change which it produces in the blood of a living animal may be seen by agitating it with a portion of blood drawn from a vein, the dark colour becomes a fine vermilion red, characteristic of arterial blood. Oxygen gas then is absolutely essential to arterialization, though to maintain animal life it must be diluted.

An animal can live longer in a vessel of pure oxygen than in the same volume of atmospheric air: nevertheless its continued respiration in a state of purity is injurious, nay, fatal. A rabbit is found to breathe it without inconvenience for some time, but after an interval of an hour or more the circulation and respiration are much quickened, and a state of great excitement of the general system supervenes; this is followed by debility, and death occurs in from six to ten hours. The blood is found to be highly florid in the veins as well as in the arteries, and the heart continues to act strongly after the breathing has ceased.—*Broughton.* The animal lives as it were too fast, and death is occasioned by a general inflammatory fever.

In every case of ordinary combustion there is a consumption of oxygen, and the heat produced depends exclusively upon the quantity of that principle consumed. The chemical combinations of oxygen are of all chemical phœnomena those which we most frequently witness, and are all attended with the evolution of heat. When a body combines with oxygen, it is said in ordinary language to be *burned,* instead of undergoing oxidation it is said to suffer combustion; a body which can combine with oxygen and emit heat, is termed a *combustible* and the oxygen in which the body burns, is called a supporter of combustion.

We have seen that when iron is made to burn *rapidly* in pure oxygen gas, great heat and light are emitted, and the metal becomes an oxide; but oxidation is often a very slow and imperceptible process, as in the rusting of iron, and the tarnishing of lead exposed to the atmosphere: the heat is then evolved in a very gradual manner and is dissipated, but never accumulates. Every circumstance which favours oxidation and quickens the process, occasions a greater or less development of heat, of this fact, lead furnishes a very instructive example; when that metal gradually tarnishes in the air, the heat, as has been observed, is dissipated, but when it is exposed in a fine state of division, (as it occurs in the lead pyrophorus,) to oxygen even in the diluted state in which it exists in atmospheric air, sufficient heat is developed to cause ignition, the pyrophorus spontaneously takes fire and burns.

The heat occasioned by the absorption of oxygen is also well seen in the formation of vinegar from spirituous liquors; it may even be observed in tallow, which, by peculiar management, may be made to undergo oxidation without producing any flame, though the heat evolved is sufficient to keep it melted. This is an instructive experiment, it may be made by heating some tallow in a little cup, with a wire attached, till it boils and catches fire, the flame must then be blown out; nevertheless, the tallow will continue in a state of low combustion, but without any visible flame, but on introducing the cup into a jar of oxygen, high combustion is renewed.—*Graham.* As oxidation produces heat, so is the disposition of bodies to absorb and combine with oxygen much increased by heating them; hence it is, that to make bodies burn, they must be previously heated to a certain point, and from the circumstance of their continuing to burn till they are entirely consumed, we learn that the heat evolved during combustion is greatly superior to that required, merely to inflame the combustible.

All ordinary combustibles such as wood, coals, oil, tallow, wax, &c. yield, during their combustion, carbonic acid, gas, and water, both of these compounds being volatile, disappear, forming part of that ærial column that rises from the burning body: by this continuous removal of the products of combustion, oxidation is greatly favoured. The interference of air in combustion is seen every day, in the facility with which fires are checked or extinguished, when the supply of air is lessened or witheld, and increased and invigorated when a larger supply of air is furnished them by blowing with the bellows.

The following experiment the student will find interesting, as proving that a constant supply of oxygen is essential to maintain the combustion of an inflammable body.

Experiment 12. Fix a small taper into a piece of cork, so that it may float in water; light it; then cover it with a bell-glass jar, open at the top; the taper will burn for some time without change, then more and more feebly in proportion as the oxygen is exhausted, and at last will expire. The air remaining in the jar will be found unable to support further combustion, and a second lighted taper will be extinguished immediately after it is introduced by the opening at top.

It is very common to speak of the *destruction* of bodies by combustion; in a general sense this is true, as their properties and appearances are entirely changed by the process: but matter is indestructible, and substances when they burn are merely entering into fresh chemical arrangements, and passing from one state of usefulness to another; no loss of ponderable matter occurs;—nothing is annihilated: charcoal, coal, &c., by their combustion, yield carbonic acid gas, and though we lose the carbon as a combustible, we find it again as the basis of that endless variety of vegetable matter with which our earth is clothed.

It is not difficult to collect the products of combustion, and when this is carefully done, the matter formed is found to have exactly the weight of the oxygen and combustible together which have disappeared.

When four grains of phosphorus are burnt in a given measure of oxygen gas, they are found after combustion in the state of a white powder which weighs nine grains, or the phosphorus acquires five grains; at the same time fifteen cubic inches of oxygen gas have disappeared, the weight of which is exactly five grains.

The most complete illustration of what occurs in combustion, is furnished by the oxidation of mercury. Exposed for a considerable time to a moderate heat, in a vessel of oxygen gas, that metal is converted into red scales of oxide, which possess the additional weight of a certain volume of oxygen which has disappeared. This oxygen is again liberated by a red heat, as has been already stated, and the apparatus for observing which is given in *Fig.* 41.

The following was the explanation of this process, offered by Mr. Kirwan, on the Phlogistic Theory. "The mercury, when exposed to a certain degree of heat in contact with pure air, imbibes indeed the pure air and nothing else, retaining the whole of its own *phlogiston*; so that then it may be said to contain fixed air, which is composed of phlogiston and dephlogisticated air; and that in a greater degree of heat, the latter is expelled while the former is retained: so that this calx was always possessed of phlogiston sufficient for its own removal."

All the facts which have been noticed, and all the phœnomena which have been observed connected with combustion, have not hitherto enabled us to account for the most striking phœnomenon;—the evolution of heat; its reference to a loss of latent heat by the combustible and oxygen, from their change from gas or liquid, to solid; to a reduction of capacity for heat; to a discharge of electricities; &c. is speculative and unsatisfactory; and we must at present be content to receive the evolution of heat during intense chemical combination, such as oxidation, as an *ultimate fact*, for which, in the present state of our knowledge we are unable to provide an adequate explanation.

LECTURE SIXTH.

HYDROGEN—ITS ABUNDANCE—PREPARATION BY THE DECOMPOSITION OF WATER—ANALOGY OF WATER AND METALLIC OXIDES.—DECOMPOSITION OF WATER BY POTASSIUM—BY IRON.—CURIOUS CASE OF INVERSION OF AFFINITIES BY MODIFYING CIRCUMSTANCES.—DECOMPOSITION OF WATER THROUGH THE AGENCY OF A METAL AND AN ACID—RATIONALE OF THIS METHOD OF PROCURING HYDROGEN GAS.—OTHER PROCESSES FOR OBTAINING THE GAS—BY VOLTAIC ELECTRICITY.—PECULIARITY OF AMALGAMATED ZINC.—EXPERIMENTS TO ILLUSTRATE THE PROPERTIES OF HYDROGEN GAS—ITS INFLAMMABILITY, LEVITY, ETC.—ITS VIOLENT DETONATION WHEN MIXED WITH OXYGEN AND IGNITED.—WATER SHOWN TO BE THE RESULT OF THE UNION OF THE TWO GASES—CIRCUMSTANCES AFFECTING THEIR COMBINATION—EXPLOSION BY THE ELECTRIC SPARK.—METHOD OF MAKING EUDIOMETER TUBES.—SILENT COMBINATION OF OXYGEN AND HYDROGEN GASES.—INFLUENCE OF SPONGY PLATINA ON INFLAMMABLE GASES—OTHER CURIOUS PROPERTIES OF THAT METAL IN A FINE STATE OF DIVISION.—INTENSE HEAT OF THE FLAME OF A MIXTURE OF OXYGEN AND HYDROGEN GASES—THE HYDRO-OXYGEN BLOWPIPE—DIFFERENT FORMS OF THE INSTRUMENT—HEMMING'S SAFETY JET—INTENSE LIGHT OCCASIONED WHEN THE FLAME IS DIRECTED AGAINST A CYLINDER OF LIME—THE OXY-HYDROGEN MICROSCOPE—WATER—EXPERIMENT OF BERZELIUS—INQUIRY AS TO THE TRUE DISCOVERER OF THE THEORY OF ITS COMPOSITION—THE GRAND EXPERIMENT OF FOURCROY, VAQUELIN, AND SEGUIN.—PROPER-

TIES OF WATER—ROCKS DISINTEGRATED BY ITS SOLIDIFICATION.—CLOUDS—MISTS—FOGS, ETC.—GREAT IMPORTANCE OF WATER IN CHEMICAL PHŒNOMENA—WATER DISSOLVES AIR—THE AIR FOUND IN RAIN AND SNOW WATER IS VERY RICH IN OXYGEN—IMPURITIES OF WATER AS IT IS FOUND IN NATURE—RAIN WATER THE PUREST—FILTRATION—THEORY OF CLARIFICATION BY THE WHITE OF EGG.

Hydrogen, though it does not exist in nature in an uncombined state, is one of the most extensively diffused of the elements: entering into the composition of nearly every organic substance both vegetable and animal, and forming one-ninth of the weight of water. Hydrogen gas was long confounded with other inflammable airs, it was formerly termed *inflammable air*, from its combustibility; and *phlogiston*, from the supposition that it was the matter of heat; its true nature was first pointed out by Mr. Cavendish, in 1766, and its present name is derived from ὕδωρ, water, and γεννειν, to generate.

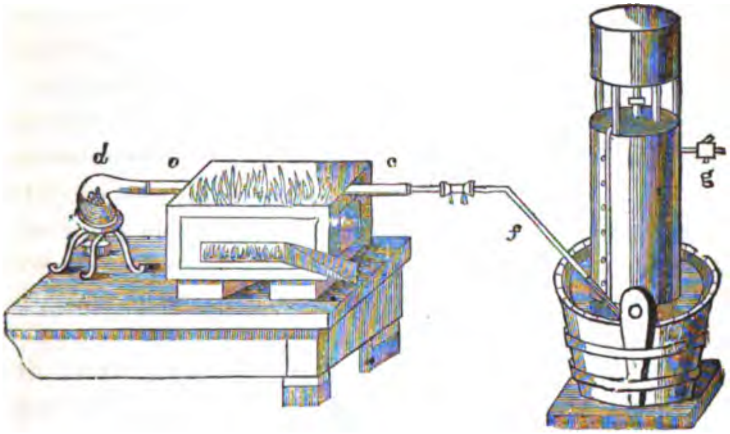
Preparation. It is by the decomposition of water, that hydrogen gas is always obtained for experimental purposes, and as this decomposition is readily effected by various simple means, so the preparation of hydrogen gas is a very easy operation.

Now water is to be viewed as an oxide of hydrogen, in the same manner as red precipitate is regarded as an oxide of mercury, and litharge as an oxide of lead, but these two metallic oxides differ very considerably in the tenacity with which they retain their oxygen, the former parting with that principle on the application of a moderate heat, as we have seen in the last lecture, while the latter retains it under the most intense heat to which it may be submitted. The oxides of gold and silver become decomposed by very slight causes, and other oxides, such as peroxide of manganese, require a very strong heat to effect even their *partial* decomposition.

But although litharge cannot be decomposed by heat *alone*, it may by igniting it with inflammable matter, such as charcoal, under which circumstances metallic lead is produced, while the oxygen combines with the charcoal, giving rise to carbonic oxide. Oxide of hydrogen or water is in the same case, if we heat it alone, we convert it into steam, a different state of existence it is true, but still it is its physical condition alone which is altered, for steam consists as essentially of oxygen and hydrogen as water itself. But if we heat water with certain inflammable matters, such as iron, we effect its decomposition, the metal becomes oxidized, and hydrogen gas is evolved. Some metals cause the decomposition of water with great rapidity by simply being brought into contact with it, and *without* the application of heat; potassium, the metallic base of the alkali potash is one of these metals. The experiment is a striking one, and the best that can be exhibited for proving the composition of water. Take a large test tube filled with common water; drop a small piece of potassium into it and immediately invert it over water; the metal will almost instantly disappear, potash will be formed, (as may be shown by inserting a slip of turmeric paper,) and a gaseous substance will be collected in the upper part of the tube, which will prove to be hydrogen gas. If a piece of the alkaline metal be dropped into water, in contact with the atmospheric air, a sufficient quantity of heat is generated by the energy of the decomposition to inflame the hydrogen gas, which burns as it is produced, with a beautiful purple flame.

By employing the arrangement represented in *Fig.* 44. hydrogen gas may be obtained from water, in quantities sufficient for practical purposes, *d*, a small retort, containing water, is adapted to a gun-barrel *c c*, filled with coils of iron wire, and heated to full redness, by being laid horizontally across a furnace: *f* is the delivery tube for transferring the evolved gas into the gas-holder *g*. When the fire in the furnace is lighted, heat is applied to the retort, the water in which is made to

Fig. 44.



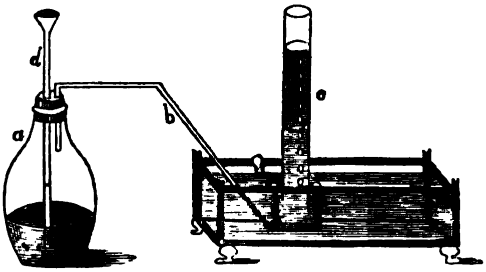
boil, and the steam passing over the red-hot iron undergoes decomposition, its oxygen entering into combination with the metal, and its hydrogen being disengaged in large quantities.

On examining the iron wire in the gun-barrel after the operation, it is found to have passed into the same state as when burned in oxygen gas, or at the smith's forge, namely, into the black-oxide, which is a compound of the protoxide and peroxide of iron.

In this experiment we have occasion to notice the striking manner in which the results of affinity are determined, by modifying circumstances, a subject which so fully engaged our attention in a former lecture. On passing steam over red-hot iron, it becomes decomposed, oxide of iron being formed, and hydrogen gas evolved; but if we pass a current of hydrogen gas over red-hot oxide of iron, the oxide is reduced to the metallic state, and water is generated; now, according to Bergman, (who supposed that in all cases, decompositions are determined *solely* by chemical attraction,) by the first of these two experiments, it is proved that iron has a greater affinity for oxygen than hydrogen has; and by the second, the affinity of hydrogen for that principle is shown to be the strongest; two decompositions, precisely the reverse of each other, may thus go on at the same temperature: the fact is, this appears to be a case in which affinities, nearly equal otherwise, are directed to one or the other object, according as one or the other substance is in excess. When the iron is kept in a stream of watery vapour, the latter is decomposed, and the hydrogen being carried away, according as it is formed by the current, it cannot interfere by its presence in any opposing manner. On the other hand, when oxide of iron is heated in a stream of hydrogen gas, it is decomposed, and the water being removed as rapidly as it is produced, the tendency to reaction is prevented.—*Kane.*

But hydrogen gas is most conveniently obtained by the agency of a dilute acid, with which view we place some fragments of zinc into the bottle *a*, *Fig.* 45, and pour over them oil of vitriol or concentrated sulphuric acid, diluted with six or eight times its bulk of water; rapid and instantaneous decomposition of water takes place, with the appearance of ebullition, and the evolution of considerable heat; the zinc is speedily dissolved, and the reaction which takes place, may be conveniently illustrated by a diagram :—

Fig. 45.



BEFORE DECOMPOSITION.			AFTER DECOMPOSITION.
613½ Oil of vitriol, or Sulphate of water	Hydrogen	12½	.... 12½ Hydrogen.
	Oxygen	100	1004 Sulphate of oxide of zinc.
	Sulphuric acid	501	
403 Zinc............	Zinc	403	
1016½		1016½	1016½

By this it will be seen that the hydrogen gas obtained in this experiment is derived from the decomposition of the water, combined with the sulphuric acid in the form of oil of vitriol, and that the change consists in the substitution of zinc for hydrogen, or in the formation of sulphate of oxide of zinc, in the place of sulphate of oxide of hydrogen. The object in employing such a large quantity of water is to remove by dissolving it, the crystallizable sulphate of oxide of zinc as fast as it is formed.

Zinc is conveniently prepared for making hydrogen gas by fusing some fragments in a crucible, and pouring it, while liquid, from a height of six or eight feet into a vessel of cold water; by this means it becomes *granulated*, and is easily broken into small pieces. The metal may even be reduced to a powder by pouring it, while in fusion, into a wooden box, the inside of which has been rubbed with chalk to prevent the wood from becoming charred, and agitating it smartly, as the metal gets cold it separates into minute grains, which are found very convenient for many experimental purposes.

When large quantities of hydrogen gas are to be collected, a half-gallon stone-ware jar may be mounted as a gas bottle, with a flexible metallic pipe, fitted to the cork as an exit-tube, and before collecting the gas, care must be taken to allow the first portions to escape, as it will be mixed with the air of the gas bottle, forming an explosive compound. From one ounce of zinc, 615 cubic inches of hydrogen gas are procurable.

The hydrogen gas obtained by this process is not chemically pure, as is proved by its offensive odour, which is ascribed by Berzelius to the presence of a volatile oily compound of carbon and hydrogen, and which may be entirely removed by transmitting the gas through alcohol. The zinc of commerce generally contains sulphur; hence the formation of a small quantity of hydro-sulphuric acid, which may be removed by passing the gas through a solution of pure potassa; a minute quantity of metallic zinc is also contained in it, probably in a state of chemical combination; but the greater part of these impurities are removed by generating the gas slowly, and allowing it to bubble through caustic potash before collecting it for use; but when it is required perfectly pure, distilled zinc should be employed, or the gas obtained by acting on pure water with a mixture of the alkaline metal sodium with quicksilver.

A very elegant extemporary process may be resorted to for preparing small quantities of pure hydrogen gas, by those who are in possession of a platina crucible. Fill the crucible with dilute sulphuric acid, and invert it in a basin of the same, so that it shall be completely covered, then lay on the top a piece of amalgamated zinc,* by this means a voltaic circle is formed, of which the platina is the negative element; hydrogen gas is therefore evolved from it, and a portion collects within the crucible. By a series of ten of Daniell's large constant batteries, I find I can obtain an uniform evolution 'of from ten to twelve cubic inches of the mixed gases per minute, for several hours; now two-thirds by volume of this mixture is pure hydrogen gas, which may be collected separate by using a decomposing apparatus, consisting of a glass cup, made in two parts, and having a slip of membrane secured in the centre, so as to divide the cup into two cells; bent glass tubes are fitted airtight by grinding over each cell, which also contains a large platina plate, communicating with a binding screw or mercury cup on the outside; the cup is then filled with dilute sulphuric acid, and connection made with the battery; from the positive element, (the plate connected with the copper cell) oxygen gas is given off; and from the negative element, (the plate connected with the zinc rod) hydrogen gas is evolved, and both may therefore readily be collected over the hydro-pneumatic trough. This useful and elegant little apparatus may be obtained of Messrs. Knight and Sons, of Foster Lane, the price is two pounds ten shillings. We are thus furnished with a ready method of procuring both oxygen and hydrogen gases in considerable quantities. The hydrogen may be regarded, after being

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* Zinc may be amalgamated by washing it with dilute sulphuric acid, and rubbing it over with quicksilver, which will then readily adhere to it.

dried, as perfectly pure; the oxygen probably contains some hitherto uninsulated substance from which it derives that peculiar odour, from which, as was mentioned in the last Lecture, it is never free, when prepared by Electricity.

It may here be remarked that the student will find, that pure or amalgamated zinc is much more sluggishly acted on by dilute acid, than the common or granulated metal, this arises from the fact, that owing to the impurity of the latter, a series of Electric currents are put in circulation from one part of the metal to another, through the liquid; these currents by affording a ready escape for the hydrogen gas, favour the chemical action to a very considerable extent.*

Properties. Hydrogen gas is the lightest of the Elements, being only one-fifteenth of the specific gravity of atmospheric air, or as 68·8 to 1000. It is not poisonous, except inasmuch as it contains no oxygen; it may be inspired for a short time without inconvenience, and is found to have an amusing effect on the voice, which it makes for a time remarkably shrill.

To familiarize himself with the characters of hydrogen gas, let the student make the following experiments.

Experiment 1. Generate a quantity of the gas from zinc and dilute sulphuric acid, and collect it in several jars over the hydro-pneumatic trough; suddenly turn one of the jars which has a wide mouth, with its orifice upwards, and apply a lighted taper; the whole mass of gas will rush out and give a sheet of pale white or yellowish flame.

Experiment 2. Hold a jar of the gas with its open orifice downwards: have ready a small piece of green wax taper, fastened to the end of a piece of bent copper wire; light it, and introduce it quickly into the jar of gas; the hydrogen will inflame the surface where it is in contact with the atmosphere, but on plunging the taper upwards into the pure gas, it will be extinguished: lower it again to the surface, and it will become

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* See my Lectures on Electricity, &c.,—Lectures Third and Fourth; on Galvanism.

re-ignited; raise it again, and it will be again extinguished, and this may be repeated till the gas is exhausted.

From these experiments it is learnt that hydrogen gas, though inflammable, will not burn unless oxygen is present.

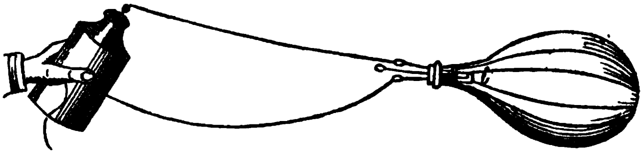
Experiment 3. Turn another jar of gas with its mouth upwards; let it stand a few minutes; then introduce a lighted taper; no inflammation will take place, but the taper will burn as in common air; the hydrogen has escaped, proving its levity.

Experiment 4. Remove the delivering tube from the gas bottle, *Fig.* 45, and substitute in its place another tube bent upwards at *b*; generate gas in the bottle as usual, and when the common air has entirely escaped, ignite the gas as it issues from the bent tube; the light will be very feeble: sift some powdered magnesia through the flame, it will become much brighter: introduce a coil of fine platina wire into the flame, it will become white hot, emitting intense heat and light. We shall advert to this experiment hereafter.

Experiment 5. Fill a bladder with hydrogen gas; attach a tobacco-pipe to the aperture; force the gas through some soap lather; the soap bubbles being filled with hydrogen gas, will rise rapidly in the air.

Experiment 6. Fill a similar bladder with a mixture of two parts of hydrogen and one of oxygen; insert a good sound cork into the aperture, through which two wires pass into the bladders attached outside to two others of considerable length: then connect one of these with the outer coating of a charged Leyden phial, and all things being prepared, complete the circuit by touching the other wire with the brass knob of the jar; the electric spark enters at *i*, *Fig.* 46, and igniting the mixture, causes the bladder to explode with great violence, producing a large body of flame; or fill the bladder with the mixed gases and force a stream through soap lather; the bubbles will not rise, but explode with great violence on a light being presented.

Fig. 46.



The explosion in these last experiments is occasioned by the sudden condensation of air in consequence of the formation of water by the union of the oxygen and hydrogen gases; the water condensed occupying a thousand times less space than the vapour which is first formed. Thunder is occasioned by a similar sudden compression and immediate subsequent dilatation of air; and these detonations may be made to succeed one another so rapidly as to form a continuous musical note: with hydrogen this may be done in an amusing manner, as in—

Experiment 7. Kindle a stream of hydrogen as it escapes from an upright glass jet, having a small aperture; it will burn silently; now hold over it an open glass tube of about two feet in length, like a chimney; the appearance of the flame will become altered, it will be elongated and flickering, a succession of little detonations is produced from the gas being carried up and mixing with the air of the tube, which follow each other so quickly as to produce a continuous sound or musical note.

Experiment 8. Procure a small balloon made of gold-beaters skin, or of the serous membrane of the turkey's craw; (they may be had of Mr. Ward, of Bishopsgate street, 12 inches in diameter, price 3*s*. 6*d*.; 24 inches, 8*s*. 6*d*. each,) fill it with *dry* hydrogen gas, in the manner shown in *Fig*. 47, where *t* represents a tube of chloride of calcium,* a substance having a powerful affinity for water, through which the gas is made to pass before it enters the balloon; it is thus completely dried, and the balloon, when full, will rise rapidly in the air; now

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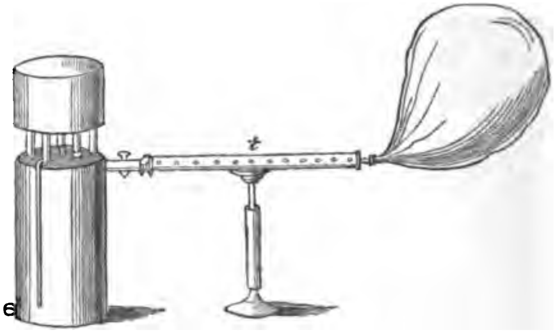
* Made by dissolving carbonate of lime in muriatic acid, evaporating to dryness, and then heating to low redness.

pure hydrogen gas has been calculated to be about 14½ times lighter than atmospheric air. If the balloon be six inches in diameter, and made of gold-beaters skin, it will weigh about 35 or 36 grains, and the hydrogen which enters it about 5 grains, these both amount to 40 or 41 grains, but an equal space of atmospheric air weighs at least 50 grains, 9 or 10 grains heavier than the gas and balloon taken together. In äerostation the balloon is prepared of varnished silk; a balloon of twenty feet in diameter contains about 4000 cubic feet of gas, and besides the silk it carries about 260 lbs.: one of thirty feet in diameter contains about 14,000 cubic feet of gas, and can carry 928 pounds. At present however hydrogen gas is but seldom employed for filling balloons, it being found cheaper to make them very large and to use ***coal gas***, which, although much heavier than hydrogen, is still considerably lighter than atmospheric air under the same volume.

Fig. 47.

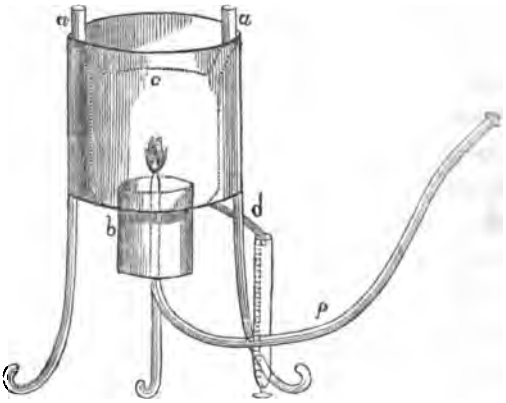


Experiment 9. Allow a jet of hydrogen to burn under a white porcelain saucer; remove it before it gets hot, and it will be found covered with minute drops of water. To prove more satisfactorily that water is the sole result of the combustion of pure hydrogen, make the following experiment.

Experiment 10. Procure a cylinder of japanned tin plate, A A, *Fig.* 48, open at the top and closed at the bottom, except where the small copper cylinder B, open at both ends enters it and is soldered to it. Let another copper cylinder, C, close at the top, be fixed inside the cylinder, AA, and soldered all round B, with two slanting pipes, A A, proceeding from the top, and opening into the air in the manner of flues. Fill the vessel

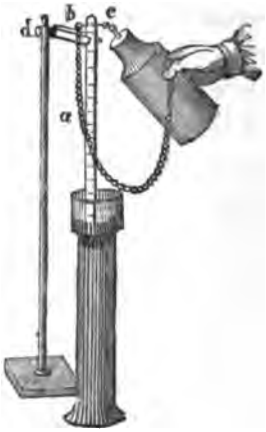
A A, with cold water; now allow a stream of hydrogen gas, issuing from the gas-holder, through the pipe P, to burn inside the interior copper cylinder; by its combustion vapour of water will be produced, which being condensed against the sides of the vessel, kept cool by the water, will trickle down the cylinder and make its exit through the pipe D, from which it may be collected in any convenient vessel. The oxygen in the cylinder C, would soon be exhausted, and the hydrogen would cease to burn, but for the two slanting flues, A A, through which the rarefied azote ascends, while cold air from the bottom passes in to supply the flame. The water in the outer vessel must be renewed from time to time, as it gets warm, and in this manner, water in any quantity may be generated by the combustion of hydrogen, forming a very instructive yet simple experiment, admirably calculated for illustration in the lecture-room.

Fig. 48.



Let us now examine more particularly the circumstances affecting the combination of hydrogen with oxygen. These two gases may be mixed together in a glass vessel, and kept for any length of time without combining; though having a powerful affinity for each other, they cannot by simple mixture be brought into sufficiently close contact to enable them to exercise that attraction, but combination is instantly determined by flame, by the electric spark, or even by a red-hot glass rod; hydrogen being one of the most easily inflammable gases. The most elegant method of performing the experiment is to introduce the mixture into a strong graduated glass tube, and explode by the Electric spark, in the manner shown in *Fig.* 49. The oxygen and hydrogen gases are introduced into the tube *a*, previously filled with mercury, and the explosion is passed through the wires *b* and *c*, sealed into the upper part of the tube: the holder, *a*, prevents the tube from being displaced by the explosion. If the gases are quite pure, and in the exact proportions; viz.:—two volumes of hydrogen and one of oxygen, no residue is found after the explosion; but if either be in excess, that excess remains behind: one-third of the volume which disappears being oxygen, and the other two-thirds hydrogen; bearing this in mind, we shall find presently that we are hereby furnished with an excellent method of analysing atmospheric air.

Fig. 49.



A little practice will enable the student to prepare for himself these eudiometers; the wires, *b c*, must be of platina, a metal, which, as has been observed in a former Lecture, is admirably adapted to the purpose, from its chemical relations, its infusibility, and its close agreement with glass in the rate of its expansion and contraction, by changes of temperature. In describing the method of sealing the wires into the sides of the tube, I cannot do better than quote the instructions given by Dr. Faraday, in his "Chemical Manipulation."

" If a wire is to be inserted through and sealed into the side of a tube, that part of the tube through which the wire is to pass, is to be softened in the lamp, and the wire pressed against it until it appears in the interior of the tube; it should then be drawn out again in the same direction, and both tube and wire left to cool. The wire will be found coated with glass, which may easily be broken off. The tube will be drawn out of the place, forming a conical projection, the end of which, when broken off, will afford a passage to the interior. The wire is then to be put into the aperture, heated, and the glass fused round it; ultimately the wire is to be pushed inwards, until that portion of glass which projected has been returned nearly to its first position. By a little practice this may be done, so that the glass shall be in perfect contact with the wire on all sides, and with little disturbance as to its form and position, from that which it possessed at first, the wire at the same time having the exact position required. When two wires are required in the same tube, at a certain distance from each other, as in an eudiometer, the distance is easily regulated by a little previous consideration: allowance being made for the extent to which the wires will require to be moved, before the operation is finished, and they are finally fixed in their places."

The wires being thus securely fixed in the tube, the next step is to graduate it, which may be done by weighing into it successive portions of water, or mercury; a cubic inch of water weighs at 60°, 252·5 grains, and a cubic inch of mercury, 3425·35 grains. Water is very convenient for the estimation down to a cubic inch, and some divisions below it; but for the tenths and hundredths, mercury is far more exact and expeditious; for tenths of a cubic inch, the operator must carefully weigh into the tube 342·53 grains of mercury, and make a mark with a file or diamond, at the exact height at which the fluid metal stands; for hundredths of a cubic inch, 34·25 grains are required; and it is desirable to employ mercury that is *not quite pure*, such for instance, as contains in every four or five thousand grains, one grain of lead, whereby a film is formed on its surface, which thus becomes *flat* instead of *round*, a shape the pure metal, in consequence of its cohesive attraction, always presents, and which, in the graduation of small tubes, would lead to considerable errors.

But oxygen and hydrogen are capable of entering into combination without any explosion or visible combustion. If the mixed gases be heated in a vessel, containing a quantity of pulverized glass, or any sharp powder; they begin to unite in contact with the foreign body without violence, at a temperature not exceeding 660°. The presence of a slip of gold or silver, disposes them to unite at a still lower temperature; but the most rapid union is effected by platinum, which occasions the combustion at ordinary temperatures. It was discovered by M. Dobereiner, in 1824, that newly prepared spongy platinum* possesses the singular property of causing the immediate combination of oxygen and hydrogen independently of its temperature, instantly becoming red-hot when a jet of hydrogen gas is thrown upon it; in consequence of which ignition, the hydrogen is soon inflamed. An instrument, depending on this action of platinum has been invented, and is well-known as a lamp for instantaneous light.

Professor Faraday has more lately observed, that a plate of platinum, if its surface be chemically clean, will cause the gases to combine, accompanied with the same phœnomena as the spongy platinum, and that at temperatures even below the freezing point of water, and in an explosive mixture largely diluted. The rationale of this remarkable action of platinum is by no means clear. By some chemists it is supposed to be

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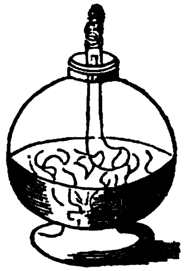
* Spongy platinum is the metal in a state of minute division. It is prepared by dissolving chloride of platinum and sal-ammoniac separately in alcohol, and mixing the solutions: the double chloride of platinum and ammonium is thus produced as a fine yellow powder, which, while yet moist, is to be made into balls like peas, and heated to full redness. The chlorine is all carried off by the hydrogen of the ammonia, and the platinum remains as a light grey sponge, in the form of little balls. The *platinum-black* may be obtained either by precipitating a solution of bichloride of platinum with zinc, and boiling the precipitate with muriatic acid, for a few minutes; or better, by dissolving protochloride of platinum, in a boiling solution of potash, and adding thereto alcohol in small quantities at a time, until all effervescence ceases: a jet black precipitate is produced, which is to be boiled successively with alcohol, muriatic acid, and potash, and finally four or five times in water. The substance thus obtained, is pure metallic platinum; but it is a dull black powder, which absorbs oxygen in considerable quantity.

occasioned by the retention of a thin layer of gas on the metallic surface, with a force sufficiently powerful to bring, by condensation, the molecules of the oxygen and hydrogen gases within the sphere of their mutual attraction: the spongy metal always contains a quantity of air in this condensed state, and consequently its oxygen is in the most favourable condition for combining with hydrogen. On introducing a ball of spongy platina, into a vessel of oxygen and hydrogen gases, mixed in suitable proportions to form water, an instantaneous explosion ensues; but if the metal in this spongy state be made into pellets with a little pipe-clay, and dried, its action will be weakened, and it will then cause a silent and gradual combination, not only of hydrogen, but of *all combustible* gases with oxygen, and in whatever proportions they may be mixed. The best proportions for forming these pellets are, one part of platinum sponge, and four parts of clay; the gaseous mixture on which it is to act, must be confined over mercury, and the balls heated before using; they are not the least injured by the process.

A very interesting method of exhibiting this property of platinum is, to take a wine glass and pour into it a few drops of strong alcohol or ether, and wet the sides with the same; then suspend in the middle of the glass, a coil of fine platinum wire, previously heated to redness; the wire will continue to glow until the alcohol or ether has been exhausted. The products of this slow combustion are very different from what they would have been if the alcohol or ether had been inflamed; the influence of the metal has caused the inflammable vapours to combine with oxygen in such proportions as to form acetic and formic acids, and by this combination heat is evolved sufficient to keep the platinum ignited: or the platinum wire may be fixed over the wick of a spirit-lamp, as in *Fig.* 50, being allowed to project about a fourth of an inch above it. The lamp is then lighted and suffered to burn for a few seconds, when the flame is put out by an extinguisher, which is instantaneously removed; nevertheless the metal continues to glow till all the alcohol is consumed, the spirit rising through the capillary wick, and forming over its top an explosive atmosphere in which the coil of platinum works.

Fig. 50.



It has been mentioned that the flame of hydrogen gas is very feeble, it is nevertheless intensely hot, few combinations producing so high a temperature as the combustion of hydrogen. When oxygen and hydrogen gases are brought by tubes from different gas-holders, in the exact proportions for forming water, and allowed to mix immediately before they escape from the same orifice, and then caused to burn, the heat produced is the most intense that can be obtained by artificial means, though the light is so feeble as hardly to be perceptible.

This arrangement is called the oxy-hydrogen blowpipe; the safest though not the most powerful form of which, is that in which the jet for the oxygen is fixed within that for the hydrogen, a construction first proposed by Mr. Maugham, and adapted to the use of coal-gas instead of hydrogen by Mr. Daniell. This jet consists of a cylindrical tube, ⅜ of an inch in diameter, and 7½ inches long, and an internal tube, 6 inches long, and ⅛ of an inch in diameter; the curved jet being 3¼ inches long. The instrument is usually furnished with an arrangement for holding a cylinder of lime for exhibiting the intense light occasioned by the flame of the mixed gases, when directed against that earth.* In applying the gases to this instrument, the flexible pipe from the gas-holder, containing hydrogen, is attached to the stop-cock of the exterior tube, and the gas turned on, and ignited as it issues from the jet; the oxygen is then conveyed through the hydrogen by a pipe, communicating with a gas-holder of oxygen; if this be done sud-

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* Mr. Ward sells these oxyhydrogen jets for 17*s*. each; or furnished with two stop-cocks, for £1. 3*s*.

denly, so as to throw too large a quantity of oxygen into the flame, it will be immediately extinguished; but if the quantity be so adjusted as to allow one volume of oxygen to pass for every two volumes of hydrogen; then a great alteration will be observed to take place in the appearance of the flame; instead of a thick cone, like that of a common candle, it will assume the appearance of a long pencil, very feebly luminous; in shape, resembling the flame produced by injecting a stream of air through the flame of a candle by a well formed blowpipe. It requires a little practice to regulate the gases with nicety, so as to produce the maximum effect, and the only directions that can be given are to keep the thumb on the stop-cock of the oxygen gas-holder and turn it gently, keeping the eye steadily fixed on the flame, so that the alterations in its appearance may be instantly noticed; when it assumes the character above described, the gases will be passing in proper proportions; the gas-holder containing the hydrogen should be double the size of that containing the oxygen, and the upper reservoirs kept quite full of water.

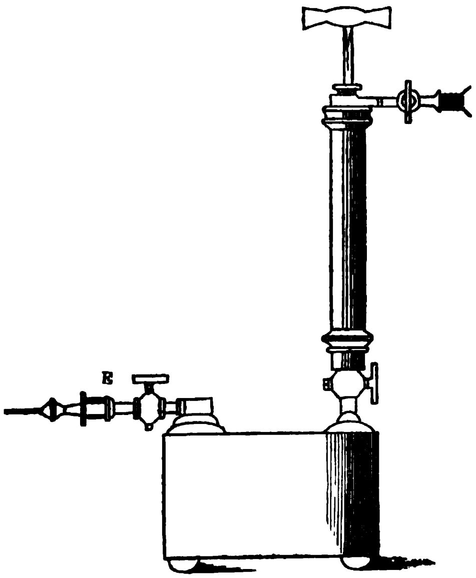
In the flame of the oxyhydrogen blowpipe, the most refractory substances, such as pipe-clay, silica, and platinum are not only fused but actually volatilized; the combustion of some of the metals, such as iron and copper, is exceedingly brilliant. Lime and magnesia however resist its highest power, but produce, when introduced into the flame, a light so intensely luminous as to rival the noon-day sun; this is particularly the case with lime, and as by moving the mass of earth slowly before the flame, the brilliant white light may be sustained for hours; it has been very usefully substituted for the solar ray in the microscope, constituting the instrument now daily exhibiting in London, with such amusing and instructive effect—the oxyhydrogen microscope.

The lime-light has been also proposed for use in light-houses, for which it would appear to be admirably adapted, as in an experiment made by Mr. Drummond, the light when placed in the focus of a parabolic reflector, was visible in the direction in which it was thrown, at a distance of nearly seventy miles.

The heating effects of the oxyhydrogen blowpipe are much increased when the gases are forced into one vessel and caused to escape from the jet under pressure; this is the form of Dr. Clarke's apparatus, which consists of a metallic box, made exceedingly strong, into which the gases, previously mixed in the proper proportions are forced, by means of a condensing syringe, and when a sufficient quantity has been introduced the syringe is removed, and a stop-cock, connected with a jet opened. The pressure of the condensed gas forces out a stream which is ignited, and if the flame be not allowed to burn too long, the rapidity of the current is sufficient to prevent the retrogression of the flame. This is an exceedingly dangerous apparatus, and exposes the operator to the greatest risk, for if the flame should by chance pass back through the exit tube, the whole mixture would explode, inevitably blowing the instrument to pieces. By using the very ingenious safety jet of Mr. Hemming, and employing a large bladder to hold the mixture, this form of the blowpipe may be adopted without the least fear of danger; and for experiments on the small scale, it is exceedingly convenient, combining power, security, and simplicity.

Mr. Hemming's safety jet consists of a brass cylinder, about six inches long and three-fourths of an inch wide, filled with fine brass wire of the same length, which is tightly wedged by forcing a brass rod into the centre. The interstices between the wires form thus a collection of exceedingly minute tubes, through which the gas must pass. To one end of this cylinder is connected a bladder, containing the mixed gases, the other terminates in a jet from which the gases issue; now should the flame pass back through this tube, it would have to encounter a large mass of metal, which conducts heat so rapidly as to reduce the temperature of the gases much below that at

Fig. 51.

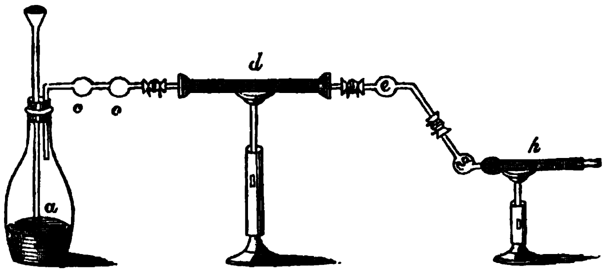


which their union can occur,* and further combustion is consequently prevented. *Fig.* 51, is a view of the compression oxy-hydrogen blowpipe, the safety tube of which contains a pile of circular discs of wire gauze, contained in the brass box, E. The wire gauze here acts in precisely a similar manner to the wires in Hemming's jet.

Water:—

By repeating the following experiment of Berzelius, the most positive determination of the composition of water may be obtained. Introduce into the small glass bulb, *e*, *Fig.* 52, a known weight of black oxide of copper; connect it by caoutchouc connectors, with the bulb *g*, on one side, and the tube containing chloride of calcium, *d*, on the other; the bulb *g*, is then to be connected with another tube of chloride of calcium, *h*, and the tube *d*, with the bottle *a*, in which hydrogen gas is

Fig. 52.



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* This will be fully explained in our 10th Lecture.

slowly generated; the two bulbs, *c c*, serve to collect any vapour which may be mixed with the gas, and by afterwards passing over the chloride of calcium in *d*, the hydrogen is completely dried before it comes into contact with the oxide of copper in *e*. Things being thus arranged, and the apparatus being filled with hydrogen gas, apply a spirit-lamp to *e*, and heat it to dull redness; decomposition takes place, the oxide becomes glowing red, and even though the heat of the lamp be much reduced, the reaction still goes on, and when complete, a mass of porous pure copper remains. Let the stream of hydrogen pass through the apparatus till it is quite cold; then remove *e*, and having carefully wiped it, weigh it, and note the loss; then weigh the bulb *g*, and the tube of chloride of calcium, *h*, and note the *increase* of weight. If the experiment has been carefully conducted, we shall find it will turn out thus:—

Supposing 100 parts of oxide of copper to have been employed, we shall find 79·85 parts of copper to have been produced; the loss being 20·15, and the gain of *g* and *h* will be 22·67, of which, 20·15 is what was lost by the oxide of copper, and is oxygen; and 2·52 hydrogen, the whole forming 22·67 of water; and the experiment proves that 22·67 of water consists of 20·15 of oxygen, and 2·52 of hydrogen; or in 100 parts:—

88·9........ OXYGEN.
11·1...... HYDROGEN.

There appears to be some uncertainty with respect to the real discoverer of the true theory of the composition of water; though it is generally acknowledged that Mr. Watt was the first person who reduced the theory to writing. The following is an extract from a letter to Dr. Priestley, of the 26th of April, 1783. (Phil: Trans: p. 333.) "Let us now consider what obviously happens in the case of the deflagration of the inflammable and dephlogisticated air. These two kinds of air unite with violence, they become red hot, and upon cooling totally disappear. When the vessel is cooled, a quantity of water is found in it, equal to the weight of air employed. This water is then the only remaining product of the process, and *water*, *light*, and *heat* are all the products: are we not then authorized to conclude, that water is composed of dephlogisticated air and phlogiston, deprived of their latent or elementary heat: that dephlogisticated or pure air is composed of water deprived of its phlogiston, and united to elementary heat and light: that the latter are contained in it in a latent state, so as not to be sensible to the thermometer or to the eye: and if light be only a modification of heat, or a circumstance attending it, or a component part of the inflammable air, then pure or dephlogisticated air is composed of water deprived of its phlogiston and united to elementary heat?"

The celebrated paper of Mr. Cavendish, was read before the Royal Society, on the 15th of January, 1784; in this is related the capital experiment of burning oxygen and hydrogen gases in a close vessel, and finding pure water to be the produce of the combustion, and the conclusion is drawn, that the two gases were converted or turned into water. This was nine months *after* the letter of Mr. Watt, just quoted, was written; but there was afterwards inserted in the paper by Sir Charles Blagden, with Mr. Cavendish's consent, a statement, that the experiment had first been made by Mr. Cavendish, in the summer of 1781, and mentioned to Dr. Priestley, though it is not said *when*, neither is it said that any conclusion was mentioned to Dr. Priestley, nor at what time Mr. Cavendish first drew that conclusion.

It appears to have been a reluctance to give up the doctrine of phlogiston: a kind of timidity on the score of that long-established and deeply-rooted opinion, that prevented both Mr. Watt and Mr. Cavendish from doing full justice to their own theory: while Lavoisier, who had entirely shaken off these trammels, first presented the new doctrine in its entire perfection and consistency, "all three," observes Lord Brougham,* "may have made the important step nearly at the same time, and unknown to each other: the step namely, of concluding from the experiment, that the two gases entered into combination, and that water was the result: for this, with more or less of distinctness, is the inference which all three drew."

But to whoever the discovery of the theory of the composition of water is due, there is no doubt that the inquiry, at least in England, originated in the experiments of Mr. Warltire, which consisted in firing by electricity, a mixture of inflammable and common air in a close vessel, and two things were said to be observed: first, a sensible loss of weight; second, a dewy deposit on the sides of the vessel: this experiment was related by Mr. Warltire to Dr. Priestley, in 1781, who published it in the appendix to the second volume of "Experiments and Observations relating to various branches of Natural Philosophy." Mr. Warltire's first experiments were made in a copper ball or flask, which held three wine pints, the weight, 14 oz.; and his object was to determine "whether heat is heavy or not." After stating his mode of mixing the airs and adjusting the balance, he says, he always accurately balanced the flask of common air; then found the difference of weight after the inflammable air was introduced, that he might be certain he had confined the proper proportions of each. The electric spark having passed through them, the flask became hot, and was cooled by exposing it to the common air of the room: it was then hung up again to the balance, and a loss of weight was always found, but not constantly the same: upon an average it was two grains.

He then goes on to say, "I have fired air in glass vessels, since I saw you (Dr. Priestley) venture to do it, and I have observed, *as you did*, that though the glass was clean and dry before, yet, after firing the air it became dewy, and was lined

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* See Appendix, No. 1, to the Historical Eloge of James Watt, by M. Arago translated from the French, by Mr. Muirhead.

with a sooty substance." It thus appears that Dr. Priestley was the first person who observed the formation of moisture by firing a mixture of common and inflammable air, though so far from his having contributed anything towards the formation of the true theory of the composition of water, he was one of its most strenuous opponents, and one of the last scientific papers he ever wrote, was a pamphlet in support of the doctrine of phlogiston, and a refutation of the theory of the composition of water.

In remarking on Mr. Warltire's experiments, he says, "I do not think however that so very bold an opinion, as that of the latent heat of bodies contributing to their weight, should be received without more experiments, and made upon a still larger scale. If it be confirmed, it will no doubt be thought to be a fact of a very remarkable nature, and will do the greatest honour to the sagacity of Mr. Warltire. I must add, that the moment he saw the moisture on the inside of the close glass vessel, in which I fired the inflammable air, he said that it confirmed an opinion he had long entertained; namely, *that common air deposits its moisture when it is phlogisticated.*"

It seems evident that neither Mr. Warltire nor Dr. Priestley attributed the dew to anything else than a mechanical deposit of the moisture suspended in common air.*

The *grand* experiment of the composition of water, was made by Fourcroy, Vauquelin, and Seguin. It was commenced on Wednesday, May 13th, 1790, and was finished on the 22nd of the same Month. The combustion was kept up 185 hours, with but little interruption, during which time the machine was not quitted for a moment. The experimenters alternately refreshed themselves when fatigued, by lying for a few hours on mattresses in the laboratory.

To obtain the hydrogen. 1. Zinc was melted and rubbed into a powder in a very hot mortar. 2. This metal was dissolved in concentrated sulphuric acid, diluted with seven parts

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* See Mr. James Watt's notes in the Appendix to the work above referred to.

of water. The air procured was made to pass through caustic alkali. To obtain the oxygen. Two pounds and a half of crystallized hyper-oxymuriate of potash were distilled, and the air was transferred through caustic alkali.

The volume of the hydrogen employed was 25963·568 cubic inches, and the weight was 1039·358 grains. The volume of oxygen was 12570·942, and the weight 6209·869 grains.

The total weight of both elastic fluids was 7249·227 grains.

The weight of water obtained was 7244 grains, or 12 ounces 4 gros, 45 grains.

The weight of water should have been 12 ounces, 4 gros, 49·227 grains; the deficit being 4·227 grains. The quantity of azotic air before the experiment, was 415·256 cubic inches, and at the close of it, 467. The excess after the experiment was consequently 51·744 cubic inches. This augmentation is to be attributed, the academicians think, to the small quantity of atmospheric air in the cylinders of the gasometers, at the time the other airs were introduced. These additional 51 cubic inches could not arise from the hydrogen, for experiment showed that it contained no azotic air. Some addition of this lost fluid, the experimenters think cannot be avoided, on account of the construction of the machine.

The water being examined, was found to be as pure as distilled water. Its specific gravity to distilled water, was as 18671 to 18670.—*Ure's Dictionary of Chemistry.*

Properties of water. The general properties of water are too well known to require any minute description. It is colourless, transparent, and destitute of smell or taste. When agitated, it solidifies at 32°, but if kept perfectly still it may be cooled much lower without freezing. When the barometer stands at 30 inches, water boils at 212°, but it undergoes evaporation at all inferior temperatures. It is the solidification of water which effects the disintegration of the hardest rocks, and makes from them soils fitted for the support of vegetable life. In the summer, the liquid water percolates into minute crevices and fissures of the rock; in successive winters, the expansive force of the solidifying fluid, breaks and crumbles down the substances of masses apparently indestructible. This action of water in its solid and liquid state, is probably the most influential cause of the vast ruin observed in all countries where high mountain chains are intersected by deep narrow gorges, bounded by bare, precipitous, and irregularly fissured escarpments.

Building materials differ materially in their destructibility by frost; the compact tenacious sand-stone of Edinburgh is but little injured, while the less tenacious and porous oolitic buildings of Oxford have suffered greatly.

The influence of water in effecting the decomposition of rocks is much aided by the affinity of carbonic acid for the alkalies contained in them. By the combined action of these agents, a total alteration is effected, not only in their mechanical but in their chemical constitution. The tenacity of the rock is entirely destroyed, so that the slightest force, a shower, or a breeze is sufficient to overcome the cohesion of its particles. The alkali of the felspar is entirely washed away, and an earthy mixture, combined with water remains. Hence the source of the alkalies present in springs and in the soil, and hence probably also the alkaline matter of the nitrates of potash and soda, generated so abundantly in parts of India and America.

It is an established fact, that siliceous minerals are frequently formed from aqueous solutions. Silex, though when in a state of powder it resists the action of boiling water, is freely dissolved in the nascent state, and in still larger quantities by alkalies. Now in the decomposition of felspathic rocks, the silex is exposed to the united action of water and alkali, at the moment of passing from the state of combination which constitutes felspar, and the quantity carried off in solution is enormous.

The silica thus dissolved in water is in a state of unstable equilibrium, and is consequently very prone to decomposition. A solution of silica oozing slowly into the cavities of a porous or cellular rock might yield a deposit as a consequence of evaporation;—of a slight affinity between the silica and some substance with which it may accidentally come into contact; or in consequence of the solvent power of an alkali which had contributed to its solution being lessened by passing from the state of a simple carbonate, into that of a bicarbonate, &c.

The siliceous matter being once solid could not be redissolved, and in this manner might cavities of considerable size be filled up with calcedony, flint, or rock crystal. In the case of flint, it is necessary to account for that remarkable tendency which silica possesses of occupying the place of organic matter, as exemplified by silicified wood or coral.

Siliceous solutions, infiltrating through organic masses in process of decay, might, observed the late Dr. Turner, readily become decomposed, in which case a deposit of silex would result; consistently with this view it is well known that flints contain traces of bitumen or some similar substances of organic origin; hence the dark colour of flints.

When mixed with air, the vapour of water has a tendency to condense in vesicles, which inclose air; forming in this condition the masses of clouds which remain suspended in the atmosphere from the lightness of the vesicles, the substance of mists and fogs, and "vapour" generally in its popular meaning. The vesicles may be observed by a lens of an inch focal length, over the dark surface of hot tea or coffee, mixed with an occasional solid drop which contrasts with them.—*Graham.* According to the experiments of Saussure, made upon the mists of high mountains, these vesicles generally vary in size from the 1-4500th, to the 1-2780th of an inch; but are occasionally observed as large as a pea. They are generally condensed by their collision into solid drops and fall as rain; but their precipitation in that form is much retarded in some conditions of the atmosphere.

Owing to the nature of its elements, and its own extensive range of affinity, water may be considered the most powerful agent we possess; there are indeed few complex changes where oxygen and hydrogen are present, which do not give rise either to the production or decomposition of water. In its chemical relations it is eminently a neutral body, and to all its definite compounds, the term *hydrate* is applied by Chemists:—thus, concentrated sulphuric acid is composed of *one* equivalent of *real* acid and one equivalent of water; it is therefore called *hydrate of sulphuric acid*, or *hydrous sulphuric acid.* Water enters into the generality of saline bodies, whilst undergoing crystallization, sometimes to the amount of more than half their weight; in sulphate of magnesia or epsom salt for instance, every 124 grains of which contains 63 grains of water; on the application of a moderate heat, this water separates, and frequently the salt dissolves in its own water of crystallization on being heated, undergoing what is called *watery fusion.*

Many of the acids cannot exist without water; among these are the nitric, the chloric, the oxalic, and the acetic acids, neither of which have ever been obtained in a separate form, and are therefore in reality to be regarded as salts,—*salts of water* possessing a complete similarity to the salts of zinc and copper: from which fact an idea has by some Chemists been entertained, that hydrogen is *a volatile metal.*

Water combines also with bases; most of the metallic oxides unite with it; many with the evolution of heat, as lime, barytes, and strontia; the heat produced in the slaking of which is sufficient to ignite gunpowder, and when in large quantities to become red hot.

Water is capable of dissolving a certain quantity of air and other gases, which may again be expelled from it by boiling. Rain water generally yields 2½ per cent of its bulk of air, in which the proportion of oxygen is so high as 32 per cent. and according to Gay Lussac and Humbolt, in freshly melted snow, as high as 34·8 per cent.

In nature, water is never found perfectly pure; its most important impurities being air and carbonic acid, with certain quantities of common salt, sulphates and carbonates of lime, and chloride of magnesium. Rain water or snow, collected at a distance from houses, is the purest water that can be obtained in nature, but it should be collected before it reaches the ground, or it will soon become impregnated with various earthy and organic matters, from the soil, from which it can only be purified by distillation.

For œconomical purposes, water is rendered clear and transparent by passing it through filters of coarse sand under pressure; but this process cannot evidently affect the matter which is actually dissolved in the water; peaty matter for instance, with which river water is always more or less impregnated; the proper substance for discolouring liquids is animal charcoal, which withdraws organic colouring matter, even when in a state of solution.

It is common to employ white of egg and other albuminous fluids to clarify liquors; speaking of the process of filtering, we may here observe that the success of the operation depends on the partial coagulation of the albumen by heat, which thus forms a sort of delicate net-work throughout the liquid, which collects all the foreign matter, and raises it to the surface in the form of scum.

LECTURE SEVENTH.

PEROXIDE OF HYDROGEN—ITS PREPARATION AND PROPERTIES—CATALYSIS—NITROGEN—ITS PREPARATION AND PROPERTIES—ATMOSPHERIC AIR—DIFFERENT METHODS OF ANALYSING—BY PROTOSULPHURET OF POTASSIUM—BY NITRIC OXIDE—BY DETONATION WITH HYDROGEN GAS—DETAIL OF THE LATTER PROCESS—EXAMPLE—BRUNNER'S METHOD—GAY LUSSAC'S AND SAUSSURE'S PLAN.—CONSTITUTION OF THE ATMOSPHERE—CARBONIC ACID IN THE ATMOSPHERE—ITS GREAT IMPORTANCE—VIEWS OF LIEBIG IN RELATION TO THIS SUBJECT—WATERY VAPOUR IN THE ATMOSPHERE—PHŒNOMENA OF RAIN—AMMONIA IN THE ATMOSPHERE—METHOD OF DETECTING AMMONIA IN RAIN WATER—LIEBIG'S VIEWS—WHENCE DO VEGETABLES DERIVE THEIR NITROGEN? DISCUSSION ON THIS SUBJECT—CASE IN POINT—PRECAUTIONS TO BE ATTENDED TO IN ALL CASES OF GASEOUS ANALYSIS—IS ATMOSPHERIC AIR A CHEMICAL OR A MECHANICAL MIXTURE? DIFFUSION OF GASES.—EXAMPLES—DALTON'S THEORY OF THE CONSTITUTION OF OUR ATMOSPHERE—WEIGHT OF THE ATMOSPHERE—FACTS CONNECTED WITH IT—DENSITY OF THE ATMOSPHERE—HEIGHT AND LIMITS OF THE ATMOSPHERE—DATA FROM WHICH AN APPROXIMATIVE ESTIMATE MAY BE FORMED—THE SUN AND PROBABLY ALL THE PLANETS ARE WHOLLY DESTITUTE OF ANY ATMOSPHERE.

WATER is looked upon by Chemists, as a *binary* compound of oxygen and hydrogen, or as containing an *equivalent* of each of its constituents. In the formation of steam, two volumes of hydrogen and one volume of oxygen are condensed into two volumes, so that the specific gravity of oxygen and hydrogen being known, that of steam may readily be determined:—thus, the specific gravity of air being 1000, that of hydrogen has been ascertained to be 68·8, and that of oxygen, 1102·6.

Two volumes of hydrogen, 68·8 × 2 = 137·6
and one volume of oxygen........ = 1102·6

give two volumes of vapour of water = 1240·2

hence one volume of steam........ = 620·1

which is the specific gravity of vapour of water, at the standard temperature and pressure.

Oxygen and hydrogen form a second liquid compound, possessed of very singular properties. It was discovered in 1818, by Thenard, who called it oxygenated water, from its containing double the quantity of oxygen, which enters into the composition of that fluid. Its equivalent is 212·5, and its formula, HO_2.

Peroxide of hydrogen, or oxygenated water, is best prepared by the process recommended by Pelouze, which consists in saturating fluo-silicic acid, with peroxide of barium; the reaction is very simple, fluo-silicate of barium is formed and precipitated in the form of an insoluble white powder, and the oxygen is transferred to the hydrogen, which the acid abandons, thus forming peroxide of hydrogen, which remains dissolved. After decomposing several portions of the peroxide successively in the same liquor, the insoluble matter is separated, and the peroxide of hydrogen concentrated by slow evaporation under the air-pump.

It is a thick colourless liquid, nauseous, irritating, and bleaching: specific gravity, 1·452. Its reactions are exceedingly violent, becoming resolved into water and oxygen by merely being brought into contact with a great number of solid substances, and what is exceedingly curious, no change whatever takes place in the bodies occasioning this decomposition. When black oxide of manganese, in powder, is introduced into strong peroxide of hydrogen, in a graduated tube over mercury, the latter is decomposed with great violence, disengaging 475 times its volume of oxygen, the oxide of manganese remaining unaltered; still more remarkable is the fact, that the oxides of gold and silver, when brought into contact with peroxide of hydrogen, not only occasion the decomposition of that substance, but become themselves reduced to the metallic state, and that too in a very dilute solution of the peroxide, where the effervescence is not energetic, and the heat evolved much too feeble to allow of the supposition that the effect is occasioned by the elevation of temperature. The metallic oxides which thus give up their oxygen, with that of the peroxide of hydrogen, are those which are formed by *indirect* means, and which retain their elements with but feeble affinity; other metallic oxides, such as those of lead, bismuth, and arsenic, combine with a portion of the oxygen evolved, entering into higher states of oxygenation, and the animal substances, fibrine and albumen, which are in most respects so similar, exhibit a very marked difference in their action, the former decomposing the peroxide of hydrogen with rapidity, while the latter is without any action on it.

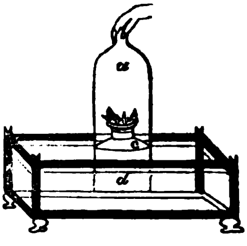
It was the remarkable characters of this substance that first induced Berzelius to propose for the consideration of Chemists, the existence of a new form of the force of chemical affinity, which he called the *catalytic* force, and the effect of its action *catalysis*, (from *κατα*, downwards, and *λυω*, to unloosen,) a body in which he supposed this power to reside, resolving others into new compounds merely by contact with them, or by *an action of presence* as he terms it, without gaining or losing anything itself.

Nitrogen. Four-fifths of the air which we breathe consists of a gas, which alone will neither support combustion or animal life, and was hence called by Lavoisier, who first demonstrated its presence in the atmosphere, *azote*, (from α, privitive, and ζωη, life); it was named *nitrogen* by Chaptal, on account of its entering into the formation of nitric acid, a term certainly more appropriate than *azote*, as the incapability of supporting animal life is common to most of the other gases.

Nitrogen appears to have been first noticed by Dr. Rutherford, in 1772, while examining the air left after the respiration of an animal. It is diffused in considerable abundance through nature, entering into the composition of most animal and several vegetable substances. Although it has never yet been decomposed, and consequently ranks among the elementary substances, a suspicion has always existed that it may be a compound body, and the opinion has been warmly advocated by Berzelius and Sir H. Davy, from considerations derived from the formation and properties of the *ammoniacal amalgam*, a curious compound we shall describe hereafter.

Preparation. Any substance which can remove the oxygen from atmospheric air may be employed to prepare nitrogen: there is no body which does this so effectually as phosphorus. On the cork *c*, *Fig.* 53, a small dish of porcelain is placed, and in it a piece of phosphorus; this is ignited, and the bell-glass *a*, placed over it; the phosphorus in burning unites with the oxygen of the air, and forms white fumes of phosphoric acid; considerable expansion consequent on the elevation of temperature at first takes place, but after about half an hour, the white fumes become condensed, the water has attained its maximum elevation in the jar, and about four-fifths of the original volume of air remain colourless as before the combustion. Or a flask may be inverted over a small jet of hydrogen burning, as it issues from the upright exit-tube of a

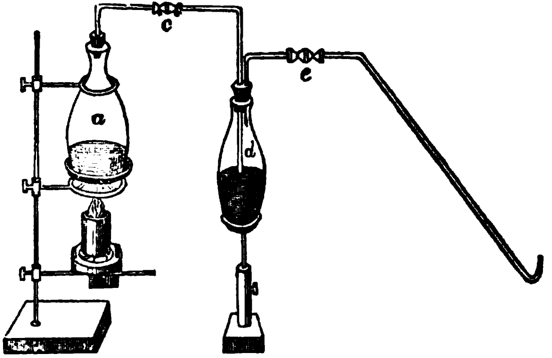
Fig. 53.



gas-bottle, and when the flame is extinguished, the flask may be removed, and the mouth closed with the thumb, and its contents thus transferred to a jar on the hydro-pneumatic trough. Spirits of wine may likewise be employed, though by this combustible the oxygen is never completely removed, and carbonic acid is generated, which renders a subsequent washing with caustic potash or lime water necessary.

The best practical method of procuring nitrogen is by the combustion of phosphorus; though there are some others which the student is strongly recommended to try, from the insight they will give him of the nature of the compounds he will employ. For instance, by boiling some pieces of muscle or albumen, or gelatine in a retort, with dilute nitric acid, he will obtain nitrogen; whence is it derived? Both from the animal matter and the acid. Most animal substances contain nitrogen; their other essential elements being carbon and hydrogen; these latter substances are readily oxidized, and nitric acid is rich in oxygen: when heated with this acid therefore, the carbon and the hydrogen of the animal matter quit the nitrogen, and form, with the oxygen of the acid, compounds differing in their nature, according to the temperature and proportions, the nitrogen of both acid and muscle, &c. being disengaged. When a solution of ammonia in water is exposed to the action of chlorine, nitrogen is set free. Into the gas flask *a*, *Fig*. 54, put some peroxide of manganese, and pour on it some hydrochloric (muriatic) acid; connect this flask with a second, *d*, by the glass tube, *c*, and into

Fig. 54.



d, pour solution of ammonia: now generate chlorine by applying heat to *a*, it will pass through the ammonia and decompose it. The ammonia consists of hydrogen and nitrogen; the chlorine seizes the former and produces with it hydrochloric acid, while the latter escapes through *e*. If the solution of ammonia be concentrated, the decomposition is very violent, attended with slight explosion and evolution of heat, and sometimes with flashes of light, unattended however with any danger; care must be taken to keep the ammonia in excess all through the process, as, if the contrary were the case, there would be a danger of a very explosive compound, called the *chloride of amidogen* being formed. Another very interesting and simple method of exhibiting the decomposition of ammonia by chlorine is, to take a glass tube about two feet long, and half an inch in diameter, and fill it to within two inches of the top with an aqueous solution of chlorine, then to pour a strong solution of ammonia carefully on the aqueous chlorine till the tube is full; now on quickly inverting the tube over the hydro-pneumatic trough, the solution of ammonia being lighter than the solution of chlorine, will rise through it, and in its passage will suffer decomposition, a torrent of minute bubbles rising to the top of the tube, with effervescence. This is a very beautiful and instructive, and at the same time simple experiment.

Properties. Nitrogen, as obtained by any of these processes is a colourless, tasteless, and inodorous gas, rather lighter than common air; its specific gravity being 976, taking air as 1000. It is characterized by the complete absence of any of the positive properties which distinguish other gases. It does not support combustion, merely because oxygen is absent; and it does not occasion death from any poisonous properties of its own, but simply because the gas absolutely essential to respiration is not present. Though possessing an extensive range of affinity, and forming several highly important compounds, it does not unite directly with any other single element, under the influence of light or a high temperature; and its use in the atmosphere appears to be to dilute the oxygen, as it will be shown hereafter that the nitrogen found in plants is derived almost entirely from a different source. If hydrogen be heated in oxygen it burns, entering into combination with it, and forming, as we have seen, water: but nitrogen cannot thus be made to unite with oxygen; nevertheless, if a series of electric explosions be passed through a tube, containing a mixture of oxygen and nitrogen, *and an alkali*, nitric acid will, after a time be formed. The lime or potash contained in old walls are found, after a certain time, to be neutralized by nitric acid, and rain water frequently contains traces of the same, particularly if its deposition has been preceded by the discharge of lightning between the clouds. In a similar manner the water which is formed by the combustion of hydrogen in air, or of a mixture of hydrogen and nitrogen in oxygen, has often an acid reaction, evidently the nitric; ammonia when mixed with air and passed over spongy platina, at a temperature of about 572°, may be converted into acid and water; and cyanogen (a compound of carbon and nitrogen) and air, under similar circumstances, occasions the formation of nitric and carbonic acids.

From these facts it appears, that in order that even the most energetic compound of nitrogen should be formed, a third substance must be present with which the compound can combine after it is formed, and which consequently may be supposed to dispose an union which would not otherwise take place.

Before describing the chemical compounds of oxygen and nitrogen, we will direct attention to that important compound, which is regarded by most Chemists as a mechanical mixture of the two gases, and which constitutes our atmosphere.

The *essential* constituents of the air which we breathe, have been ascertained by the methods we shall now describe, performed with the greatest care by the most expert experimentalists, to be 76·9 grains of nitrogen, and 23·1 grains of oxygen in every 100 grains; or by volume of 21 of oxygen and 79 of nitrogen; there are other substances continually present which will be noticed presently, but the above are *its essential constituents.*

The method of ascertaining the quantity of oxygen contained in a given portion of air, which was adopted by Scheele, was to expose it to a solution of protosulphuret of potassium* in a graduated tube, by which the oxygen was gradually absorbed, the *sulphuret of potassium* passing into the state of *hypo-sulphate of potash.* Sir H. Davy employed a liquid, formed by passing nitric oxide gas into a solution of green sulphate of iron. *Fig.* 55 represents the little instrument devised by Dr. Hope, for these experiments, and *Fig.* 56, an improvement on the same by Dr. Henry. The former consists of a small bottle holding about three ounces, into which the graduated glass tube, *d*, is carefully fitted by grinding. It has also a ground stopper at *b*. To use it, the bottle is filled with the solution of the alkaline sulphuret, and the tube *d*, containing the air to be examined, fitted into its place. After inverting and agitating the instrument, the stopper *b*, may be removed under water, and the absorption is shown by the rise of the liquid in the tube. The objection to this eudiometer is, that the liquid is constantly becoming more dilute by the admission of water through *b*, but this is obviated by substituting for the glass bottle, one of elastic gum, as shown in *Fig.* 56. The tube *d*, is accurately ground into a piece of very strong tube, of wider bore; the outer surface of which is made rough by grinding,

Fig. 55.

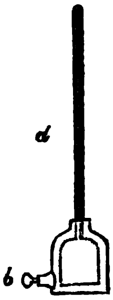
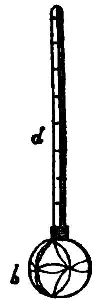


Fig. 56.



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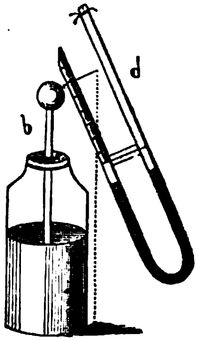
* Prepared by strongly igniting in a crucible, a mixture of charcoal and sulphate of potash, by which all the oxygen of the sulphate is removed as carbonic oxide, and sulphur and potassium remain in combination.

that it may more effectually retain the neck of the elastic bottle when fixed by wax thread. This bottle is used in every respect in the same way as Dr. Hope's, and as the eudiometric liquid rises in the tube, the elastic bottle contracts, so that the admission of a second portion of liquid is not necessary. There is some little difficulty in returning the whole of the residuary gas into the tube, which will soon be acquired by practice.

Dr. Priestley's method of analyzing atmospheric air, was to remove the oxygen by means of the deutoxide of nitrogen, or nitric oxide. When we come to this remarkable compound, we shall state the method of procuring it, and its properties; at present it will only be necessary to observe that, whenever it comes into contact with oxygen, red-coloured acid vapours are invariably formed, so that the two gases detect the presence of each other with great certainty. Dr. Priestley was the first to notice this, and supposing that combination takes place between the gases in one proportion only, he inferred that a given absorption must always indicate the same quantity of oxygen, and hence was led to employ nitric oxide in eudiometry. He was however mistaken in this supposition; nitric oxide and oxygen unite in several proportions, giving rise to three compounds, hyponitrous, nitrous, and nitric acids. It was found by Dalton and Gay Lussac, that for 100 measures of oxygen, 400 of nitric oxide may be employed as a maximum, and 133 as a minimum: and that between these extremes, the quantity of nitric oxide corresponding to 100 of oxygen is exceedingly variable. In the usual mode of operating, all of these compounds above mentioned may be generated at the same time, and in a proportion to each other by no means uniform; a circumstance fatal to the employment of nitric oxide in eudiometry. In the careful hands of Dalton and Gay Lussac however it appears to give accurate results; but as the student will not be likely to resort to this method of analyzing atmospheric air, after being put in possession of others so much superior, it will not be worth while to detail the precautions necessary to be attended to, to ensure uniform and accurate results.

One of the simplest, most elegant, and at the same time one of the most accurate methods of analyzing atmospheric air is, by detonating it with hydrogen by the electric spark. The syphon eudiometer of Dr. Ure, *Fig.* 57, is the most convenient for this purpose. We saw in the last lecture that oxygen and hydrogen gases, enter into combination in the proportion of one volume of the former to two of the latter, to form water; if, therefore, we add to a known measure of air, a slight excess of hydrogen more than is sufficient to combine with its oxygen, and explode the mixture, it is clear that as the nitrogen is unaffected by the operation, the sole result of the explosion will be water; and as, into the composition of that fluid, two volumes of hydrogen and one of oxygen enter, *one third* of the total diminution, after the explosion, will represent the volume of the oxygen in the measure of air employed.

Fig. 57.



Experiment. To 100 volumes of atmospheric air, add 50 volumes of hydrogen, carefully prepared in the manner directed for accurate experiments in the last lecture. Procure a moderately stout tube, about 22 inches long and a quarter of an inch internal diameter, and closed at one end; hermetically seal two platina wires into the sides of this tube, about half an inch from its closed end, and let the wires approach in the tube to within one-tenth of an inch from each other; next, graduate one half the tube nearest the closed end very carefully into hundredths of a cubic inch, in the manner detailed in the last number; and lastly, bend the tube neatly in the middle, by the aid of a spirit lamp and blowpipe; the syphon eudiometer, *d*, *Fig.* 57, will thus be formed.* A little practice

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* Should the student be disinclined to prepare his own eudiometer tubes, he may

will enable the experimenter to transfer a portion of the gaseous mixture to the sealed limb of the instrument, at the water or mercurial trough; having done so, the measure of the confined portion must be accurately noted, ***with the liquid at the same height in each limb:*** this must be rigidly attended to, as being the only circumstances under which a correct estimation of the volume of the mixture is to be made. The mouth of the open limb may now be closed firmly with the thumb, and a chain having been attached to one of the platina wires, pass the explosion from a small Leyden jar, as shown in the figure. The very great convenience of this form of eudiometer will immediately be apparent; the portion of air between the liquid in the open limb and the thumb becomes compressed, and acting as a recoil spring on the occurrence of the explosion, every chance of fracture is avoided. The instrument is now allowed to cool; after which, the liquid being brought to the same height in each limb, the diminution in volume is to be observed; one third of that diminution represents the oxygen. A fresh portion of the gaseous mixture may then be introduced; the experiment may be repeated several times, and the mean of the whole taken as a datum from which to calculate the result.

The author always adopts this plan of analyzing air; he gives the following extract from his laboratory journal, to show the accuracy of which it is susceptible.

"*Feb. 9th,* 1840. Atmospheric air detonated with hydrogen, obtained by inverting a platinum crucible in a basin of acidulated water, and placing a piece of zinc on the top: proportions:—air, three volumes: hydrogen, two volumes.

Ex:	1.	45 measures, became	28·25
—	2.	44..................	27·75
—	3.	44·5	28
—	4.	40..................	25

---

procure them of Messrs. Knight, Foster lane; or Mr. Ward, 79, Bishopsgate street, London, for 8s. 6d. each.

— 5. 39·75 .... 24.85
— 6. 40 25

253·25 158·85
158·85

3) 94·40 = total diminution.

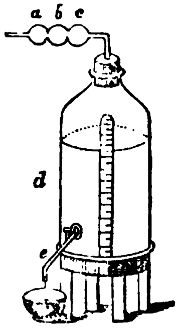
31·466 = oxygen.

Three fifths of the mixture was atmospheric air: therefore $\frac{3}{5}$ of 253·25 = 151·95; consequently 151·95 : 31·466 :: 100 : 20·7."

If it is inconvenient to employ an electrical machine, the combustion of the mixed gases may be determined without explosion, by means of spongy platinum, and the experiment may thus be conducted in an ordinary jar, over the mercurial trough.*

The following method of analyzing atmospheric air has been proposed by Brunner; by it, he states, that the error which attends, more or less, all the other processes, is reduced to 0·2 per cent. *a*, *b*, *c*, *Fig.* 58, is a tube, consisting of a wide portion, *b*, and a narrower, *c*; the wider part being drawn in *a*, to a capillary opening. Into it is introduced a quantity of loose cotton and some bits of phosphorus; and being then warmed, the melted phosphorus is allowed to spread over the fibres of the cotton, so as to expose a very great surface. The tube at *c*, fits air-tight to the orifice of the vessel *d*, which is graduated and filled with mercury: a cock at *e*, allows the mercury to flow out on occasion. To use this apparatus, the tube *a*, *b*, *c*, is weighed, and then attached to the vessel *d*; the cock *e*, is then slightly

Fig. 58.



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* Or an electrophorus may be used, which in the Laboratory is far more convenient than the electrical machine: for an account of the method of constructing and using this instrument, see my Lectures on Electricity; Lecture 2nd.

opened; the mercury issues out in a properly graduated stream, and its place is supplied by air, which entering at the capillary orifice, *a*, streams over the surface of the phosphorus, by which all its oxygen is removed, and the residual nitrogen passing into the graduated vessel, its volume can be easily read off: or the mercury which flows off, being caught in a graduated glass, its volume is equal to that of the nitrogen which has passed in. Besides extending the surface of the phosphorus, and thus quickening the absorption of the oxygen, the mass of cotton serves as a filter to collect the white fumes or flakes of phosphorus formed. When a sufficient quantity of air has passed through the apparatus, the tube *a*, *b*, *c*, is to be weighed again: the increase of weight is the quantity of oxygen absorbed, from which the volume may be known; and the mercury measured is the volume of nitrogen, from whence its weight may be calculated. The air must of course be dry. This is effected by securing to the tube *a*, *b*, *c*, by means of a caoutchouc connector, a small tube, containing fragments of fused chloride of calcium, through which, the air streaming, deposits the moisture it may contain.—*Kane's Chemistry.*

The celebrated French Chemist, Gay Lussac, recommends slips of copper, moistened with hydrochloric acid, for absorbing the oxygen; and Saussure has employed, in his accurate researches, metallic lead in thin turnings, which, with a small quantity of water, absorb oxygen with great avidity, becoming *white hydrated oxide of lead.*

Either of these methods, if applied with the requisite caution, is capable of giving accurate results, and the result of all appears to indicate from 20·79 to 21.08 of oxygen gas in 100 volumes. It is generally assumed as 21 volumes, which give the proportions :—

ATMOSPHERIC AIR BY WEIGHT.

OXYGEN	23·1
NITROGEN......................	76·9
	100·0

Carbonic acid gas in the atmosphere. The presence of this compound in air is shown by the pellicle of carbonate of lime, which soon forms on the surface of lime-water exposed to it. Though forming a very small part of the volume of the atmosphere, its presence is of immense importance, since there can be little doubt, that nearly the whole of the carbon in the vegetable world, is derived from its decomposition.* On this interesting subject, the following remarks are made by Liebig.† "One man consumes by respiration 24·8 cubic feet of oxygen in 24 hours, and 10 cwt. of charcoal consume 32 cubic feet; yet the proportion of oxygen in the atmosphere is not diminished. The air contains in minimo $\frac{21000}{100000}$ oxygen gas, and $\frac{66}{100000}$ carbonic acid gas. A man consumes (according to Lavoisier, Seguin, and Davy,) 45000 cubic inches of oxygen in one day. A thousand million of men must therefore consume 166 *billion cubic feet* in one year; this is equal to $\frac{1}{1000}$th of the quantity contained in the air in the form of carbonic acid. The carbonic acid in the air would thus be doubled in 1000 years, and man alone would exhaust all the oxygen, and convert it into carbonic acid in 303 times as many years. This calculation is independent of the consumption of oxygen by animals and combustion." It was ascertained by Saussure that the mean proportion of carbonic acid in the atmosphere,

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* It is carbon which, by combining with water, or with its elements, gives birth to matters of the highest importance for the vegetable. If twelve molecules of carbonic acid are decomposed, and abandon their oxygen, the result will be twelve molecules of carbon, which with ten molecules of water, may constitute either the cellular tissue of plants, or their ligneous tissue, or the starch and the dextrine which are produced from them. With the same elements, in the same proportion, vegetable nature, with a fecundity wonderful and admirable, produces either the insoluble walls of the cells of cellular tissue, and of the vessels; or starch, which she accumulates as nourishment around buds and embryos, or the soluble dextrine which the sap can convey from one place to another for the wants of the plants. It is also, by means of carbon, united with water, that the saccharine matters. so frequently deposited in the organs of plants for peculiar purposes are produced. Twelve molecules of carbon, and eleven molecules of water form the cane sugar. Twelve molecules of carbon, and fifteen molecules of water, make the sugar of the grape.

† See his "Organic Chemistry," in its applications to agriculture and physiology.

is 4·9 volumes in 10000 volumes of air, or 1 in 2000 volumes; but it varies from 6·2 as a maximum, to 3·7 as a minimum in 10000 volumes. Its proportion near the surface of the earth is greater in summer than in winter, and during night than during day, upon an average of many observations. Over the surface of lakes, as that of Geneva, the quantity of carbonic acid is smaller; it is also rather more abundant on elevated situations, as on the summits of high mountains, than in plains. "There is no reason" observes Liebig, "for supposing the proportion of carbonic acid to have been less in past ages; there must therefore be some cause which preserves the balance and prevents an accumulation on the one hand, of carbonic acid; or a diminution on the other, of oxygen. Both these causes are united in the process of vegetable life. Plants consist, for the most part of carbon, and the elements of water, and the relative proportion of oxygen which they contain, is less than in carbonic acid; they must, therefore, decompose carbonic acid, assimilate the carbon, and return the oxygen to the atmosphere." Plants and animals are, therefore, connected intimately with each other; plants exhale the vital principle of animals: animals exhale the food of plants. Carbonic acid gas, as will be shown hereafter, contains its own volume of oxygen, consequently the atmosphere must receive a volume of pure oxygen gas, for every volume of carbonic acid which has been decomposed. Every person may convince himself of the existence of the property, in the leaves and green parts of plants, to decompose carbonic acid, and that it is independent of the plant itself. For this purpose, let some potatoe tops, green and fresh, be exposed in a large bell-glass, filled with *spring water*, to the sun's rays; in a few hours a considerable quantity of gas will be collected in the receiver, which, on examination, will prove to be oxygen; now, if we use distilled water, or water that has been recently well boiled, we shall look in vain for this production of oxygen; the reason is evident; spring water contains carbonic acid dissolved in it; the green vegetable matter decomposes this acid with the assistance of light, assimilates the carbon, and sets free the oxygen, and when the whole of the carbonic acid is thus decomposed, no more oxygen is collected, but on giving the water a fresh supply, the process recommences. That the oxygen thus produced is derived from the carbonic acid, and not from the water, is still more convincingly shown, by dissolving an alkali in the water, in which case no oxygen gas is generated, the carbonic acid being otherwise employed.* "It may be asked," observes Liebig, "is the quantity of carbonic acid in the atmosphere, which scarcely amounts to $\frac{1}{10}$th per cent. sufficient for the wants of the whole vegetation on the surface of the earth,—is it possible that the carbon of plants has its origin from the air alone? This question is very easily answered. It is known that a column of air of 2216·66 lbs. weight, Hessian measure, rests on every square Hessian foot of the surface of the earth;† the diameter of the earth, and its superficies are likewise known, so that the weight of the atmosphere can be calculated with the greatest exactness. The thousandth part of this is carbonic acid, which contains upwards of 27 per cent, of carbon. By this calculation it can be shown that the atmosphere contains 3000 *billion Hessian pounds of carbon*;‡ *a quantity which amounts to more than the*

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* It is a circumstance (observes M. Dumas,) well worthy of interest, that these green parts of plants, which manifest the admirable phœnomenon of the decomposition of carbonic acid, are also endowed with another property not less peculiar, or less mysterious. In fact, if their image were to be transferred into the apparatus of M. Daguerre, these green parts *are not found to be reproduced there*; as if all the chemical rays essential to the Daguerrian phœnomena had disappeared in the leaf absorbed and retained by it. The chemical rays of light disappear, therefore entirely in the green parts of the plants; an extraordinary absorption doubtless, but which explains without difficulty the enormous expense of chemical force necessary for the decomposition of a body so stable as carbonic acid. Green vegetables constitute the great laboratory of organic Chemistry. It is they which, with carbon, hydrogen, water, azote, and oxide of ammonium, slowly build up all the most complex organic matters.

† 3630·8 lbs. English, of air on every English square foot.

‡ 3306 billion English lbs.

weight of all the plants, and of all the strata of mineral and brown coal, which exists upon the earth. This carbon is, therefore, more than adequate to all the purposes for which it is required. The quantity contained in sea-water, is proportionally greater." The proportion of carbonic acid gas in the atmosphere, is determined by introducing into a large glass bottle or globe of known capacity, a solution of barytes, and agitating it well with the air, until it is found by browning turmeric paper, to be in excess. The carbonic acid combines with the barytes, forming a white insoluble powder, carbonate of barytes, which being collected on a filter, and weighed, gives, by a simple calculation, the volume of carbonic acid in the air.

Watery vapour in the atmosphere. The presence of water in atmospheric air is easily shown by exposing to it, certain *deliquescent* substances, such as chloride of calcium, which soon becomes moist, and finally liquid, by the absorption. The properties of our atmosphere, are considerably affected by the presence of watery vapour, which it derives from the sea, lakes, rivers, and moist soil. The quantity of vapour which can be taken up by the air, is governed by the temperature. It was formerly supposed that spontaneous evaporation could not take place without air. Dalton has, however, clearly shown that when a liquid forms vapour, the quantity produced is regulated by the space over which it can diffuse itself, and the temperature, and that it is of no consequence whether the space is occupied by vapour or air, or whether it be a vacuum. The causes of clouds and rain are deduced from these facts. Air can only retain a certain quantity of vapour at a certain temperature; now there are several causes by which the temperature of air is diminished. Radiation from the surface of the earth produces cold; hence the deposition of dew from the air in contact with it. Rarefaction is always attended by cold, and as air ascends, it becomes rarefied; hence the clouds and mists observable on the summits of mountains. Dr. Hutton was the first who referred the phœnomena of rain to the fact, that the quantity of vapour capable of entering into air, increases in a *greater ratio than the temperature;* from which it follows, that whenever two volumes of air of different temperatures are mixed together, each being previously saturated with vapour, a precipitation of a portion of vapour must ensue, in consequence of the *mean* temperature not being able to support the *mean* quantity of vapour. "This," observes Professor Graham, "may be a cause of rain, but it is inconsiderable compared with the following:—contact of air in motion with the cold surface of the earth, and its consequent refrigeration. Though the mean temperature in this country in January, is about 34°, still, the occurrence for 24 hours of a south-west wind, may frequently be observed to occasion a rise of the thermometer to 54°. If this wind be saturated with moisture, a very considerable deposit must take place on its being cooled to 34°, which it is on its first arrival."

Ammonia in the atmosphere. In considering the source of the different elements constituting the food of plants, the question naturally arises, whence do they obtain the *nitrogen* which enters into the composition of vegetable albumen and gluten, and which is essential to the perfection of their fruits and seeds? The atmosphere is admitted by all chemists to be, in all probability, a mechanical mixture of oxygen and nitrogen, and if so, the latter element cannot exist in a state fit for assimilation by plants, and we must look for some other source, whence, by decomposition it may be taken up, in a manner similar to that in which carbon is assimilated by the decomposition of carbonic acid. But in atmospheric air we look in vain, by analysis, for any chemical compound containing nitrogen. Is this inconsistent with its containing *ammonia,* which has been already shown to be a compound of hydrogen and nitrogen? Certainly not; as Liebig has most convincingly proved, and of which any person with very little trouble may satisfy himself. Ammonia is capable of assuming the most various and opposite forms. Formate of ammonia changes by heat into hydro-cyanic *(prussic)* acid and water, without losing any of its constituents. All the salts formed by ammonia, are remarkable for their solubility, and *ammonia is always present in the atmosphere,* being invariably produced during the decomposition of animal matter ; it is the *last* product of putrefaction, though in hot climates it precedes the formation of nitric acid. For the following remarks on this highly interesting subject, I am indebted to Liebig's admirable Essay, already repeatedly alluded to.

When it is considered that a generation of a *thousand million* men is renewed every 30 years; and that in a much shorter period, thousands of millions of animals cease to live; the question naturally presents itself; what has become of the nitrogen they contained during life? And when we learn that the decomposition of animal matter is always attended by the production of ammonia; that ammonia is the simplest compound of nitrogen, and hydrogen the element for which it exhibits the greatest attraction, the question becomes easily solved. The nitrogen which animals contain during their life, is given off after death in the form of a volatile compound, capable of entering into combination with carbonic acid, and of forming with it a volatile salt.*

From its solubility, ammonia must be continually precipitated to the earth with *rain,* and in the largest quantities after a drought; hence, though it can never be detected in the analysis of atmospheric air, *it may in rain water ;* by evaporating carefully a few pints, having first added a little muriatic acid to fix it, when nearly dry, ammonia may readily be detected by rubbing with quick lime.

Liebig makes the following calculation with reference to the ammonia in the atmosphere. A cubic metre, or 35·2 English cubic feet of aqueous vapour, are contained in 17,142 cubic feet of atmospheric air, at 59° F. and 28 Bar : and 35·2 cubic feet of vapour weigh about 1½lb. consequently, if we suppose that the air, saturated with moisture at 59°, allows all the water which it contains in the gaseous form to fall as rain, then 1·1 lb. of rain water must be obtained from every 11,440 cubic feet of air. The whole quantity of ammonia contained in the same number of cubic feet, will also be returned to the earth in this one pound of rain water.

But if 11,440 cubic feet of air contain a single grain of ammonia, 10 cubic inches must contain only 0·000,000,048 of a grain, a quantity so inconceivably minute, that were it multiplied ten thousand times, it would be inappreciable by the most delicate eudiometer. If a pound of rain water contains only ¼th of a grain of ammonia, then a field of 40,000 square feet, must receive annually upwards of 80lbs of ammonia, or 65lbs. of nitrogen,* which is more than is contained, in the form of vegetable albumen and gluten, in 2650 lbs. of wood, 2800 lbs. of hay, or 200 cwt. of beet root, the yearly produce of such a piece of ground, but it is less than the straw, roots, and grain of corn, which might grow on the same surface would contain.

Ammonia may be detected in snow water, and it is a singular fact, that it possesses an offensive smell of perspiration and animal matter, a fact which leaves no doubt respecting its origin. The sensation which is perceived upon moistening the hand with rain-water, so different from that produced by pure distilled water, and to which the term *softness* is commonly applied, is to be referred to the *carbonate of ammonia* contained in the former.

The ammonia which falls with rain is, in a great measure, lost by evaporation; a part of it, no doubt, however, supplies plants and is assimilated, entering into the composition of albumen, gluten, quinine, morphia, cyanogen, &c. &c., and that portion which is thus withdrawn from the air is soon re-

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* This calculation is deduced from the observations of Schübler, from which it appears, that 700,000 lbs. of rain fall over this surface in four months, and consequently the annual fall must be 2,500,000 lbs.

placed by putrefaction. Liebig ascertained by numerous experiments, and by methods which we shall hereafter describe, the existence of the elements of ammonia in every part of plants; in the root, (as in the beet-root); in the stem, (as in the maple tree); and in all blossoms and fruit in an unripe condition.

It is the *manner* in which ammonia is presented to the soil by manures, more than its quantity, which renders them so valuable; it is presented in the form of *fixed salts*, and consequently the whole is assimilated; in the rain-water, on the contrary, it is presented in a highly volatile form, and consequently, as has been already observed, a portion only is rendered available for plants. The following case, cited by Liebig, is too interesting and conclusive to be omitted. "Let us," says he, "picture to ourselves the condition of a well-cultivated farm, so large as to be independent of assistance from other quarters. On this extent of land, there is a certain quantity of nitrogen contained, both in the corn and fruit which it produces, and in the men and animals which feed upon them. We shall suppose this quantity to be known. The land is cultivated without the importation of any foreign substance containing nitrogen. Now the products of this farm must be exchanged every year for money, and other necessaries of life; for bodies therefore which contain no nitrogen; a certain proportion of nitrogen is exported with corn and cattle, and this exportation takes place every year, without the smallest compensation: yet, after a given number of years, the quantity of nitrogen will be found to have increased. Whence, we may ask, comes this increase of nitrogen. The nitrogen in the excrements cannot reproduce itself, and the earth cannot yield it. Plants, and consequently animals must, therefore, derive their nitrogen from the atmosphere."

On this subject, the following remarks occur in a most interesting Lecture, recently delivered by Dumas, at the Ecole de Médicine, in Paris, and translated into the London and Edinburgh Philosophical Magazine; Nos. 125 and 126.

Nitrogen, or azote. During its life, every plant fixes azote, whether it borrows it from the atmosphere, or takes it from manure. In either case it is probable that the azote enters the plant and acts its part there, only under the form of ammonia or of nitric acid.

M. Boussingault's experiments have proved that certain plants, such as Jerusalem artichokes, borrow a great quantity of azote from the air; that others, such as wheat, are, on the contrary, obliged to derive all theirs from manure; a valuable distinction for agriculture, for it is evident, that all cultivation should begin by producing vegetables which assimilate azote and air, to rear by their aid the cattle which will furnish manure, and employ this latter for the cultivation of certain plants which can take azote from the *manures only*.

One of the most interesting problems of agriculture then, consists in the art of procuring azote at a cheap rate. As for the carbon, no trouble need be taken about it; nature has provided for it; the air and rain-water suffice for it.* But the azote of the air, that which the water dissolves and brings with it; the ammoniacal salt which rain-water itself contains, are not always sufficient. With regard to most plants, the cultivation of which is important, their roots should be surrounded with azotated manure, a permanent source of ammonia or of nitric acid, which the plant appropriates as they

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* It is from the air especially that plants most frequently derive their carbon. How could it be otherwise, when we see the enormous quantity of carbon which aged trees have appropriated to themselves, and yet the very limited space within which their roots can extend? Certainly, when a hundred years ago, the acorn germinated which has produced the oak that we now admire, the soil on which it fell did not contain the millionth part of the carbon that the oak itself now contains. It is the carbonic acid of the air which has supplied the rest, that is to say, nearly the whole! But what can be clearer and more conclusive than the experiment of M. Boussingault, in which, peas, sowed in sand, watered with distilled water, and having no aliment but air, have found in that air, all the carbon necessary for development, flowering, and fructification.—*Dumas.*

are produced. This, as we know, is one of the great expenses of agriculture, one of its great obstacles, for it possesses only the manure which is of its own production. But Chemistry is so far advanced in this respect, that the problem of the production of a purely chemical azotated manure cannot be long in being resolved.

M. Schattenman, the skilful director of the manufactories of Bouxvilliers, in Alsace, M. Boussingault, and M. Liebig, have turned their attention to the functions of ammonia in azotated manures. Recent trials show that the nitric acid of the nitrates also merit particular attention.

But for what purpose is this azote, of which plants seem to have such an imperious want? M. Payen's researches partly teach us; for they have proved that all the organs of the plant, without exception, begin by being formed of an azotated matter, analogous to fibrine, with which, at a later period, are associated the cellular tissue, the ligneous tissue, and the amylaceous tissue itself. This azotated matter, the real origin of all the parts of the plant, is never destroyed; it is always to be found, however abundant may be the non-azotated matter which has been interposed between its particles.

This azote, fixed by plants, serves therefore to produce a concrete fibrinous substance, which constitutes the rudiments of all the organs of the vegetable. It also serves to produce the liquid albumen, which the coagulable juices of all plants contain, and the caseum, so often confounded with albumen, but so easy to recognise in many plants.

Fibrine, albumen, and caseum exist then in plants. These three products, identical in their composition, as M. Vogel has long since proved, offer a singular analogy with the ligneous matter, the amadin and the dextrine. Indeed, fibrine is like ligneous matter, insoluble; albumen, like starch, coagulates by heat; caseum, like dextrine, is soluble; moreover, the azotated matters are neutral, as well as the three parallel non-azotated matters, and by their abundance in the animal kingdom, they act the same part that these latter exhibit in the vegetable kingdom.

Besides, in like manner, as it suffices for the formation of non-azotated neutral matters, to unite carbon with water, or with its elements; so also, for the formation of these azotated neutral matters, it suffices to unite carbon and ammonium with the elements of water: forty eight molecules of carbon, six of ammonium, and seventeen of water constitute, or may constitute fibrine, albumen, and caseum.

Thus, in both cases, reduced bodies, carbon and ammonium, and water, suffice for the formation of the matters which we are considering, and their production enters quite naturally into the circle of re-actions which vegetable nature seems especially adapted to produce.

The function of azote in plants is, therefore, worthy of the most serious attention, since it is this which serves to form the fibrine which is found as the rudiment in all the organs, since it is this which serves for the production of the albumen and caseum, so largely diffused in so many plants, and which animals assimilate or modify according to the exigencies of their own nature.

It is in plants then, that the true laboratory of organic chemistry resides:—thus carbon, hydrogen, ammonium, and water are the principles which plants elaborate; ligneous matter, starch, gums, and sugars on the one part; fibrin, albumen, caseum, and gluten on the other, are then the fundamental products of the two kingdoms, products formed in plants, and in plants alone, and transferred by digestion into animals."

Such are the principal chemical substances which are continually present in our atmosphere. To the Chemical student there can be no analytical experiment more interesting than that which shows him the constitution of the air which we breathe. It is one of the first which he will attempt at the pneumatic trough, and which consequeutly he will be most anxious to succeed in. Let me point out to him some precautions in the management of his gases, which may save him from much annoyance and disappointment. He will probably collect his hydrogen, nitric oxide, &c. over the same water; now, the pneumatic apparatus, as a writer in the American Journal of Medical Sciences well observes, requires to be used with circumspection. It is indeed impossible to keep oxygen, nitrogen, or any other gas in its original purity, if confined by water. This fluid, which when reduced to a thin imperceptible film, is instantaneously permeated by almost every substance, undergoes the like action in course of time, even in deep masses. Gases are absorbed and thrown off by it in its purest state; how much more complicated then must its action be in that impure condition in which it is commonly used! Connected with this point there is another: if a series of jars stand on the pneumatic trough, each will affect all the others, communicating a part of its contents, and receiving from them in return. A jar, containing nitric oxide, standing by one of common air, seriously affects it; this I have several times had opportunities of noticing. Gases should never therefore, be kept for any considerable time over the general pneumatic trough, if required for particular use; but transferred to bottles, and the stoppers well greased before they are put aside, inverted in vessels of water or mercury.*

The permanency of the constitution of atmospheric air, led Chemists to consider it a chemical combination of oxygen and nitrogen, and not a mere mechanical mixture. It was imagined, that if it were a mere mixture, the oxygen, as the heavier gas, would be found in greater abundance in the lower regions; but the following experiment will serve to show that gases in general, have a tendency to diffuse themselves, and mix together in an uniform manner, though differing very considerably in density, a fact, completely disproving the objection to the mechanical constitution of the atmosphere.

Experiment. Provide two similar stout glass phials; fill

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* On the subject of the constitution of the atmosphere, the reader may profitably consult Dr. Dalton's remarks, in the 12th Volume of the London and Edinburgh Philosophical Magazine, and Dr. Draper's paper in the 13th Volume.

one with oxygen and the other with hydrogen gas, and connect them together by a piece of glass tube, passing air-tight through the cork of each; allow them to remain undisturbed for a few hours; the bottle containing the hydrogen standing inverted over that containing the oxygen, as shown in *Fig.* 59; *a*, being the bottle of hydrogen, *b*, the bottle of oxygen. On examination the gases will be found to have mixed together, for an explosion will take place in either phial on presenting a lighted taper, proving that a portion of the oxygen has ascended and displaced a gas sixteen times lighter than itself, and vice versâ. The same intermixture would take place if the lower bottle were filled with a still heavier gas, and one for which the hydrogen has no affinity whatever, namely, carbonic acid. Dr. Dalton was the first philosopher who attentively considered this curious property of gases, and from numerous experiments, conducted with his usual skill and care, he drew the inference, that different gases afford no resistance to each other; but that one gas spreads or expands into the space occupied by another gas, as it would rush into a vacuum, though of course the mixture takes place more slowly, in consequence of the mechanical obstruction.

Fig. 59.

The subject of the diffusion of gases has since, been ably investigated by Graham, to whose "Elements" I must refer the more advanced student for a detail of the phœnomena.

Dalton proposed, to consider the different gases which exist in the atmosphere, as being in all points independent of each other, and mixed in virtue of this diffusive power, by which the balance of proportions is preserved.

I am here tempted to make another extract from the Lecture of Dumas; alluding to the composition of the atmosphere, he shows, that its stability may be considered entirely independent of the influence of vegetables, and that the proportion of oxygen which it contains, is secured to it for many centuries. "Atmospheric air is to be looked upon as a mixture,—a true mixture. In weight, air contains 2,300 of oxygen for 7,700 of azote; in volume, 208 of the first, for 792 of the second.

The air besides contains from 4 to 6-10,000ths of carbonic acid in volume, whether it be taken in a city or in the country; moreover, it contains a nearly equal quantity of the carburetted hydrogen gas, which is called marsh gas, and which stagnant waters disengage perpetually;—a variable quantity of aqueous vapour, to say nothing of oxide of ammonium (ammonia) and of nitric acid, the existence of which can be only momentary, because of their solubility in water.

As animals breathe continually; as plants breathe under solar influence only; as in winter the earth is stript, while in summer it is covered with verdure; it has been supposed that the air must transfer all these influences into its constitution; carbonic acid should augment by night and diminish by day. Oxygen should follow an inverse process. Carbonic acid should also follow the course of the seasons, and oxygen obey the same law. But in the mass of the atmosphere, all these local variations blend and disappear, and calculation shows that 800,000 years would be required for the animals living on the surface of the earth to consume the oxygen entirely.

If, therefore, we suppose that an analysis of the air had been made in 1800, and that another should be made in 1900, a diminution amounting to not more than $\frac{1}{5000}$th of its weight would be found in the proportion of oxygen, *even though plants had ceased to perform their functions during the entire century*; but this quantity is beyond the reach of analysis; nature has, therefore so arranged that the store of air should be such with relation to the consumption of animals, that the want of the intervention of plants for the purification of the air, should not be felt until centuries have elapsed."

The following calculation is then made:—

The air which surrounds us, weighs as much as 581,000 cubic kilometres* of copper; its oxygen weighs as much as 134,000 of these same cubes. Supposing the earth peopled with a thousand millions of men, and estimating the animal population at a quantity equivalent to three thousand millions of men, we should find that these quantities consume in a century only a weight of oxygen equal to 15 or 16 cubic kilometres of copper, whilst the air contains 134,000 of it. It would require 10,000 years for all these men to produce a perceptible effect upon the eudiometer of Volta, even supposing vegetable life annihilated during all this time."

It is not then for the purpose of purifying the air that vegetables breathe, though they restore oxygen to it incessantly, in quantities at least equal to that it loses, and perhaps more, since they live just as much at the expense of the carbonic acid, furnished by volcanoes, as at the expense of the carbonic acid, furnished by animals; vegetables have another service so immediate, that if, during a single year it were to fail us, the earth would be depopulated; it is that which these same vegetables render us, by preparing our nutriment and that of the animal kingdom. In this especially is found the chain that binds together the two kingdoms. Annihilate plants, and the animals all perish of a dreadful famine; organic nature itself entirely disappears with them in a few seasons.

Thus the air is an immense reservoir, whence plants may, for a long time, derive all the carbonic acid necessary for their wants; where animals, during a much longer time, still will find all the oxygen that they can consume.

Weight of the atmosphere. It is well known that the rise of water in the sucking pump, and the suspension of the column of mercury in the barometer tube, are caused by the pressure of the atmosphere: from either of these phœnomena therefore, the weight of the atmosphere may be measured. The weight of the column of mercury in the barometer, is exactly equal to a cylinder of air of equal diameter, reaching to the

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* A kilometre is equal to 39370·79 English inches.

top of the atmosphere. The mean height of the barometer, at the level of the sea, is about 28·6 inches, and a cubic inch of mercury weighs 3425·92 grains, or 0·48956 lbs. avoirdupois; it follows, therefore, that a column of mercury whose base is a square inch, and height the mean height of the barometer, weighs 0·48956 × 28·6 inches = 14·6 lbs. avoirdupois nearly, or that the atmosphere exerts a pressure equal to 14·6 lbs. on every square inch of the surface of the earth; in round numbers it may be taken as 15 lbs. The existence of this pressure may be shown in various ways. If a bladder be tied over one end of a jar, open at both ends, and the air extracted by an air pump, the bladder will burst with a loud noise, from the pressure of the air on its outer surface, and a pair of brass hemispheres which, when filled with air are easily separated, require very considerable force to separate them when the air is removed. The pressure of tbe atmosphere plays a very important part in the animal and vegetable œconomy. Like that of all other fluids, it is exerted equally in all directions. Thus, the air in a tube, presses not only on the bottom, but on the sides of the tube, with a force equal to 14·6 lbs. for every square inch. The surface of a man of ordinary stature is about 15 square feet, or 2,160 square inches, whence the whole atmospheric pressure which his body sustains, amounts to the enormous sum of 31,536 lbs. This great pressure is not, however, sensible, because it is balanced by the reaction of the elastic fluids in the interior of the body: but if the equilibrium were suddenly destroyed, the consequences might be fatal. Under the exhausted receiver of an air-pump, animal life is soon destroyed. On the summit of very high mountains, a man experiences extreme fatigue, respiration becomes difficult, the pulse is accelerated, and it has happened that the blood has started from the eyes and ears, and other tender parts of the body, in consequence of the diminished pressure.

If the pressure of the atmosphere be taken at 15 lbs. to the square inch, it is equivalent to a column of of water nearly 34 feet in height.

Density of the atmosphere. The density of air is proportional to the pressure upon it; it is not, therefore, the same at different distances from the earth's surface, but diminishes in the *duplicate ratio of the altitude:* in other words, if at a certain distance above the surface of the earth, it be only *half* what it is at the surface, then at twice *that* altitude, the density will be only *one fourth* of what it is at the surface; now the height at which the atmosphere is of half density, has been estimated at 2·705 miles, or 11,556 feet; at this altitude therefore, a cubic foot of air is expanded into two cubic feet; the barometer would stand at 15 inches; and the density is again halved for every 2·7 miles additional elevation. The following useful table is given by Graham, constructed from the above data.

DENSITY OF THE ATMOSPHERE.

Height from the sea in miles.	VOLUME.
0.	1
2·705	2
5·41	4
8·115	8
10·82	16
13·525	32
16·23	64

Height of the atmosphere. Dr. Prout has ascertained by careful experiments, that 100 cubic inches of well dried atmospheric air, weigh, at 60° F. and 30 Bar: 31·0117 grains,* it is, therefore, 815 times lighter than water, and 11,065 times lighter than mercury. From this it follows, that were it of

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* Dr. Prout has suggested, the possibility of the existence of extremely minute portions of poisonous and foreign matters in the air, during the prevalence of epidemic disorders, and in reference to this subject a remarkable observation occurred during the prevalence of Cholera. For more than six weeks previous to the appearance of Cholera in London, he had been almost every day engaged in determining accurately

the same density throughout, its height would be 11,065 times 30 inches, or 5·238 miles. But on account of the rapid diminution of the density, the height must greatly exceed 5 miles, though we have no means of ascertaining how much. There are, nevertheless, various methods of making an approximative estimate. One of them proposed by Kepler, is derived from observations on the twilight, which is occasioned by the power the atmosphere possesses of refracting and reflecting light. It is generally assumed that twilight ceases when the sun has descended 18° below the horizon; now, it may be considered, that this takes place when a ray of light proceeding from the sun and passing by the surface of the earth, just reaches the highest stratum of the atmosphere, and is reflected back to the earth in the direction of a tangent to its surface, at the place of observation. On this principle it is calculated that reflection cannot take place at a greater altitude than 45 miles. (See the Dictionary of Science, Literature, and Art; edited by Professor Brande; article, *Atmosphere.*) With a good air-pump, air may be rarefied 300 times, and if this be supposed to be the utmost limit to which rarefaction can be carried, the atmosphere would still extend to an altitude of about 40 miles.

Although we cannot assign a precise limit to the height of the atmosphere, we have abundant proof that it *has* a limit, and that it does not extend indefinitely into celestial space, but belongs exclusively to our earth. If, as an eminent Chemist observes, we had obtained our atmosphere by gathering up, in virtue of our attracting force, the thin air which pervades all space; the other bodies of our system should also possess atmospheres whose densities should represent the masses of the bodies they include. If matter, or rather if atmospheric

the weight of a given quantity of air, under precisely the same circumstances of temperature and pressure. On the 9th of February, 1832, the weight of the air suddenly rose above the usual standard, and it continued so for six weeks. On the ninth of February the wind, which had been west, veered round to east, and the first cases of epidemic Cholera made their appearance. *See Prout's Bridgewater Treatise, page* 350.

air, were infinitely divisible, the extent of the atmosphere would also be infinite: but in this case the fluid could not be in equilibrio, unless the sun and all the planets, as well as the earth, had respectively portions of it condensed round them, proportional to their respective attractions. How, it may be asked, do we know that this is not the case? How do we know that Jupiter for instance, does not possess a dense atmosphere? Astronomers, by observing the phœnomena of Jupiter's satellites, have ascertained that the atmosphere of that planet does not, by any means, exceed that of the earth, in proportion to the great superiority of his mass and attractive power;* and indeed, from the fact, that a ray of light suffers no bending in its course, although it passes by the edge of Jupiter, it is highly probable that that immense planet is wholly destitute of any atmosphere whatever.

Dr. Wollaston also has shown from phœnomena attending the passage of Venus near the Sun, that the gravitating centre of our system possesses no sensible atmosphere; are we not, therefore warranted in concluding that the atoms of air are not infinitely divisible, and consequently, that the atmosphere has a limit; and that the limit must be situated at that height above the earth, where the gravitation of the atoms is just equal to the force of their repulsion?

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* The mean diameter of Jupiter is 87,000 miles, that of our earth 7,912 miles, or about eleven times less, consequently Jupiter is 1300 times greater than the earth. The sun is 1048·69 times larger than Jupiter, and 354,936 times larger than the earth, his diameter being 886,800 miles. If the sun possessed an atmosphere proportional to this mass and attractive force, its density would be prodigious. A man of ordinary size would weigh about two tons on the surface of the sun, and a body would fall through 334·65 feet in a second of time.

LECTURE EIGHTH.

ON THE COMPOUNDS OF OXYGEN WITH NITROGEN; NITROGEN WITH HYDROGEN; CARBON; CARBON WITH OXYGEN; POTASH; SODA, AND OXALIC ACID.

NITROUS OXIDE—METHOD OF PROCURING AND RATIONALE OF THE PROCESS—ITS PROPERTIES AND CONSTITUTION—NITRIC OXIDE—METHOD OF PROCURING AND RATIONALE OF THE PROCESS—ITS PROPERTIES AND CONSTITUTION.—NITROUS ACID.—PEROXIDE OF NITROGEN.—NITRIC ACID—ITS NATURE—METHOD OF PREPARATION—RATIONALE—PURIFICATION OF COMMERCIAL AQUAFORTIS.—COLOURED NITRIC ACID—PROPERTIES AND USES OF NITRIC ACID.—INTERESTING EXPERIMENTS WITH IRON AND TIN—TESTS OF NITRIC ACID—GENERAL CHARACTERS OF THE SALTS OF NITRIC ACID—NITROGEN WITH HYDROGEN.—AMMONIA—PROCESS FOR PROCURING—RATIONALE—PROPERTIES AND NATURE OF AMMONIA—ITS SOLUTION IN WATER—AMIDOGENE.—AMMONIUM—VIEWS RESPECTING IT—DR. BIRD'S BATTERY AND DECOMPOSING CELL.—CARBON—VARIETIES OF—THE DIAMOND—ITS NATURE—METHODS OF ANALYZING—GRAPHITE—ANTHRACITE—CHARCOAL—ITS SINGULAR AND USEFUL PROPERTIES.—ANIMAL CHARCOAL—COKE.—LAMP BLACK—CARBON WITH OXYGEN—CARBONIC ACID—PREPARATION AND PROPERTIES—ITS ACTION ON THE SYSTEM—METHOD OF NEUTRALIZING—ITS SOLUTION IN WATER—ATOMIC WEIGHT OF CARBON.—EXPERIMENTS

OF DUMAS AND STASS—OF LIEBIG AND REDTENBACHER.—THE CARBONATES—CARBONATE AND BICARBONATE OF POTASSA—SOURCE OF POTASH IN THE ASHES OF VEGETABLES—CAUSTIC POTASH—HYDRATE OF POTASH—POTASSIUM—CARBONATE AND BICARBONATE OF SODA—ALKALIMETRY—SODIUM—CARBONIC OXIDE—METHODS OF PROCURING—PROPERTIES AND COMPOSITION—OXALIC ACID—ITS PREPARATION—ITS POISONOUS NATURE—ANTIDOTES FOR.

The compounds of nitrogen and oxygen, which will engage our attention first in the present Lecture, are five in number; the name and composition of each of which is as under:—

SYMBOL. EQUIV:

Nitrous oxide, or protoxide of nitrogen,................ $N=177+O=100=NO=277$

Nitric oxide, or deutoxide of nitrogen,................ $N=177+2O=200=NO_2=377$

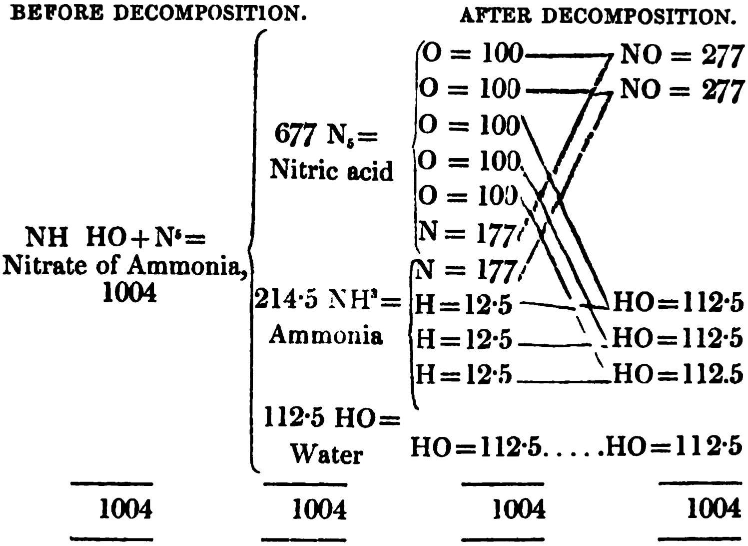
Nitrous acid, or hyponitrous acid,.................... $N=177+3O=300=NO_3=477$

Peroxide of nitrogen, or hyponitric acid.... .... $N=177+4O=400=NO_4=577$

Nitric acid................. $N=177+5O=500=NO_5=677$

Nitrous oxide, protoxide of nitrogen, laughing gas. To obtain this singular compound, pure nitric acid is to be saturated with carbonate of ammonia, and evaporated on a sand bath, till a drop taken out on the end of a glass rod, solidifies on cooling; it is then to be set aside, and when cold, the crystals of nitrate of ammonia, which are the result of the process, must be transferred to a bottle and well stopped, to prevent the access of damp air, it being a very deliquescent salt. To obtain nitrous oxide, nothing more is necessary than to heat cautiously the nitrate of ammonia; at about 300° F. it liquefies, but does not suffer decomposition till the temperature reaches 350°, when the nature of the reaction is as represented in the following diagram.

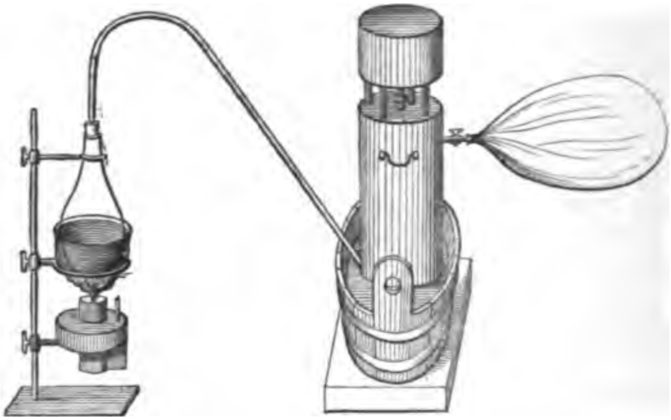
PROCESS FOR NITROUS OXIDE.



From this we learn that 1004 parts, or one equivalent of nitrate of ammonia become resolved into two equivalents, or 554 parts of nitrous oxide, and four equivalents or 450 parts of water; the operation may therefore be carried on till the whole of the salt has disappeared, for the water will pass off as steam, which will be condensed in the water of the pneumatic trough. The operator must be careful not to allow the temperature to rise too high, (not much above 350°) or the ebullition will become violent, and the gas produced quite unfit for respiration. The degree of heat is best regulated by applying it through the medium of sand, as shown in *Fig.* 61, in which the decomposition is represented as being conducted in a common Florence oil flask, furnished with a bent tube and immersed in a small iron cup of sand; the gas must be collected over warm water (about 90° F.) since cold water absorbs it very freely. If considerable quantities are to be collected, the same water should be returned to the gas-holder from time to time, it thus becomes saturated with the gas, and may then be used without being warmed.

There are other methods of obtaining nitrous oxide, but the above is the only one practically available.

Fig. 61.

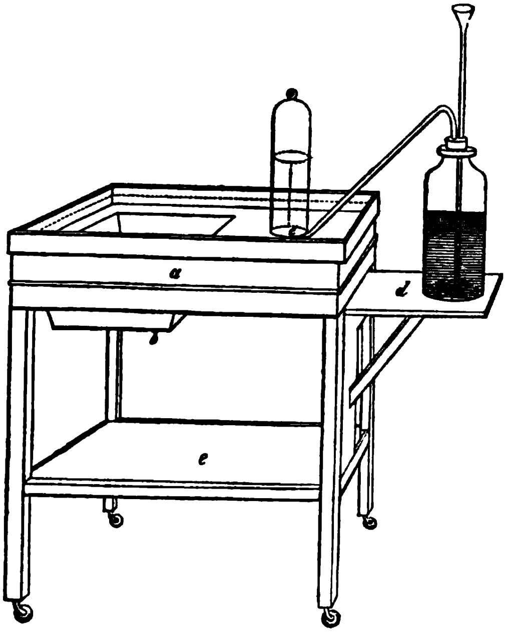


Properties. Nitrous oxide is colourless; its taste, when pure, is sweet, and its smell peculiar but agreeable. It is heavier than common air; its specific gravity being 1·527, and 100 cubic inches weighing 47·2 grains. It supports combustion; most substances burn in it with much greater energy than in the atmosphere; a lighted taper when introduced into it has its flame much enlarged and surrounded by a purplish halo. Sulphur and phosphorus when introduced in a state of vivid ignition, burn nearly as brilliantly as in oxygen; but if they are merely burning dimly, they do not decompose the gas but are extinguished. It is nearly entirely absorbed by water that has been boiled and allowed to cool without the access of air, and this property furnishes a method of testing its purity; at least nine-tenths of the bulk of the water ought to disappear. The water thus saturated has a sweet taste; it does not exhibit any signs of acid or alkaline qualities, and when heated gives out the gas unchanged. When mixed with hydrogen, it detonates loudly on passing an electric spark through the mixture: this was the method employed by Sir H. Davy, to analyze the nitrous oxide. Two volumes of nitrous oxide require for decomposition two volumes of hydrogen, and leave after combustion two volumes of nitrogen. The hydrogen decomposes the nitrous oxide, by uniting with its oxygen and forming water. Dr. Henry employed carbonic oxide gas to decompose this gas; potassium or phosphorus may also be employed; by all these methods it is proved that two volumes of nitrogen combine with one volume of oxygen, to produce two volumes of nitrous oxide.

The most singular property of this gas is the intoxication which it produces when inspired, which was discovered by Sir H. Davy, nearly at the commencement of his distinguished philosophical career. To prepare the gas for this purpose, it is necessary to attend to the purity of the nitrate of ammonia, which, as prepared for commerce, is frequently found to be contaminated with muriate of ammonia or sal-ammoniac, in which case the gas obtained may be impregnated with chlorine and nitrous acid, and prove very irritating to the lungs; a small admixture of sulphate of ammonia I have also found very considerably to diminish the intoxicating powers of the gas. Four or five quarts may be respired from a large ox-bladder filled from the gas-holder, as shown in *Fig.* 61. This will be found sufficient for one person, and may be obtained from about two ounces of the nitrate. An animal when confined in this gas soon dies.

Nitric oxide, binoxide or deutoxide of nitrogen, or nitrous gas. This compound was first collected by Dr. Hales, but its properties first studied by Dr. Priestley. It is obtained most conveniently by the action of nitric acid, diluted with an equal bulk of water on small clippings of copper, and may be collected in the usual manner over the hydro-pneumatic trough, as in *Fig.* 62, being scarcely absorbed in an appreciable manner by that fluid. It does not require heat for its production. The following diagram will explain the nature of the reaction, and the symbolic representation of the compounds concerned.

Fig. 62.



PROCESS FOR NITROUS GAS.

BEFORE DECOMPOSITION. AFTER DECOMPOSITION.

$N_5 = 677$ { N……177 — NO_2 377
O……100
O……100
O……100
O……100
O……100

Cu = 396 .. Cu 396
N_5 = 677 .. N_5 677 — Cu O, N_5 1173
Cu = 396 .. Cu 396
N_5 = 677 .. N_5 677 — Cu O, N_5 1173
Cu = 396 .. Cu 396
N_5 = 677 .. N_5 677 — Cu O, N_5 1173

3896 3896 3896

Here we find that to produce one equivalent of nitric oxide or nitrous gas, *four* equivalents of nitric acid, and *three* equivalents of copper (Cu) are required; that it is by the decomposition of nitric acid that the new gas is formed, and that this decomposition is occasioned by a fact that has been noticed more than once in these Lectures, viz:—that before a metal can enter into combination with an oxygen acid and form a salt, it is necessary that it should be in the *state of oxide*; the copper must therefore first decompose a portion of nitric acid and unite with an equivalent of its oxygen; it thus becomes protoxide of copper, and is in a state to enter into combination with the nitric acid. In the diagram it is supposed that *three* equivalents of copper take each an equivalent of oxygen from an equivalent of nitric acid which is thus left in a new form, that of nitrous gas, retaining only *two* equivalents of oxygen; the three equivalents of *protoxide of copper* now find three equivalents of undecomposed nitric acid to combine with, forming $3\,(Cu\,O,\,N_5)$ three equivalents of nitrate of copper. The only part the water plays in this process, is that of dissolving the nitrate of copper, hence the beautiful blue liquid which remains in the gas-bottle at the close of the operation.

Properties. This gas is transparent and colourless; it is heavier than common air, though not so heavy as the nitrous oxide, its specific gravity being 1·038, and 100 cubic inches weighing 32·137 grains. Though scarcely absorbed by water by standing over it, that fluid may nevertheless be made to dissolve the gas in the proportion of about one volume to twenty, but to effect this solution, the water must be previously deprived of air by long boiling and the gas agitated with it for some time. If the solution be kept a long time it will be found to contain nitrate of ammonia, resulting from the joint decomposition of the nitric oxide and the water.—*Brande.* After being well washed, nitrous gas is not acid, as may be proved by pasting a slip of blue litmus paper on the inside of a jar and filling it with the gas; the colour will remain unchanged. It is absolutely irrespirable, though from the circumstance that when introduced into the lungs it always finds sufficient oxygen to convert a portion of it into nitrous acid; its abstract effects on the system cannot be determined. It does not support the combustion of inflammables, for although phosphorus and charcoal, when introduced into it in a state of vivid ignition burn with dazzling splendour, it is in oxygen and not in nitric oxide that the combustion actually occurs; the gas being resolved into its elements by the high temperature of the combustibles, which combine with the oxygen alone, giving rise to metaphosphoric and carbonic acids, while the nitrogen remains untouched. If the charcoal or phosphorus are only burning feebly when introduced into the nitric oxide, they will not evolve sufficient heat to decompose it, and will consequently be extinguished. Nitric oxide does not form an explosive mixture with hydrogen, but imparts to its flame a green colour. It is deprived of one half of its oxygen and reduced to the state of *nitrous oxide,* by remaining for some days in contact with iron or zinc filings. Gay Lussac decomposed 100 measures of it by the action of heated potassium; 50 measures of pure nitrogen remained, and the loss of of weight corresponded to 50 measures of oxygen, so that nitric oxide is composed of one volume of nitrogen and one volume of oxygen combined, without change of volume.

The most remarkable property of this gas, and one by which it may always be recognized, is that of its forming red-coloured vapours whenever it comes into contact with *uncombined* oxygen. It is this which causes the red fumes in the flask in which the gas is generated. These red fumes are acid, as may be proved by admitting a little common air to a jar of nitric oxide, in which is pasted a piece of litmus paper, the blue colour being immediately changed to red. Though from the variable nature of the products, nitric oxide cannot in a general way be usefully employed in eudiometry, it is useful for removing oxygen from a gaseous mixture, which it completely effects if added in excess, and as the red fumes are entirely soluble in water, they may be completely removed. Nitric oxide is a neutral body, having a very limited range of affinity; it is absorbed by all the soluble proto-salts of iron, and remains attached to the oxide of iron, when precipitated in the insoluble salts of that metal. It was mentioned in the last Lecture, that the deep olive-brown solution, formed by passing nitric oxide into a solution of proto-sulphate of iron was found by Davy rapidly to absorb oxygen, and was hence employed by him in eudiometric experiments; it cannot however be relied on, the absorption of oxygen being soon followed by the evolution of gas from the liquid itself.—*Turner.*

Nitrous acid. When nitric oxide is added in excess to oxygen or atmospheric air, this acid is the principal product. It is obtained in a direct manner by mixing four volumes of nitric oxide with one volume of oxygen, and exposing it to a great degree of cold, by which it is condensed into a deep green-coloured and very volatile liquid. When nitre is exposed to a high heat, it melts; and then undergoes decomposition, giving off oxygen gas, and becoming *nitrite* instead of *nitrate* of potash, NO_5 KO, giving off 2 O, and becoming NO_3 KO. This salt cannot be crystallized and therefore cannot be readily obtained pure, a sparingly soluble salt, nitrite of silver, may however be obtained from it in a state of purity, by dropping into it previously filtered solution of nitrate of silver, and from this salt pure nitrites may be obtained by double decomposition.—*Mitscherlich.*

Peroxide of nitrogen. This compound of oxygen and nitrogen is produced *alone*, when four volumes of nitric oxide and two volumes of oxygen, both quite free from moisture are mixed, and exposed to a great cold, the six volumes being condensed into two volumes. It is likewise formed by distilling nitrate of lead in a hard glass retort, and collecting and condensing the vapours in a receiver, surrounded with a mixture of snow and salt; a quantity of oxygen gas escapes, NO^5 PbO gives PbO, free NO_4, and O. As thus obtained, the peroxide of nitrogen is a highly volatile liquid, boiling at 82° and forming a white solid mass at —40. It is powerfully corrosive, staining the skin yellow like nitric acid. In a stoppered bottle it preserves its liquid form at common temperatures, but when exposed to the atmosphere it is rapidly dissipated. It is a powerful oxidizing agent. It is the presence of peroxide of nitrogen which causes the disagreeable fumes in the coloured nitric acid of commerce, and by gently warming that acid, and condensing the vapour that comes over the liquid, peroxide of nitrogen may be obtained.

Nitric acid. This is by far the most important compound of oxygen and nitrogen, being extensively used in the arts, and constituting one of the most valuable re-agents in the laboratory of the Chemist. Although known in the earliest ages of Chemistry, it was not till 1785, that its true nature and composition was first demonstrated by Mr. Cavendish, who, by passing a succession of electric sparks through a mixture of seven volumes of oxygen and three of nitrogen during several days, the mixture being confined in a small tube over water, obtained a solution of nitrate of potash. This experiment may be made in a less laborious but equally satisfactory manner by moistening a very small slip of litmus-paper in a solution of caustic potash, and then passing a succession of electric sparks from a powerful machine, over its length in air, the alkali will gradually become neutralized, and ultimately the litmus paper will be reddened; on drying the paper it will be found to have become *touch-paper*, proving that *nitrate of potash* has resulted from the operation.

Preparation. The nitric acid or *aquafortis* which is met with in commerce, is prepared by decomposing nitre* by means of sulphuric acid. The proportions employed differ in

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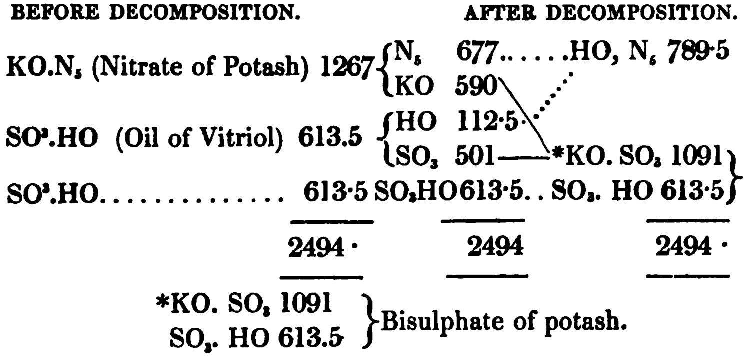
* Since the introduction of nitrate of soda into commerce, it has almost completely superseded nitrate of potash for making nitric acid. It is much cheaper, yields a larger product, requires less sulphuric acid, and less heat.

different manufactories; but the most convenient are two equivalents of oil of vitriol, and one equivalent of nitre; 97 parts of the former to 100 of the latter, or in practice, equal weights of each. It will be seen by the following diagram, that this is twice the quantity of oil of vitriol that is *absolutely* required; but this acid is so cheap, that the advantages gained by doubling the requisite quantity are quite sufficient to warrant the additional outlay. The advantages are the absence of disagreeable vescicular swelling of the materials; of ruddy fumes which are condensed with difficulty; the lower temperature required; and lastly and principally, when the operation is conducted in glass vessels, the residual formation of a soluble bisulphate, instead of a hard and less soluble neutral sulphate of potash.

PROCESS FOR NITRIC ACID.



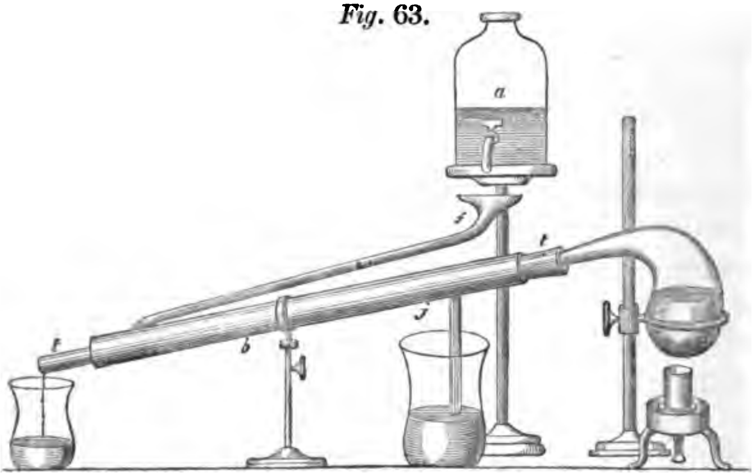
BEFORE DECOMPOSITION.			AFTER DECOMPOSITION.
KO.N_5 (Nitrate of Potash)	1267	N_5 677	HO, N_5 789·5
		KO 590	
SO^3.HO (Oil of Vitriol)	613.5	HO 112·5	
		SO_3 501	*KO. SO_3 1091
SO^3.HO..............	613·5	SO_3HO 613·5	SO_3. HO 613·5
	2494·	2494	2494·

*KO. SO_3 1091
SO_3. HO 613.5 } Bisulphate of potash.

Here we see that an equivalent, or 613·5 parts of oil of vitriol decomposes an equivalent, or 1267 parts of nitrate of potash, and that an equivalent, or 1267 parts of nitrate of potash, and that an equivalent, or 1091 parts of sulphate of potash is produced, while an equivalent, or 677 parts of real nitric acid is set free; but as this acid cannot exist in a free state without water, it takes an equivalent, or 112·5 parts of water from the oil of vitriol, forming 789·5 parts of nitric acid and water. The other equivalent of oil of vitriol is not therefore concerned in the decomposition, and is consequently ready to enter into combination with the sulphate of potash, forming an equivalent, or 1704·5 parts of bisulphate.

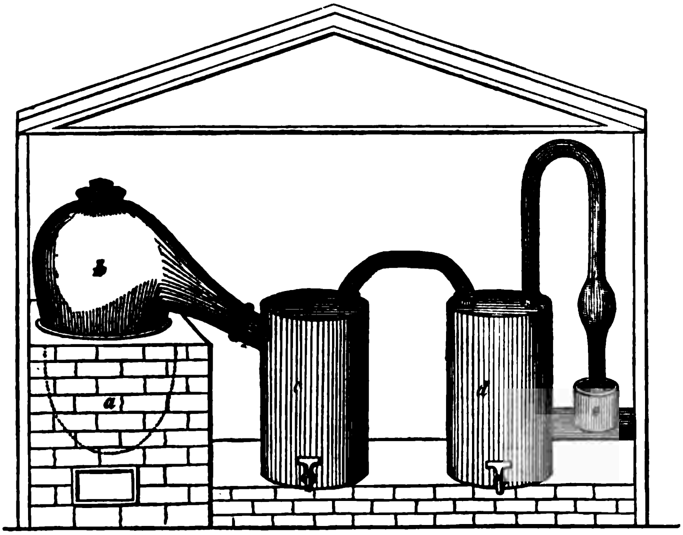
The student may prepare his own nitric acid very conveniently, using the distillatory apparatus of Liebig, *Fig.* 63. Particular attention should be paid to the purity of the *nitre*, which, as met with in commerce, is always more or less impregnated with common salt; to separate which, the nitre must be dissolved in distilled water, and repeatedly re-crystallized; one pound of it, previously melted, and after cooling, pulverized, may be mixed in a green glass retort, with one pound of the strongest oil of vitriol, and the distillation conducted as shown in the figure; the heat of an Argand lamp being quite sufficient to effect the complete decomposition of the nitre. If the sulphuric acid employed be in its highest state of concentration, the nitric acid produced should have a density of 1·522 at 58°; and the operator should obtain theoretically 10 ounces: most probably however the oil of vitriol will not be in its highest state of concentration, or it will contain *more* than one equivalent of water for one equivalent of acid. I generally obtain about nine ounces of acid, specific gravity, 1·47 from sixteen ounces of nitre, which I believe is as much as can practically be expected.

Fig. 63.



In preparing nitric acid on the large scale for commerce, no care is taken to purify the nitre, the presence of a little muriatic acid being of no consequence. *Fig.* 64 represents the arrangement of the apparatus employed at Apothecaries' Hall,

Fig. 64.



a, an iron pot set in brick-work over a fire place; *b*, an earthen head luted upon it communicating with *c* and *d*, two receivers of the same material, furnished with earthenware stop-cocks, the last of which has a tube of safety, dipping into a basin of water. The acid as thus obtained is contaminated with chlorine from the decomposition of the common salt (chloride of sodium,) contained in the nitre, sulphuric acid from too high a heat, and iron arising from the retort, or from the stoneware cylinders; all these substances are easily detected and removed, so that having once prepared the acid, to make himself familiar with the process, the student will rarely have occasion to repeat it, as the purified aquafortis of commerce will be strong enough for most of his experiments. *First*; to detect the chlorine, let a few drops of the acid be mixed with half an ounce of distilled water; dip a glass rod into a solution of *nitrate of silver* and stir the mixture with it; if any chlorine be present a white cloudiness will be immediately perceived, arising from the decomposition of the *nitrate* and the formation of *chloride* of silver. *Second*; to detect sulphuric acid, stir the mixture with a rod that has been dipped in a solution of *nitrate of barytes*; a white precipitate, occasioned by the formation of insoluble sulphate of barytes will indicate the presence of sulphuric acid. *Third*; to detect iron, which if present, will be in the state of a *peroxide*; drop a little solution of yellow prussiate of potash into the mixture, which, will form Prussian blue, if any of that metal be present.

From all these impurities, the acid may be freed by being re-distilled; the chlorine passes off with the portions that first come over, and the sulphuric acid and iron remain in the retort, provided the distillation be not pushed too far. According to Kane, from twelve pounds of commercial aquafortis, about eight ounces of pure nitric acid are obtainable, three being allowed to come over first, to carry off the chlorine, and one being left in the retort with the fixed impurities.

It is hardly possible, however careful the process is conducted, to prevent a small portion of the nitric acid from being decomposed; at the commencement of the operation nitrous fumes are disengaged, which communicate to the acid a straw-yellow or an orange-red tint, according to their quantity. If a colourless acid is required, two receivers should be used, one for condensing the colourless vapours of nitric acid, and another for the coloured products. But the strong and colourless acid, if exposed to direct solar light, very soon becomes deep yellow, whilst oxygen gas is disengaged; and indeed, if the acid be kept in a white glass bottle and not exposed to the sun, it acquires a yellow colour after a time, but this is not of the slightest consequence, as in nearly every case the coloured acid may be substituted for that which is colourless, and in some cases is even preferable.

Properties and uses. From the facility with which nitric acid parts with a portion of its oxygen, it is exceedingly useful as an oxidizing agent. It acts with remarkable energy on most of the metals, and on organic substances: forming oxides with the former, and with the latter giving rise to oxalic, malic, and carbonic acids, and sometimes to ammonia and prussic (hydrocyanic acid). If on a drachm of oil of turpentine, mixed with half a drachm of sulphuric acid, a drachm of strong nitric acid be poured, the whole will burst into a flame, and a piece of glowing charcoal thrown on the surface of the concentrated acid, burns vehemently. With animal substances containing nitrogen, it forms new bodies of a deep yellow colour, hence the stains it produces on the fingers and nails; this property is applied to a useful purpose, in stamping the yellow patterns on woollen table covers. The action of nitric acid on some of the metals is attended with some interesting phœnomena. If an iron wire be immersed in a glass containing nitric acid, of the specific gravity of 1·48, it remains unaltered, and is, even after half an hour, as bright as when first put in; but if the acid be stronger or weaker the action is very intense. A piece of iron thus inactive in strong acid, may be brought into activity by simply touching it with another. There are some curious electrical conditions involved in these phœnomena, for an account of which I refer the reader to two papers, communicated by me to the London and Edinburgh Philosophical Magazine, vols. 10 and 12, in which he will also find some other papers on the same subject by Professor Schönbein and others.

With tin, a highly interesting experiment may be made. Put some filings of that metal into a small porcelain cup, and pour on them a little concentrated nitric acid; no action will ensue; now add a little water, violent effervescence will immediately take place, and the tin will speedily be reduced to the state of peroxide; but this is not all; transfer the dry powder to a mortar, and intimately mix with it a little pulverized sal ammoniac, (muriate of ammonia); a powerful smell of *ammonia* will be evolved, proving that *nitrate* of ammonia must have been formed with the peroxide of tin: now ammonia, as will presently be shown, is composed of nitrogen and hydrogen, (NH_3); water therefore must have been decomposed, the oxygen of which united to the tin, while the hydrogen combined with the nitrogen of the acid forming ammonia, which then entered into combination with its equivalent of undecomposed nitric acid.

Nitric acid is used in fumigations, to destroy contagious and infectious matter, more especially in inhabited apartments where *chlorine* would be injurious; it is not however so efficacious as this last principle: for this purpose nitrate of potassa may be decomposed by sulphuric acid in a porcelain saucer, aided by a gentle heat. In pharmacy and surgery this acid is susceptible of application; and in the arts, particularly for etching on copper; for preparing solutions of tin for dyers and calico printers; in metallurgy and assaying, it constitutes a most valuable agent.

The action of the concentrated acid on some organic substances is singular. If a piece of paper be soaked for about one minute in an acid formed by distilling 100 parts of nitre with 60 of oil of vitriol; it is found to shrivel up a little and become nearly as tough as parchment, and when dried to be remarkably inflammable, catching fire at so low a temperature as 356° and burning without any nitrous odour.—*Pelouze.*—*Graham.*

In the laboratory, the uses of nitric acid are many and important. *First.* As a general solvent of the metals. *Second.* To effect the separation of certain metals—antimony and tin for instance, in the form of insoluble peroxides, from those which yield soluble oxides. *Third.* To separate sulphur from the sulphurets of copper, lead, or silver, for which purpose it should not be very strong. *Fourth.* To detect and destroy the fetid odour of sulphuretted hydrogen. *Fifth.* As a test of organic substances, most of which, if they contain nitrogen, it tinges yellow; it detects strychnina* by rendering it red; it distinguishes gum from starch by converting the former into mucous or saclactic acid, and cork it changes into suberic acid.

Tests of nitric acid. All the nitrates being *soluble*, it is not possible to detect this acid by precipitation; one of the following methods may, however, be resorted to with a view of ascertaining its presence. *First.* The production of red fumes of nitric oxide, when brought into contact with a metal, is characteristic of it. *Second.* When a drop of nitric acid is added to water tinged blue by sulphate of indigo, and the mixture boiled, it is bleached by the oxidizement of the indigo by the acid. *Third.* When a small crystal of copperas (proto-sulphate of iron,) is placed in contact with water containing nitric acid, a ring of deep olive-coloured liquid forms round it, according as it dissolves; from one portion of the proto-sulphate reducing the acid to the state of nitric oxide, which then combines with the remaining proto-sulphate. The mode of applying this test, as recommended by De Richemont, is this: add to a small quantity of sulphuric acid the solution to be examined, in such a proportion that the quantity added should equal three-fourths of the bulk of the acid. When the mixture has become cool, drop in a concentrated solution of proto-sulphate of iron, which, if any nitric acid be present, decomposes it, causing the evolution of nitric oxide, which produces a rose-red or purple tint. This mode of operating will allow us to detect 1 part of nitric acid in 24,000 of water. *Fourth.* Nitric acid gives to hydro-chloric (muriatic) acid, the property of dissolving gold leaf. *Fifth.* It produces a deep red colour with morphia. It is always however, advisable to neutralize the liquor to be tested with potash, and evaporate to dryness. The salt thus obtained, crystallizes in sharp needles, and deflagrates when placed on ignited charcoal: heated with a little bisulphate of potash and some copper filings, it evolves copious red fumes, and with a drop of sulphuric acid, and a crystal

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* A most poisonous vegetable alkali, obtained from the nux vomica.

of proto-sulphate of iron, produces the olive-coloured liquid already noticed. All solid compounds of nitric acid, such as the basic nitrates, may be recognized in this way.—*Kane.*

The salts formed by nitric acid are called *nitrates*; they are all, without exception, decomposed by a high temperature, especially when combustible matter is present, hence the great use of nitre as an oxidizing agent. The process for oxidizing by means of this salt is called *deflagration*, and is generally performed by mixing the inflammable body with an equal weight of nitre, and projecting the mixture in small portions at a time, into a red hot crucible.

Nitre or nitrate of potash is spontaneously produced upon the soil in many parts of the world, as Spain and the East Indies. Nitric acid is indirectly formed by the conjoint action of decomposing animal matter, and of earthy bases on atmospheric air. The grand cause of nitrification on the surface of the earth is probably ammonia. Let us see in what way. Nitrogen is remarkable for its feeble affinity for oxygen, and the spontaneous decay or *eremacausis* of organic substances which contain that principle, always gives rise to the formation of ammonia, but never to that of nitric acid.

It has been supposed by Chemists however, that under certain circumstances, the nitrogen in an animal substance, when exposed to the action of the air, water, and alkaline bases, obtains the power to combine *directly* with oxygen and form nitric acid.

Liebig asserts that such a supposition is unnecessary. Ammonia is changed into nitric acid with great facility; it is owing to this that the determination of nitrogen is so difficult in an organic analysis. Ammonia is formed by the elevation of temperature, and when this compound passes over red hot oxide of copper, it is converted either partially or completely into an oxide of nitrogen.

Ammonia and oxygen, when passed together over red hot spongy platina, occasion the formation of nitric acid.

Ammoniacal gas, when conducted over red hot oxide of manganese or iron, gives rise to the production of nitrate of ammonia.

Nitric acid is *never* formed during the combustion of carbon and oxygen, nitrogen being present; though if *ammonia* be present, nitric acid *is* invariably formed. The reason of this seems to be, that *both* the constituents of ammonia combine with oxygen *and with each other*, and more, that nitric acid cannot exist without one of the products, namely, *water*.

With a compound of carbon and nitrogen on the other hand, there is not this predisposing cause: on the contrary, the carbonic acid formed probably, opposes the production of nitric acid on account of its gaseous form.

Azotized matter is not, therefore, the *immediate* cause of nitrification; it contributes to the production of nitric acid, only in so far as it is a slow and continued source of ammonia. By lixiviating the soil on which the natural nitre beds are formed with water, a solution is obtained, containing among other saline matters, a considerable quantity of nitrate of lime: this is then decomposed by an impure carbonate of potash, and carbonate of lime being precipitated, a solution of nitrate of potash is obtained, from which the salt is procured by evaporation and crystallization.

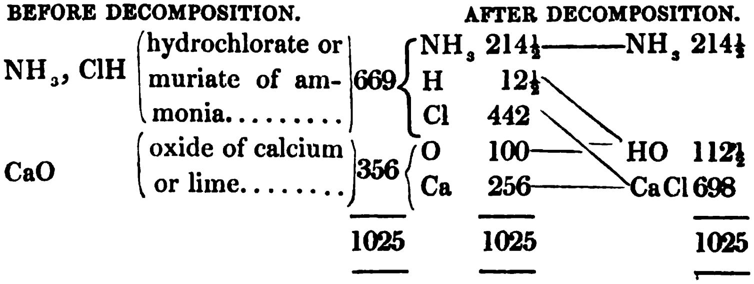
Nitrogen with hydrogen. It is now generally admitted by Chemists, that there exist *three* compounds of nitrogen and hydrogen, to which there have been given the names of *1st*, amidogen, (NH_2); *2nd*, ammonia, (NH_3); and *3rd*, ammonium, or ammonyle, (NH_4). Of these, ammonia is the only one that can be obtained in a separate state, and therefore it is the only one which, in a work like this, it will be necessary to describe minutely.

Ammonia is a volatile alkali; its solution in water forms the well known stimulant, *liquid ammonia*, or spirit of hartshorn. It derives its name from *sal ammoniac*, the salt from which it is prepared. Sal-ammoniac or muriate of ammonia is a natural production, occurring in crystalline masses in the vicinity of volcanoes. According to Pliny, it derived its name from the circumstance of its having been found near the temple of Jupiter Ammon, in Africa. Ammonia is produced in the destructive distillation of all organic substances containing nitrogen, and also, as has been already stated, during the spontaneous putrefaction of animal matters in the atmosphere.

The preparation of ammonia is exceedingly interesting and instructive: as its formula (NH_3) indicates, it is a compound of one equivalent of nitrogen and three equivalents of hydrogen; nevertheless, the gases may be mixed in that proportion without any tendency to combination being evinced; but if we present nitrogen and hydrogen to each other in what is termed their *nascent* state, that is, before they have combined with that *something* which gives them their gaseous form, ammonia is invariably produced; there is no experiment which shows this in a more striking manner than the one recently alluded to with nitric acid, water, and tin.

Ammoniacal gas is prepared by mixing intimately equal weights of pulverized sal ammoniac and quicklime, and distilling in a glass retort; the product, if intended for examination in a gaseous form, must be collected over mercury. The following diagram exhibits the nature of the reaction.

PROCESS FOR AMMONIA.



By this we see, that by using equal weights of lime and sal ammoniac, all the ammonia is sure to be separated from the muriate; chloride of calcium and excess of lime remaining in the retort.

This gas is permanently elastic at common temperatures; but submitted to a pressure equal to about 195 inches of mercury, or 6·5 atmospheres; at the temperature of 50° it becomes liquid. It is very pungent and acrid, and of course, therefore, unrespirable, except when diluted with common air, in which state it forms an agreeable stimulant. Its specific gravity, compared with hydrogen, is as 8·5 to 1; compared with common air, as 0·59 to 1; 100 cubic inches weigh 18·19 grains. Ammonia extinguishes flame; but it may be burned when issuing from a capillary orifice in an atmosphere of oxygen; mixed with its volume of oxygen it burns with a feeble explosion, and with an equal volume of nitrous oxide it may be detonated by the electric spark, affording water and free nitrogen.

Ammonia possesses in a very marked manner all the properties of an alkali; it combines with and neutralizes the most powerful acids, forming salts; all of which suffer decomposition by being heated with the fixed alkalies or alkaline earths, and none can sustain a red heat without undergoing decomposition. It is resolved into its elements the instant it comes into contact with chlorine, whether in a gaseous state, or in a liquid form. The latter experiment has been already alluded to as a process for obtaining pure nitrogen. Its decomposition by chlorine, while in a gaseous state, we shall describe when we come to *chlorine.*

When a succession of electric sparks is passed through ammoniacal gas, it is likewise resolved into its elements, and the same effect is produced by conducting ammonia through porcelain tubes heated to redness. Berthollet thus found, that 200 volumes of ammonia occupied the space of 400 volumes, 300 of which were hydrogen and 100 nitrogen, and the same has since been verified by Dr. Henry.

When conducted into water, that fluid dissolves several hundred times its volume, and the solution of ammonia thus obtained is always specifically lighter and has a lower boiling point than water. When a concentrated solution is required, the distilled water in which the gas is condensed must be kept cool by means of ice or damp cloths; it may thus be obtained of specific gravity, 0·936, in which state of concentration it boils at 130° owing to the rapid escape of pure ammonia, though the whole of the gas cannot be expelled by this means, as at last the solution itself evaporates. It freezes at about —39°, the same temperature as mercury. On account of its great volatility it should be kept in well-stopped bottles, a measure which is also required to prevent the absorption of carbonic acid. It may always be known by its smell, and by its temporary action on yellow turmeric paper.

Amidogene (NH_2) is supposed by Dr. Kane, to exist in the *white precipitate** of pharmacy, and this opinion is strengthened by the observations and experiments of Ullgren. It was suggested by Dumas, that the explosive compounds of nitrogen might contain amidogene, and the same view has been applied to the fulminating compounds produced by the action of ammonia upon the oxides of gold and silver. Although there appears to be no doubt in the minds of Chemists as to the existence of this compound, it has not yet been insulated. Mercury is the only *metal* with which it has hitherto been found in combination, but with oxalic and other organic acids, and with sulphurous acid it forms compounds which are termed *amides*, as *oxamide*, ($NH_2C_2O_2$) sulphamide, ($NH_2\ SO_2$) &c.

Ammonium (NH_4) is a hypothetical compound, with respect to which there is a diversity of opinion among Chemists. When mercury is alloyed with one per cent. of sodium and poured into a saturated cold solution of sal-ammoniac, it undergoes a prodigious increase of bulk, increasing sometimes from one volume to two hundred, without becoming in the least degree vesicular, and acquires a butyraceous consistence, whilst its metallic lustre is not impaired. A small addition is at the same time made to its weight, estimated at from 1 part in 2,000 to 1 in 10,000, and which certainly consists of am-

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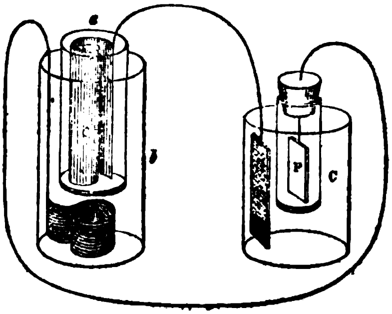
* Formed by adding ammonia to a solution of chloride of mercury.

monia and hydrogen, in the proportions of ammonium. The sodium, some suppose, combines with the chlorine of the *chloride of ammonium*, (sal-ammoniac,) and the liberated ammonium with mercury, so that the metallic product is an amalgam of ammonium.—*Graham.* The same sort of amalgam is formed by placing a solution of muriate of ammonia in the decomposing cell c, of the voltaic arrangement, *Fig.* 65, with mercury in contact with the platina plate P.* After a few hours the fluid metal swells to five or six times its former bulk, and when put into water gives off hydrogen gas and slowly returns to its former state, ammonia in solution being obtained. Some Chemists imagine that *nitrogen* is the substance here decomposed, a *metal* being extricated from it which forms an amalgam with mercury. Daniell thinks such an assumption unnecessary, and explains the phœnomenon by referring it to the force of *adhesion* by which the elasticity of the hydrogen and ammoniacal gases is restrained by the mercury, and which reacting upon the cohesion of the metal, causes it to expand and increase its volume. He instances silver as presenting a similar phœnomenon, which at a white heat, absorbs large quantities of oxygen, giving it off again when it solidifies.

Fig. 65.



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* This simple arrangement is a contrivance of Dr. Golding Bird, and is well adapted for the investigation of the decomposing power of feeble electrical currents, *a* is a cylinder of glass, four inches long, closed at the lower end by a plug of plaster of Paris; this is fixed within the plain jar, *b*, about eight inches deep, by two inches in diameter; a piece of sheet copper, *c*, four inches long and three inches wide, having a copper conducting wire soldered to it, is loosely coiled up and placed in the inner cylinder: a piece of sheet zinc, *z*, of equal size, is also loosely coiled and placed in the outer cylinder, the zinc being likewise furnished with a conducting wire. The outer cylinder is nearly filled with a weak solution of common salt, and the inner with a saturated solution of sulphate of copper. The decomposing cell is the counterpart of the battery itself; *p*, is a slip of platina foil, and *z*, a slip of amalgamated zinc.

The metallic character of ammonium is not however essential to it as an alkaline radical; other basyles, (ethyle and benzoyle for instance, are now admitted, which certainly have no claim to such character.)*

The elementary substance which stands next to nitrogen in the "Table of Elements," is *carbon,* (C) a highly important and extensively diffused principle, to which, with its combinations, our attention must next be directed.

There is no element which presents itself to our notice, in so many varied states as carbon; we have it in its purest form in the diamond; it occurs also as a mineral in the form of graphite, plumbago or black lead; and as anthracite, mineral charcoal, or glance coal; we have it also as common charcoal, coke, gas carbon, lamp black, and animal charcoal or ivory black.

Of the claim of the diamond to be considered as pure crystallized carbon, there is no doubt whatever. From its high refractive power, it occurred to Newton that it was combustible, or, that it was an "*unctuous substance coagulated*;" but it was in 1694 that it was first burnt by the Florentine academicians, by exposing it to the heat of the sun, concentrated in the focus of a large lens; the flame was blue and lambent. The products of its combustion were first examined by Lavoisier, in 1772, who showed that it produced carbonic acid, and subsequent experiments have completely proved that this compound is the *sole* result.

The diamond cannot be burned in the atmosphere unassisted; it does not produce sufficient heat during its combination with oxygen, but it is quickly consumed in fused nitre, the potash of which retains the carbonic acid formed, and this is the simplest way of analyzing it.

Fig. 66 represents an apparatus which may be used for burning the diamond. It consists of a glass globe of about

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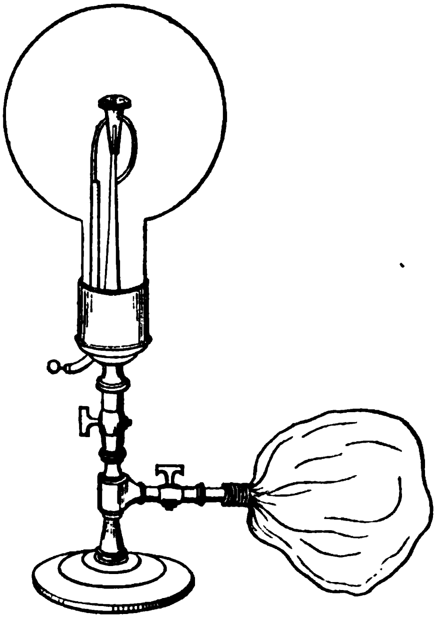
* For the new views of the nature of the ammoniacal salts, suggested by the above theory of ammonium, I must refer the more advanced student to the admirable elements of Professor Graham, to which I have so frequently before alluded.

140 cubic inches capacity, in the centre of which there passes from the lower stop-cock a jet, on which is fixed a small platina capsule pierced full of holes: on either side of this jet there is a wire, one of which commences from the jet, while the other is insulated by passing through a glass tube and making its exit through the upper part of the stop-cock, it terminates in a ball or ring, at which sparks may be taken from an electrical machine; the pierced capsule serves as a grate to hold the diamonds. The globe is first exhausted, and then filled with pure oxygen, and a small stream of hydrogen is then sent in from the bladder, and a spark passed between the wires; the gases begin to burn, and the platina capsule and diamonds soon become white hot, and when the latter have entered into combustion the hydrogen may be turned off and the bladder detached; the diamonds continue to burn, producing a strong white heat, until so far reduced in size as to be cooled too low by the platinum with which they lie in contact.

Fig. 66.



Diamonds were originally discovered in Bengal, and in the island of Borneo: about the year 1720 they were found in Brazil. They always occur in a detached state in an alluvial soil. The primitive crystalline form is a regular octahedron, of which there are numerous modifications. Diamonds are found of various colours, but the colourless are the most esteemed. It is the hardest substance known, and can only be polished by its own dust or powder. The largest known diamond is probably that mentioned by Tavernier, in possession of the Great Mogul; it was found in Golconda, in 1550; it is the size of half a hen's egg, and is said to weigh 900 carats.

Graphite is well known as the substance of which blacklead pencils are made, for which purpose it is almost exclusively obtained from Borrowdale, in Cumberland. It is of an iron-gray colour, metallic lustre, and soft and greasy to the touch. It always contains a small quantity of iron.

Anthracite is nearly pure carbon; it is found in Wales, where it is known by the name of *culm*, and in Ireland as Kilkenny coal; it resembles coal but does not burn so readily. It always contains hydrogen.

Charcoal is too well known to require minute description. It is obtained by burning wood with the imperfect access of air, or by heating 'or distilling it in iron cylinders, so constructed as to allow of the collection of the volatile products, among which are *tar and pyroligneous* acid, which is impure vinegar. Exclusive of its important use as a fuel, charcoal is possessed of some curious and valuable properties. It is a very bad conductor of heat, and hence powdered charcoal is used to surround tubes and vessels which are required to retain their heat. It is not injured by air and moisture, hence stakes and piles are superficially charred to preserve them. It is infusible: and provided air be carefully excluded it undergoes no change in the most intense heat. It absorbs air and moisture, also the colouring and odoriferous parts of many animal and vegetable substances. Tainted flesh and putrid water are thus sweetened by the action of powdered charcoal, especially by *animal charcoal,* obtained by burning bone, or the clippings of hides, leather, &c. Coloured vegetable solutions filtered through this form of charcoal are materially discoloured by it. The charcoal produced by calcining bones contains 10 times its weight of phosphate of lime in a state of extreme division, and if this be dissolved out by an acid, its discolouring power is greatly diminished. According to Graham, one hundred parts of pipeclay, made into a thin paste with water, and well mixed with 20 parts of tar and 500 parts of finely pulverized coal afford, after the mass is well dried, and ignited out of contact of air, a charcoal very little inferior in quality to ivory black. The charcoal employed in the manufacture of gunpowder, is now always obtained by the distillation of woods which are free from resin, such as beechwood, logwood, willow, &c.

Coke is the carbonaceous residue of the distillation of pit-coal; it has a porous texture, and frequently a metallic lustre; it is well known to be exceedingly useful as a fuel, and when mixed with charcoal it gives a most intense heat.

Lamp-black is principally prepared by the combustion of refuse and residuary resin, left by the distillation of turpentine. It is burned in a furnace, so constructed that the dense smoke arising from it may pass into chambers hung with old sacking, where the *soot* is deposited, and from time to time swept off and sold without any further preparation. When heated red hot it may be regarded as a very pure form of charcoal.

At a low temperature carbon is chemically indifferent to most bodies, but at a high temperature it probably surpasses all other substances in its affinity for oxygen. It combines with this element in two proportions, forming carbonic oxide (CO) and carbonic acid, (CO^2) the latter of which must be described first.

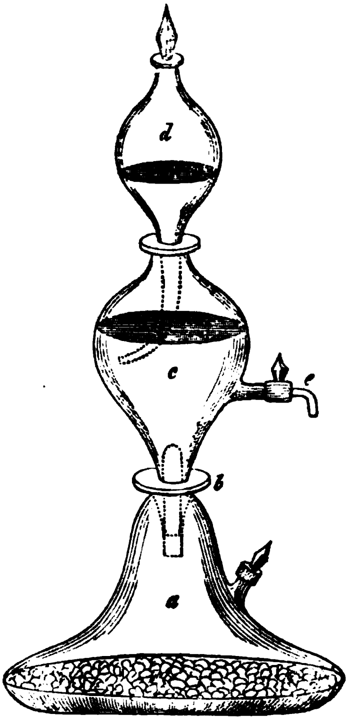
Carbonic acid, CO_2, Eq : 276. When a fragment of red hot charcoal is plunged into a jar of pure oxygen gas, it burns with splendour and changes the oxygen into a gas, which, when cool, is found not to have increased or diminished in volume: this gas is carbonic acid. We do not however resort to this method for procuring the gas for examination, but to the decomposition of white marble by hydrochloric acid: White marble is a compound of carbonic acid and lime; the acid seizes the latter and liberates the former in a gaseous form.

The arrangement of the apparatus may be the same as in *Fig.* 62, as, though the gas cannot be retained over water without considerable loss, it may be collected over that fluid.

Properties. Carbonic acid gas is colourless, considerably heavier than atmospheric air, and 22 times heavier than hydrogen. 100 cubic inches weigh 47·25 grains. It cannot be taken into the lungs, as when an attempt is made to breathe it in a pure state, the epiglotis is spasmodically closed, and no air entering the lungs, suffocation is the direct consequence. It immediately extinguishes flame, even when considerably diluted with air: this is shown in an interesting manner by placing a lighted taper at the bottom of a tall jar, and pouring carbonic acid gas from a bottle upon it, in the manner of a liquid; the gas by its superior weight displaces the common air from the jar, and coming in contact with the flame extinguishes it. In this manner carbonic acid may be poured from one jar to another several times. Another pleasing manner of showing the incapacity of this gas to maintain flame, is the following. Provide two jars of precisely the same diameter, one being open at both ends, but furnished with a stopper and the bottom being ground, the other may be a plain jar, with the top accurately ground, so that the first jar may rest upon it air-tight; fill the lower jar with carbonic acid gas, and the upper one with oxygen; slip a glass plate under the latter and slide it dexterously on the top of the jar containing carbonic acid; you now have a stratum of pure oxygen immediately over one of carbonic acid. Now take a taper with a large wick, and having lighted it, plunge it into the jar of oxygen, and when it is brilliantly burning thrust it into the jar of carbonic acid; the flame will be extinguished; before the last spark is expired, raise it again into the jar of oxygen, it will again burst into a flame; depress it, it will again be extinguished, and this may be repeated several times. When so far diluted with air as to admit of being taken into the lungs, it acts as a narcotic poison, and air containing not more than two per cent of it, has been known to produce alarming effects on the system, although a candle would not be extinguished in such an atmosphere. The circumstance, therefore, of a light not being extinguished when let down into deep wells or pits, should not be taken as a proof that the air is wholesome, for it requires at least four per cent. of carbonic acid to extinguish flames. It may be useful to state that by mixing recently slaked lime with an equal weight of Glauber's salt, a *hydrate* is formed, which, in a stratum of not more than an inch in thickness, intercepts carbonic acid most completely, and may rise in temperature to above 200° from the rapid absorption of the gas. It is quite possible to respire through a cushion of that thickness filled with this mixture, and thus armed, a person may venture into an atmosphere overcharged with carbonic acid with perfect safety.—*Graham.* Lime, in this state of dryness, is more efficacious than when either quite dry or wet. When it is required to remove carbonic acid from a gaseous mixture, it may be done completely by lime-water, which, by the milky appearance which it assumes, becomes a valuable test of the presence of this acid gas.

Carbonic acid is the product of every ordinary combustion, and of the vinous fermentations: it is the cause of the agreeable pungency of fermented liquors. It is also thrown off from the lungs during respiration, as may be proved by breathing through a glass tube into lime water. According to *Prout*, the air of an ordinary respiration contains 3·45 per cent. of carbonic acid gas, and the proportion varies from 3·3 to 4·1 per cent., being greatest at noon, and least during the night. It was explained in the last Lecture to what wise provision we owe the important fact, that numerous and extensive as are the sources of carbonic acid, it does not accumulate in the atmosphere.

Carbonic acid gas is soluble in water; by simple agitation, that fluid, at common temperatures, takes up its own volume of the gas; under a pressure of two atmospheres, it takes up twice its volume, and so on. A saturated solution is most conveniently made by using Nooth's apparatus, *Fig.* 67. It consists of three vessels, *a*, *c*, *d*, which fit air-tight into each other: in the bottom vessel the carbonic acid is generated by the action of muriatic acid on fragments of marble; the gas passes through the tube *b*, furnished with a glass valve opening upwards into *c*, which contains the liquid to be saturated, and which may, when required, be drawn off by the glass stop-cock, *e*; the tube of the uppermost vessel dips into the liquid of the second, thereby occasioning a pressure, and producing a circulation or agitation. This upper vessel is furnished with a heavy stopper, which acts as a valve—regulating the pressure.



Water and other liquids that have been thus saturated with carbonic acid under pressure, lose the greater part of the gas when the pressure is removed; hence the effervescence of ginger beer, cider, champagne, &c. Carbonic acid is present in all kinds of spring and rain water, to which they are, in a great measure, indebted for their pleasant flavour; when boiled, water is well-known to have an insipid taste; this is owing to the absence of carbonic acid. Carbonic acid has been procured in a liquid, and even in a solid state; the experiment of its liquefaction was first made by Faraday; Thilorier, and Addams have subsequently repeated it on a large scale, by decomposing at once several pounds of bi-carbonate of soda; by an equivalent of sulphuric acid, in strong sheet-iron vessels; they have obtained as much as two or three pints of the liquid acid at a time. The iron vessels for this experiment require to be sufficiently strong to resist a bursting pressure of 60 atmospheres. The liquid when allowed to escape from the receiver becomes frozen by its own evaporation, in which state it has the appearance of flakes of snow. Its temperature cannot be more than —148.

In the table of elements, 76·44 is given, on the high authority of Berzelius, as the equivalent of carbon; a series of experiments has, however, recently been undertaken by M. M. Dumas and Stass, the result of which shows that this number is too high, and that the number should be altered to 75. The paper communicated by these Chemists to the Académie Royale des Sciences, is translated in the 15th number of the "*Chemist*;" it well deserves attentive perusal, and may be taken as a model of scientific accuracy. To show the perfection to which they brought their apparatus, the following is extracted as the result of the combustion of the diamond.

"The first time that we burned the diamond, we had it weighed by a person who was a stranger to our experiments; we remaining ignorant of its weight. We acted on pieces of diamond,. as much to try the apparatus as to make a precise experiment. The combustion finished, we found, 2598 of carbonic acid, and we concluded that the diamond burnt weighed 708 milligrammes. At this declaration, the person who weighed the diamonds was much surprised; she had put 717 milligrammes into the tray. We told her that she would find nine milligrammes residue in the tray, *and it actually did contain nine milligrammes of pieces of Brazilian topaz.*

In weighing the diamond, and the carbonic acid resulting from it, with all the skill and precaution that ingenuity could devise; they found the oxygen and carbon to combine in the proportion of 8 : 3
80 : 30
800 : 300
8000 : 3000

This gives 75 as the real equivalent of carbon. It is in the construction of correct formula to represent the constitution of *organic* compounds, that the importance of having the equivalent of this element correctly assigned is felt, and should Chemists decide on adopting the new value of Dumas and Stass, the formula for a vast number of organic compounds must undergo revision.

Professors Liebig and Redtenbacher have also recently been engaged in investigations, the object of which was the determination of the true atomic weight of carbon. Instead of burning a known quantity of pure carbon, and ascertaining the quantity of carbonic acid formed, they preferred the less complicated method of determining the atomic weights of many organic compounds, namely, numerous organic acids, as the acetic, tartaric, racemic, and malic, &c., by causing them to combine with *silver*.

It would be foreign to the popular character of this work to enter into a detail of these admirable analyses. The advanced student will find a translation of their paper in the 123rd number of the London and Edinburgh Philosophical Magazine, or in the 1st number of the Memoirs of the Chemical Society.

The mean results of the investigation gave 75·8 as the atomic weight of carbon. In this uncertain state of the question, it will be better perhaps, at present, to assume 75·6 as the atomic weight of this important element.

Carbonates. The salts formed by carbonic acid are exceedingly well marked, though from its feeble acid properties, it is unable to neutralize completely the alkaline properties of potash and soda: all the carbonates, without any exception, are decomposed by hydrochloric and the stronger acids, when carbonic acid is displaced and escapes in the form of gas. They are all, with the exception of the carbonates of potash, soda, and lithia deprived of their acid by heat, and most of them are of sparing solubility in pure water.

Carbonate of potash KO, CO_2; 866·3. This highly useful salt is obtained by the incineration of plants. Plants derive it from the soil. All fertile soils contain alumina as an invariable constituent, yet this earth is rarely found in the ashes of plants, though silica is always present, having in most places entered the plants by means of alkalies.

The influence of alumina on plants, depends on its invariably containing *potash and soda.* Amongst aluminous minerals, felspar contains 17¾ per cent. of potash; albite, 11·43 per cent. of soda; mica, 3-5 per cent; and zeolite, 13-16 per cent. of both alkalies taken together. Basalt contains from ¾ to 3 per cent. of potash, and from 5-7 per cent. of soda; clayslate, from 2·75—3·31 per cent. of potash; and loam, from 1½ to 4 per cent.

When we thus take into consideration the immense distribution of potash over the surface of the earth in combination with clays; there is no necessity, as Liebig observes, for supposing, as many physiologists have done, that the presence of this alkali in plants is due to a peculiar organic process, from the component parts of the atmosphere. A thousandth part of loam, mixed with the quartz in new red sandstone, or with the lime in the different limestone formations, affords as much potash to a soil only 20 inches deep as is sufficient to supply a forest of pines growing upon it for a century. A single cubic foot of felspar is sufficient to supply a wood covering a surface of 40,000 square feet with the potash required for five years. The temporary diminution of the fertility of soils is owing to the exhaustion of the alkalies, and not as is generally supposed to the loss of *humus.* On the sandstone and limestone of the Carpathian mountains and the Jura, only trees of the fir tribe grow; while on soils of gneiss, mica-slate, and granite, clink-stone, basalt, and clay-slate on the Rhone and Rhine, the finest forest trees are met with; now fir-trees require very little *alkali*; one thousand parts of the dry leaves of the pine give only 29 parts of ashes, of which only 4·6 parts are soluble salts; but 1000 parts of oak leaves yield 55 parts of ashes, of which 24 parts consist of alkalies soluble in water.

The quantity of silicate of potash removed from a meadow in the form of *hay*, is very considerable; an instance is mentioned by Liebig, of a haystack, in a field between Manheim and Heidelberg, having been struck by lightning, and nothing was found but a vitreous mass, which proved to be *silicate of potash.*

Thus then we see the source of potash in the ashes of plants; shrubs, when burnt, are found to yield three, and herbs five times as much saline matter as trees, and the branches are more productive than the trunks. The quantity of ashes rarely exceeds one per cent., of which 1-6th may be saline matter, soluble in water; this is evaporated to dryness, and the carbonate obtained is known by the name of *potash,* and when partially purified and ignited as *pearlash.* The process is carried on on an extensive scale in Russia and America. This carbonate of potash is not however pure, since it contains sulphate of potassa and chloride of potassium; it is readily however obtained so by igniting cream of tartar (bi-tartrate of potash) to redness: the tartaric acid is decomposed, and a pure corbonate of potassa mixed with charcoal remains. A still better plan is to burn together two parts of cream of tartar and one of nitre; in which operation the carbon and hydrogen of the tartaric acid* are destroyed by the oxygen of the nitric, and carbonate of potash, mixed with charcoal, remains. Pure carbonate of potash has a taste strongly alkaline and slightly caustic, and communicates a green tint to the blue colour of the violet. It dissolves in less than an equal weight of water at 60°, deliquesces rapidly on exposure to the air, and crystallizes from its solution with great difficulty. In

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* The formula for tartaric acid is $C^4 H O^5$.

pure alcohol it is insoluble. It fuses at a full red heat, but undergoes no other change.

Bi-carbonate of potash, HO,CO_2+KO,CO_2; 1255·3. This salt is prepared by passing a stream of carbonic acid through a cold saturated solution of the neutral carbonate. It is sometimes made by the action of carbonate of ammonia or carbonate of potassa, but this process is expensive. On the large scale, 100 lbs. of purified carbonate of potash are dissolved in 17 gallons of water, which, when saturated with carbonic acid, yield from 35 to 40 lbs. of crystallized bi-carbonate: 50lbs. of carbonate of potash are then added, with a sufficient quantity of water to make up 17 gallons, and the operation repeated. The *purified carbonate of potash* of the shops should be perfectly soluble in twice its weight of cold water; it often contains *silica, sulphate of potassa, chloride of potassium, and carbonate of lime.* To detect these, dissolve 100 grains in excess of nitric acid, diluted with eight parts of water. The silica, if any be present, remains undissolved, or may be rendered insoluble by evaporation: separate the solution into three equal parts; to the first, add nitrate of baryta, which causes a precipitate of sulphate: collect, wash, and dry it: 100 parts are equivalent to 74 of sulphate of potash; to the second, add nitrate of silver; 100 grains of the precipitate washed, and dried at a dull red-heat, are equivalent to 52 of chloride of potassium; to the third, add oxalate of ammonia, and dry the edulcorated precipitate at a heat of 300°; 100 parts are equal to 77 of carbonate of lime.—*Brande.*

Caustic potash is made by boiling one part of the carbonate dissolved in 10 parts of water, with one part of finely powdered slaked lime; carbonate of lime in minute crystals of *arragonite* is deposited, and, when no effervescence takes place on testing the clear supernatant liquid with muriatic acid, the carbonate of potash has been entirely decomposed, and the caustic potash may be drawn off by a siphon, and allowed to cool, carefully protected from the air. It is a singular fact, that if carbonate of potash be dissolved in less than *six* parts of water, it is *not* decomposed by lime: on the contrary, when a strong solution of caustic potash is boiled with carbonate of lime, carbonate of potash is produced and lime set free.

The *fused potash* of the shops, is the solution of caustic potash, evaporated to dryness in iron basins; its colour is a proof of its impurity. It should be of a *pure* white, in which state it is only to be obtained by dissolving in *absolute alcohol*, and evaporating in a clean silver basin. It is a *hydrate*, or a compound of one atom of potash, (oxide of kalium or potassium,) and one atom of water; and its formula therefore is KO, HO. Its uses in Chemistry are far too numerous to mention; from its being the strongest base, it is employed in almost all cases of saline decomposition, and its various compounds are of great importance in the chemical arts.

Potassium. In our introductory Lecture it was stated, that this singular metallic body was discovered in 1807, by Sir H. Davy, by electrifying a stick of caustic potash slightly moistened, by means of a powerful galvanic battery.* It was first obtained by chemical means by M. M. Gay Lussac and Thenard; but it is by the process of Brunner that the metal is now almost universally obtained. It will not be worth while to describe this process, potassium being only prepared in the most extensive and best appointed laboratories; it will suffice to state here, that the deoxidation of potash is effected by raising it to an intense white heat in contact with iron or charcoal.

Potassium at common temperatures, is a soft metallic body; at 32° it is quite brittle and crystallizes in cubes; at 70° it is pasty, and at 150° perfectly liquid. At a dull red heat it boils, forming a green vapour. It is lighter than water, in contact

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* By employing the little apparatus shown in *Fig.* 65, and substituting a small glass funnel for the inner tube, *c*, of the decomposing cell, the lower opening of which was stopt with stucco, and pouring into it a weak solution of chloride of potassium in contact with mercury placed in a little glass tube, Dr. Bird succeeded in obtaining an amalgam of potassium.

with which it burns with a beautiful purple flame, so great is its affinity for oxygen: when heated in air it also burns, leaving a crust of pure potash. In consequence of the great avidity with which it combines with oxygen, it must be kept in a liquid which contains none of that principle, in rectified naptha for instance. It is of great use in chemical analyses for abstracting oxygen, and in the preparation of boron and silicon.

Carbonate of Soda. $NaO, CO_2 + 10\,HO$; 667·3+1125. The source of this alkali is the ashes of sea-weed. It is known in commerce as *barilla*, which is the semi-fused ash of the *salsosa soda*, a plant cultivated largely on the Mediterranean shore of Spain, in the vicinity of Alicant; and as *kelp*, which is an impure and inferior kind, prepared from sea-weeds, on the northern shores of Scotland. A much purer carbonate of soda than either of these, is very extensively prepared by heating a mixture of sulphate of soda, sawdust, and lime, in a reverberatory furnace, the sulphuric acid undergoes decomposition, and furnishing oxygen to the carbonaceous matter, gives rise to carbonic acid, which unites with the soda; but a small portion of sulphuric acid still remains united to the alkali, from which it is difficult to free it.

Bicarbonate of soda; $HO,CO_2 + NaO, CO_2$; 1056, is made by the same processes as the bicarbonate of potassa. It requires 13 times its weight of cold water to dissolve it; and contains, when pure, 37 per cent. of alkali, though the salt of commerce generally contains upwards of 40 per cent., owing to the presence of neutral carbonate in the state of protohydrate.

It is frequently an object of considerable importance in commerce. To ascertain the value of different samples of potash and soda; this is conveniently done by means of the little instrument called an *alkalimeter*. The following directions for making these tubes are given by Faraday.* "Into a tube, sealed at one end, 9½ inches long, ¾ of an inch in di-

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* See Chemical Manipulation, page 292.

ameter, and as cylindrical as possible in its whole length, pour 1000 grains of water, and with a file or diamond mark the place where its surface reaches, and divide the space occupied by the water into 100 equal parts; opposite to the numbers 23·44, 48·96, 54·63, and 65, draw a line, and at the first, write soda; at the second, potassa; at the third, carbonate of soda; and at the fourth, carbonate of potassa. Then prepare a dilute acid, having the specific gravity of 1·127 at 60°, which may be made by mixing one measure of concentrated sulphuric acid, with four measures of distilled water.

This is the standard acid, to be used in all the experiments, being of such strength that when poured into the tube till it reaches either of the four marks just mentioned, we shall obtain the exact quantity which is necessary for neutralizing 100 grains of the alkali written opposite to it. If when the acid reaches the word carb: potassa, and when consequently we have the exact quantity which will neutralize 100 grains of that carbonate, pure water be added until it reaches 1, or the beginning of the scale; each division of this scale will neutralize one grain of carbonate of potash. All that is now required, in order to ascertain the real quantity of carbonate in any specimen of pearlash, is to dissolve 100 grains of the sample in warm water; filter to remove all the insoluble parts, and add the dilute acid in successive quantities, until by the test of litmus paper* the solution is exactly neutralized."†

Methods of distinguishing between potash and soda, and of quantitatively estimating each, will be given in a future Lecture.

Sodium. The discovery of this metal was made in the same manner and immediately subsequent to that of potassium, by Sir H. Davy; and it is now prepared in exactly the same

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* Litmus test paper is best prepared by dipping good letter-paper several times in a filtered infusion of litmus, and drying it after each immersion, till the paper is of a deep purple colour.

† Alkalimeters, correctly graduated and marked, may be obtained at Messrs. Knight's, Foster-lane, Cheapside, London.

manner as that metal. Its preparation is not however so difficult, as its reduction does not require so high a temperature. It is lighter than water, on which it floats. It decomposes that fluid, but the action is not so energetic as with potassium: the gas does not take fire spontaneously.

Carbonic oxide, CO; Eq: 176. This gas which was discovered by Priestley may be formed by heating in an iron retort, a mixture of chalk and charcoal, or of equal weights of chalk, and iron or zinc filings, equal parts of carbonate of baryta and clean iron filings may also be employed; but the most convenient process is by gently heating oxalic acid or binoxalate of potassa, with five or six times its weight of sulphuric acid. The charcoal, iron, or zinc deprive the carbonic acid of the carbonates of lime and baryta of one half of its oxygen, and in the last mentioned process, the decomposition of the oxalic acid (C^2O^3) or rather $CO + CO_2$) is occasioned by the powerful affinity which sulphuric acid possesses for water, and by the fact that oxalic acid cannot exist unless in combination with water or some other base: when binoxalate of potassa is employed, the sulphuric acid combines with both the water and the potassa, and the oxalic acid being set free is instantly decomposed, being resolved into equal measures of carbonic acid (CO_2) and carbonic oxide, (CO) the former of which may be separated by agitation with lime water.

Carbonic oxide is a colourless and tasteless gas. It is inflammable, burning with a blue flame, and producing by its combustion carbonic acid. It cannot be breathed with impunity, as it acts injuriously on the system, even when much diluted with air. 100 cubic inches weigh 30·207 grains. To gain a practical knowledge of its constitution, the student may introduce into the syphon eudiometer, *Fig.* 49, 100 measures, mixed with rather more than 50 measures of pure oxygen; on passing the electric spark and inflaming the mixture, he will find that the 150 volumes will become diminished to rather more than 100 volumes which will prove to be carbonic acid.

Oxalic acid which may be considered as a definite compound of carbon and oxygen, may be obtained by introducing into a retort, four ounces of nitric acid diluted with two of water, and one ounce of white sugar; nitric oxide is copiously evolved, and when the sugar is dissolved, about one-third of the acid may be distilled over. The contents of the retort are then emptied into a shallow vessel, and, in the course of two or three days, an abundant crop of white crystals is deposited; and upon further evaporation an additional portion is obtained. The whole is then re-dissolved and re-crystallized, and pure oxalic acid amounts to about half of the weight of the sugar employed, is obtained. In this reaction, changes of a very complicated nature ensue, as oxalic acid does not contain any hydrogen, and has a smaller proportional quantity of carbon than sugar;* there can be no doubt that the production of this acid essentially depends upon the sugar being deprived of all its hydrogen and a portion of its carbon, by oxygen, derived from the nitric acid. Oxalic acid is well known to be a powerful and rapidly fatal poison, and it is also known that accidents have frequently occurred from its being sold and taken for Epsom salts, (sulphate of magnesia) to which its crystals bear considerable resemblance. The strong acidity however of oxalic acid, which may be tasted without danger, is sufficient to distinguish it from Epsom salts, the taste of which is saline and bitter and quite neutral. When a dose of this poison is unfortunately received into the stomach, ***chalk*** with water should be immediately administered; an insoluble and consequently innocuous oxalate of lime is immediately formed; magnesia may also be used, and when either of these substances cannot immediately be procured, large draughts of soap and water will be found very efficacious.

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* The formula for oxalic acid is C_2O_3; that for sugar, $C^{12}H^{10}O^{10}$.

LECTURE NINTH.

CARBON WITH NITROGEN—BICARBURET OF NITROGEN OR CYANOGEN—ITS PREPARATION AND PROPERTIES.—HYDROCYANIC OR PRUSSIC ACID—ITS PREPARATION AND PROPERTIES—ANTIDOTES IN CASES OF POISONING BY PRUSSIC ACID—TESTS FOR.—PRUSSIAN BLUE—PREPARATION OF—SULPHUR—ITS HISTORY AND PROPERTIES—ITS COMPOUNDS WITH OXYGEN—SULPHUROUS ACID—ITS PREPARATION AND PROPERTIES—SULPHURIC ACID—THEORY OF ITS FORMATION—ITS MANUFACTURE ON THE LARGE SCALE—MR. PEREGRINE PHILLIPS'S METHOD OF MAKING SULPHURIC ACID—THE NORDHAUSEN SULPHURIC ACID—PROPERTIES OF SULPHURIC ACID—ITS DISTILLATION—CARE REQUIRED—PREPARATION OF SULPHURIC ACID FROM IRON PYRITES—TESTS FOR SULPHURIC ACID—SULPHATES.—HYPOSULPHUROUS ACID—USE OF HYPOSULPHITE OF SODA IN THE DAGUERROTYPE—THE DAGUERROTYPE PROCESS—HYPOSULPHURIC ACID—SULPHUR WITH HYDROGEN—PREPARATION AND PROPERTIES OF SULPHURETTED HYDROGEN—DANIELL'S OBSERVATIONS ON THE SULPHURETTED HYDROGEN IN THE WATERS OF THE WESTERN COAST OF AFRICA.—PERSULPHURET OF HYDROGEN—SULPHUR WITH CARBON—BISULPHURET OF CARBON—ITS PREPARATION AND COMPOSITION—SELENIUM—PHOSPHORUS—PREPARATION—PROPERTIES—PHOSPHORUS WITH OXYGEN—OXIDE OF PHOSPHORUS—HYPOPHOSPHOROUS ACID—PHOSPHOROUS ACID.—PHOSPHORIC ACID—ITS PREPARATION AND

PROPERTIES—PHOSPHORUS WITH HYDROGEN—ITS PREPARATION AND PROPERTIES—BORON—ITS COMPOUND WITH OXYGEN.—SILICON—SILICA OR SILEX—GLASS—COMPOSITION OF WINDOW GLASS—OF PLATE GLASS—OF BOHEMIAN GLASS—OF COMMON WINE-BOTTLE GLASS—HISTORY OF THE APPLICATION OF GLASS TO THE GLAZING OF WINDOWS—METHODS OF COLOURING GLASS.—CHLORINE—ITS HISTORY—PREPARATION ON THE SMALL AND LARGE SCALE—ITS PROPERTIES AND PRACTICAL APPLICATIONS.—BLEACHING PROCESSES—CHLORINE WITH HYDROGEN.—HYDROCHLORIC ACID—ITS PREPARATION—ITS PROPERTIES AS A GAS.—ITS SOLUTION IN WATER, FORMING MURIATIC ACID—IMPORTANT PRACTICAL USES OF MURIATIC ACID.—CHLORINE WITH OXYGEN.—HYPOCHLOROUS ACID.—CHLOROUS ACID—ITS UNSTABLE AND DANGEROUS CHARACTER—EXPERIMENTS WITH IT.—CHLORIC ACID—CHLORATE OF POTASH—HYPERCHLORIC ACID.—CHLORIDE OF NITROGEN—ITS FORMIDABLE PROPERTIES.—IODINE—ITS PREPARATION AND PROPERTIES—TESTS OF—ITS COMPOUNDS WITH MERCURY AND LEAD—ITS COMPOUNDS WITH OXYGEN.—IODOUS—IODIC—AND PERIODIC ACID.—IODIDE OF NITROGEN.—BROMINE—ITS SOURCE.—FLUORINE.—HYDROFLUORIC ACID—ITS USE FOR ETCHING ON GLASS—DESCRIPTION OF THE PROCESS.—FLUORIDE OF SILICON—ITS PREPARATION AND USE TO THE CHEMIST.

CARBON WITH NITROGEN. *Bicarburet of nitrogen, or cyanogen*, NC_2. This compound, at ordinary pressures, is a gas, and was first obtained by Gay Lussac, in 1815. To obtain it, bicyanuret of mercury* is heated in a small glass tube and the gas collected over mercury; a black coaly mass remains in

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* This salt is prepared by boiling finely powdered, pure, and dry Prussian blue, with an equal weight of red oxide of mercury in powder; the blue colour of the pigment disappears and a colourless solution is obtained, which when filtered and concentrated yields bicyanuret of mercury in quadrangular prismatic crystals.

the tube, which has been shown by Professor Johnston to consist of the same ingredients as the gas itself. Cyanogen is colourless, and has a strong and very peculiar odour; it is easily liquefied, requiring only a pressure of 3·6 atmospheres at 45°. It burns with a beautiful purple flame, but extinguishes burning bodies. It can support a strong heat without decomposition. Water at 60°, absorbs 4·5 times, and alcohol 23 times its volume of it. The solution in water undergoes spontaneous decomposition. It derives its name from two Greek words, *κυανος*, blue, and *γεννάω*, I generate, because it is an essential ingredient of Prussian blue. Cyanogen unites with all the metals, forming a class of salts called cyanides. It combines also with hydrogen, forming that well-known powerful poison, hydrocyanic, or prussic acid.

Hydrocyanic acid; $H+NC_2$ was discovered by Scheele, in 1782. The method of preparing it recommended by Vauquelin, consists in filling a narrow tube, placed horizontally, with fragments of bicyanuret of mercury, and causing a current of *dry* sulphuretted hydrogen to pass over it very slowly. The instant that gas comes into contact with the cyanuret, double decomposition ensues, and hydrocyanic acid and bisulphuret of mercury are generated. When pure, this acid is a limpid and colourless fluid of a strong odour, similar to that of peach blossoms; it is exceedingly volatile and poisonous in a most astonishing degree; one drop of it placed on the tongue of a dog, causes its death in very few seconds. Its very preparation is exceedingly injurious if great care be not taken to have the apartment well ventilated. Notwithstanding its violently poisonous properties it is used in medicine, and fatal accidents have occasionally occurred, from its not being generally known, that owing to its undergoing spontaneous decomposition its strength gradually becomes impaired. In consequence of this continual diminution in strength, persons who are accustomed to take it are apt to increase the quantity as the acid becomes older, and should they, on obtaining a quantity recently prepared, neglect to diminish the dose accordingly, a fatal effect would very probably result. An instance of this has fallen under the writer's own observation. The acid cannot be preserved in a concentrated form more than two weeks. In cases of poisoning by prussic acid, should death not be instantaneous, recourse may be had to diffusible stimulants, such as ammonia. An aqueous solution of chlorine may be used as an antidote, as it decomposes the acid instantly with the formation of hydrochloric acid.

The presence of free hydrocyanic acid is easily recognized by its odour. A very delicate test is the following. To the liquid supposed to contain prussic acid, add a solution of green vitriol; throw down the protoxide of iron by a slight excess of pure potassa, and acidulate with hydrochloric or sulphuric acid, so as to redissolve the precipitate; *Prussian blue* will then make its appearance, if hydrocyanic acid had been originally present.

In criminal cases, the stomach or other substances to be examined, are cut into fragments and introduced into a retort, with water slightly acidulated with sulphuric acid. The distillation is then conducted by the heat of boiling water, and the volatile products collected in a receiver surrounded with ice. The presence of hydrocyanic acid in the distilled matter is tested by the method above described.

Cyanogen forms numerous combinations in organic Chemistry, for an account of which, the student must be referred to more extended chemical treatises. I shall only introduce one other compound, which from its important practical use could not be omitted, namely, Prussian blue. The chemical name of this celebrated pigment is, *sesquiferrocyanide of iron*, and its composition is rather complicated, being represented by the formula, Fe_4, ($3\ Cy_3\ Fe$) or 4 equiv: of iron, and 3 equiv: of ferrocyanogen. It was accidentally discovered in the year 1710, by Diesbach, a colour-maker at Berlin. Several methods are resorted to for preparing Prussian blue, each manufacturer probably thinking his own the best. We have, however, the high authority of Liebig, for recommending the following process for its preparation in quantity. Six parts of green vitriol and six parts of yellow prussiate of potash are to be dissolved, each separately, in 15 parts of water; the solutions mixed, and an addition then made to them of one part of oil of vitriol and twenty-four parts of strong hydrochloric acid; after some hours, a clear solution of one part of chloride of lime in eighty parts of water is gradually added, by small portions, observing the precaution to stop as soon as an effervescence is observed, from the disengagement of chlorine. After being allowed to subside for several hours, the precipitate is washed and dried at the usual temperature, or by artificial heat. It is said, that the finest colour is obtained by heating the precipitate with dilute nitric acid, till it acquires a deep blue colour, instead of oxidizing by chlorine. Another method of preparing Prussian blue is, to add ferrocyanuret of potassium, (prussiate of potash of the shops) to a solution of sulphate of *per*oxide of iron,* both being largely diluted, and the latter in excess. The blue precipitate must be repeatedly washed, first with water acidulated with sulphuric acid, and then with cold water. It is thus obtained in small lumps of an intensely blue colour, with a copper-red shine on its surface.

The properties of this substance are too well-known to require much description. It is tasteless and not poisonous; alkalies decompose it,—a circumstance which renders it of little value in dyeing, as it is injured by washing with soap. In its preparation, care must be taken to avoid an excess of the ferrocyanuret of potassium, as the precipitate is apt to carry down a portion of that salt.

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* This salt is prepared by mixing with a solution of pure green vitriol, exactly half as much sulphuric acid as that salt contains, and adding to the mixture, in a boiling state, successive portions of nitric acid, till fumes cease. It is then evaporated to dryness to expel the excess of nitric acid, and the persulphate of iron remains as a white salt.

Sulphur. S. Eq: 201. This is another element which is very extensively diffused through nature. It is found in combination with many of the metals, as iron, lead, copper, zinc, &c., constituting some of the most important ores, and from the bisulphuret of iron, or iron pyrites, a considerable quantity of the sulphur, met with in commerce, is derived. Sulphur is also exhaled in large quantities from volcanoes, both in its pure state and in combination with hydrogen, and becoming deposited in fissures, it forms those immense sulphur beds which occur in Sicily in a blue clay formation, occupying the central half of the south coast of the island. The supply of sulphur, derived almost exclusively from Sicily, is enormous: the average annual importation into England, is between sixteen and seventeen thousand tons, at from £6. to £10. per ton.—*Brande.* Sulphur exists also in combination with oxygen and various metallic oxides, forming native sulphates, the most abundant of which are those of lime and gypsum. In the organic kingdom it is found invariably associated in minute quantity with *albumen*; it is found in the hair, horns, and hoofs of animals, and in the black mustard seed it exists in considerable quantity.

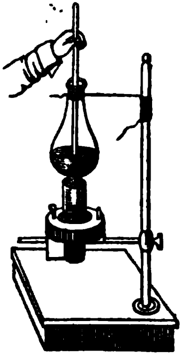
Properties. We meet with sulphur in commerce under two forms; that of roll and flowers: The first is merely the rough native sulphur, cast in cylindrical moulds; the latter, the purity of which is more to be depended upon, is obtained by sublimation, and though apparently a powder, impalpable and soft, consists in reality of minute right, rhombic octohedron crystals. Sulphur, destitute of all crystalline structure, is obtained by precipitating it from its solution, on decomposing the persulphuret of potassium (KS_5) for instance, by muriatic acid, it is then a milk-white powder, and is known in pharmacy as *sulphur precipitatum.*

When sulphur is heated it exhibits some singular phœnomena; at about 226° it melts into an amber-coloured liquid; at 400° it becomes dark brown, opaque and viscid; and at 601°

it boils, and becomes as thin and limpid as when it first began to melt; when at the temperature of about 300°, if poured into warm water, it acquires the consistency of soft wax, and hardens on cooling. In this state it is sometimes used for taking impressions of gems and medals. If two or three pounds of sulphur be fused in a stone-ware crucible, and allowed to cool till it begins to solidify, on breaking the exterior crust and pouring out the internal liquid, the interior will be found lined with crystals.

Sulphur is insoluble in water or alcohol. It combines readily with most metals; some of them, as copper and silver, in very thin plates, burning in its vapour, as iron does in oxygen. The following experiment illustrates this in an interesting manner. Fuse some sulphur in a flask, *Fig.* 68, and when its vapour fills the whole vessel, introduce a slip of rolled copper; the metal will instantly become red hot, enter into fusion, and combining with the copper, form a dark coloured crystalline brittle substance, sulphuret of copper; or, heat a small bar of iron in a blacksmith's forge, till it scintillates; have ready a roll of sulphur, and touch with it the end of the heated bar; the iron and the sulphur will enter into combination, and the sulphuret of iron will drop to the ground in a liquid state.

Fig. 68.



In many respects, sulphur is considered by chemists, to bear considerable analogy to oxygen. Thus, heat and light are disengaged when it combines with simple substances, and they both combine with the same bodies, according to the same proportions, and generate completely parallel classes of acids, bases, and salts. Some highly oxidized bodies, when heated, give off oxygen, peroxide of manganese for instance; so too, pyrites, a combination of sulphur and iron, when heated, gives off sulphur; and a combination containing less sulphur remains.

Sulphur combines with oxygen in four proportions, forming

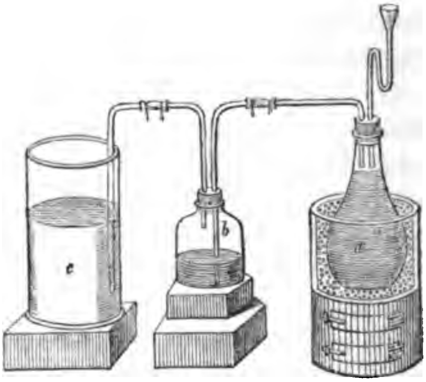
Sulphurous acid..........	SO_2	Eq: 401·17
Sulphuric acid...........	SO_3	Eq: 501·17
Hypo-sulphurous acid.....	S_2O_2	Eq: 602·34
Hypo-sulphuric acid......	S_2O_5	Eq: 902·34

Sulphurous acid, SO_2. To form this compound, which at ordinary temperatures and pressure exists in a gaseous form, sulphur may be burnt in pure oxygen; or, sulphuric acid decomposed by a metal not very readily oxidized, as mercury or copper. In the first case, the sulphurous acid gas produced, is exactly equal to that of the oxygen consumed, and in the latter the metal becomes oxidized at the expense of part of the oxygen of the sulphuric acid; charcoal may likewise be employed to deoxidize the sulphuric acid, though the sulphurous acid is then mixed with a large quantity of carbonic acid. Another method is to heat three parts of flowers of sulphur with four of peroxide of manganese; in which case, one part of the sulphur unites with the metal, and another with the oxygen, giving rise to sulphuret of manganese and sulphurous acid.

This gas must be collected and examined over mercury, since water dissolves about 37 times its volume of it: whilst in the receiver it is transparent and colourless, but on allowing it to escape into the atmosphere it is condensed by the aqueous vapour, which causes a cloudy appearance, resembling steam. It possesses bleaching properties but not of a permanent nature, as, by degrees, it becomes converted into sulphuric acid by absorbing oxygen. Its decolourizing power is strikingly shown by exposing a rose to the fumes of burning sulphur, it becomes completely white; but on immersing the flower into dilute sulphuric acid, the colour is restored.

Sulphurous acid gas extinguishes all burning bodies; a handful of sulphur dropt into a burning chimney, is one of the most effectual means of extinguishing it. The gas cannot itself be burned, and is instantly fatal to animal life. Its solution in water may be conveniently effected by the arrangement shown in *Fig.* 69. Into the matrass or flask *a*, a quantity of well burned charcoal, in bits about the size of a hazel nut is introduced, and sulphuric acid poured on through the funnel, till the vessel is about half full; heat is applied, and the sulphurous acid gas passes into the bottle, *b*, containing about an ounce of water, which frees it from any sulphuric acid which it might have carried over, and the purified gas then passes into the second receiver, *c*, containing the water to be impregnated. In this manner the alkaline sulphites are formed, and for this purpose the presence of carbonic acid, which, as has been remarked, is always present when sulphurous acid is prepared from charcoal, is quite immaterial.

Fig. 69.

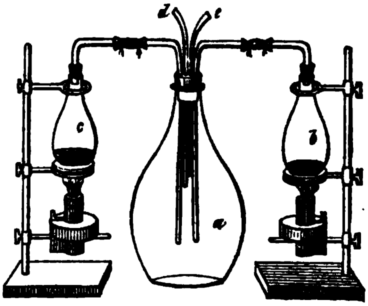


Sulphurous acid gas assumes the liquid form under a pressure not exceeding that of two atmospheres, or at a degree of cold produced by a mixture of pounded ice and salt. As a liquid, it is heavier than water; boils at 14°, and produces by its evaporation a very intense cold. It may be liquefied by its own pressure by introducing mercury and oil of vitriol into a strong tube, as shown in *Fig.* 70. On applying heat to the end, *a*, containing the materials, and cooling the other sealed extremity by means of ether, the liquefied gas collects at *b*.

Fig. 70.

Sulphuric acid; SO_3. This highly important compound, the re-agent most frequently resorted to by the Chemist, has been known ever since the end of the fifteenth century. It is never formed by the *direct* union of sulphur and oxygen, although on the large scale, it is most extensively prepared by burning sulphur in contact with vapour of water and fumes of nitrous acid. Now if *dry* sulphurous acid and nitrous acid be mixed together, no change whatever occurs; but when water is present, they combine and form a white crystalline solid; the composition of which, according to Gaultier de Claubry, is five equivalents of sulphuric acid, two of nitrous acid, and one of water.

This crystalline solid is decomposed with effervescence by a larger quantity of water, a hydrate of sulphuric acid remaining behind, and the nitrous acid is resolved into peroxide of nitrogen and nitric oxide. The nitric oxide generates a new quantity of red fumes by combining with the oxygen of the atmosphere, and oxidizes a new quantity of sulphurous acid, and thus sulphuric acid continues to be formed as long as sulphurous acid gas and watery vapour are met with. Such is the nature of this very singular process, in which it will be remarked, that the nitric oxide acts as a *medium of transference*, by means of which, the oxygen of the atmosphere is enabled thoroughly to oxidize the sulphur. In order that the student should fully understand the nature of the reactions, he is strongly advised to make the experiment, which is exceedingly interesting and instructive, and at the same time easily performed. Into the mouth of the large bottle, *a*, *Fig.* 71, fit a good sound cork, in which four holes are bored; into the flask *b*, put 400 grains of mercury and 600 grains of sulphuric acid, and into the flask *c*, 80 or 90 grains of sugar; connect the flask *b* first with the bottle *a*, and heat it till sulphurous acid begins to come over; then pour



over the sugar 300 grains of nitric acid diluted with an equal bulk of water; on heating the mixture, the sugar will take oxygen from the nitric acid, and nitrous fumes will consequently be formed and pass into the bottle *a*; the sulphurous and nitrous acids being thus brought into contact, will speedily give rise to the formation of beautiful dendritical crystals, which will gradually cover the interior of the bottle *a*, like hoar frost; and that this may proceed without interruption, the vessel may be filled with fresh atmospheric air by blowing through one of the tubes, *d*, *e*, while the residual gases are expelled through the other. When a sufficient quantity of the crystalline compound is formed, remove the flasks and pour a little water into the bottle; brisk effervescence will take place, the crystals will immediately disappear, and the vessel will be filled with ruddy-coloured fumes,—sulphuric acid, in combination with water, tinged blue by its impregnation with nitrous acid having been formed. In this experiment it is unnecessary to put any water into the bottle *a*, at the commencement of the process, sufficient being carried over from the diluted nitric acid to determine the crystalline formation.

In the manufacture of sulphuric acid on the large scale, the sulphurous and nitric acid vapours are simultaneously admitted into capacious chambers of sheet lead: the sulphurous acid is produced by the combustion of sulphur in a furnace, and the nitric acid vapour in the same furnace, by supporting over the burning sulphur an iron capsule, containing nitrate of soda and sulphuric acid; steam is admitted near the same point, and mixing with the acid vapours, the crystalline solid is formed and instantly dissolved by the water in the leaden chamber, producing sulphuric acid. Did it not happen that a certain portion of nitric acid is retained by the sulphuric acid, the same quantity of nitric oxide might convert an infinite quantity of sulphurous into sulphuric acid; as it is, it becomes necessary to supply its loss by a continued current of nitrous acid fumes. The water in the chambers is allowed to remain unchanged until it has attained a specific gravity of about 1·600; it is then removed by leaden pipes, and concentrated by evaporation in leaden cisterns, until its specific gravity is increased to about 1·76.* When of this strength, it begins to act upon the lead, and must be transferred to vessels of glass, or, still better, of platinum, in which the concentration may be finished. In the strongest form in which it can be so obtained, its specific gravity is 1·847, and it contains 81·54 of real acid in 100. —*Kane.* If the specific gravity of a sample of acid be higher than this, we may be certain that it is impure. Nearly all the oil of vitriol of commerce, contains sulphate of lead dissolved, the presence of which is easily detected by diluting a portion with water; it will become turbid if any of the salt of lead is contained in it. The simplest mode of judging of the purity of the acid is, to introduce a given weight into a platina capsule, and evaporate it; if it leaves more than one *per cent.* of solid residue, it has probably been intentionally sophisticated. —*Brande.* Oil of vitriol often holds sulphate of potassa in solution, 2·5 per cent of which increases the specific gravity of the concentrated acid to 1·860; hence, where accuracy is required, its value must be determined by its saturating power. For this purpose a given weight is diluted with six or eight parts of water, and pure dry carbonate of soda added until the solution is exactly neutral. Every 54 parts of such carbonate of soda required for this purpose, are equivalent to 40 parts of the *anhydrous acid,* or to 49 of oil of vitriol, sp: gr: 1·84.

A very beautiful method of converting sulphurous into sulphuric acid is, to mix the former with an excess of air, and by a blowing apparatus passing it through a tube filled with platinum sponge, or balls of fine platina wire. The vapours of

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* According to Orfila, Vogel, &c. all the sulphuric acid, prepared in leaden chambers, contains arsenic in considerable quantity; hence great care should be taken to avoid employing this acid for medicinal purposes: the fuming sulphuric acid of Germany, prepared from sulphate of iron, does not contain a trace of this most dangerous poison.

sulphuric acid formed, may be condensed in a long upright vessel of lead, filled with pebbles, which are constantly kept wet by a small stream of water. This interesting experiment was first made by Mr. Peregrine Phillips.

A fuming and very strong sulphuric acid is prepared at Nordhausen, in Saxony, by exposing sulphate of iron to a red heat in earthen retorts; the sulphate of iron, which contains seven equivalents of water is previously heated, till the proportion of water is considerably less than one equivalent, and the acid that passes over is a dark coloured liquid, of a thick oily consistence; specific gravity, about 1·9, and containing less than one equivalent of water to two of acid; or 90 per cent. of *real* acid. From this acid the *dry sulphuric* acid may be prepared; for when heated, it is resolved into ordinary oil of vitriol and real sulphuric acid; the latter, being very volatile, distils over in colourless vapours, which, when received into a dry vessel, cooled by a freezing mixture, condenses in beautiful white satiny fibres, constituting the dry sulphuric acid.

Properties of sulphuric acid. In its concentrated state, this is the most powerful and corrosive of all the acids, to the preparation of most of which it is the key, both on account of its superior affinities, and its cheapness. It speedily destroys organic substances, and acts strongly on the cuticle. It has a powerful attraction for water, so much so, that it is much used for purposes of desiccation under the receiver of an air pump. Three parts of concentrated acid increase to four, by exposure for 24 hours to a moist atmosphere: even at a boiling temperature it takes moisture from the air; hence, close vessels must be used to give it its highest state of concentration. It acquires a brown tinge from the smallest particles of straw, cement, or even dust that accidently fall into it, which is ascribed to its strong affinity for water, the elements of which it takes from the organic matters with which it comes into contact and thus chars them. It dissolves small quantities of sulphur, and acquires a brown, green, or blue tint. It dissolves also, when highly concentrated, small portions of tellurium and selenium, the former causing a crimson, the latter a green colour; charcoal also appears, to a small extent soluble in it, communicating first a pink, and then a dark reddish brown tint.

When a very pure sulphuric acid is required for purposes of delicate chemical research, it must be distilled, and in conducting the operation great care must be taken, in consequence of the violent jerks which the production of its vapour occasions, and which often break the vessel. The following plan, adopted by Dr. Ure, may be usefully inserted. Into a plain glass retort, capable of holding from two to four quarts of water, a pint measure of sulphuric acid is put; to the retort a receiver is connected by a glass tube, four feet long, and from one to two inches in diameter. The tube fits very loosely at both ends. The retort is placed over a charcoal fire; when the acid boils, the sudden explosions of dense vapour, which would infallibly break small vessels, are prevented from doing mischief by the easy communication with the air at both ends of the adopter tube. In consequence of the smallness of the specific caloric of the vapour of sulphuric acid, to which the danger of its distillation is attributable, it is unnecessary to apply cold to the receiver as when most other liquids are distilled. By the above method, Dr. Ure makes the concentrated acid flow over in a continuous slender stream, without the receiver becoming sensibly hot.

Sulphuric acid has lately been prepared in considerable quantities from the iron pyrites;—it is found to contain arsenic and selenium; the former of which contaminations is of great importance in medico-legal investigations, and we shall take occasion in a future lecture, to point out the most approved methods of detecting it.

Test for sulphuric acid. There is no difficulty whatever in detecting and estimating the quantity of sulphuric acid in any soluble compound. A solution of nitrate of barytes will precipitate the smallest quantity, in the form of an insoluble sulphate of barytes, which can be collected, dried, and weighed with the greatest ease; every 100 parts consist of 34·37 sulphuric acid, and 65·63 barytes.

When the sulphate is insoluble, such as that of strontia and barytes, it may be detected by mixing it in fine powder, with three times its weight of carbonate of potash or soda, and exposing the mixture in a platina crucible, for half an hour, to a red heat. Double decomposition ensues, and on digesting the residue in water, filtering the solution, neutralizing the free alkali by pure hydrochloric, nitric, or acetic acid, and adding muriate of barytes, the insoluble sulphate of that base is precipitated.

The sulphates are a class of salts that are readily formed by double decomposition, or by the action of sulphuric acid on the metals themselves, or the metallic oxides, or their carbonates: several exist in nature, but the only ones that are abundant are the sulphates of lime, (familiarly known as gypsum, selenite, and alabaster,) and barytes; they are of different solubility, but the sulphates of barytes, tin, antimony, and bismuth, lead, and mercury are insoluble in water. Some beautiful specimens of *celestine* or sulphate of strontia, have been found in considerable quantities on the line of the Great Western Railway, between Bath and Bristol.

Hyposulphurous acid; S_2O_2 or $SO_2 + S$. This acid, which is a compound of little stability, may be formed by bringing sulphurous acid and sulphuretted hydrogen gases into contact in water, but it is speedily resolved into sulphur and sulphurous acid. It would not have been worth while to have said anything on this acid, but that its compounds, in consequence of a remarkable property which they possess of dissolving those compounds of silver which are insoluble in water, as the chloride and iodide, and of forming a solution possessing an intensely sweet taste, have been brought into use, with considerable success in daguerrotype and photogenic drawing.* The hyposulphite of soda, which is the salt usually employed, is formed by saturating a solution of carbonate of soda with sulphurous acid, and digesting upon it flowers of sulphur at a high temperature, but without ebullition.

The hyposulphite of soda forms a good test, whereby to distinguish barytes from strontia, the former of which earths it precipitates, but not the latter.

Hyposulphuric acid; S_2O_5. Like the last compound of sulphur and oxygen, this acid cannot be insulated, or at least cannot be kept in an insulated state. It forms salts with metallic oxides, none of which have yet been applied to any useful purpose.

Sulphur with hydrogen. These elements combine together in two proportions, forming sulphuretted hydrogen, or hydrosulphuric acid, HS, Eq: 213·67, and persulphuret of hydrogen, HS^2 Eq: 414·8.

The first of these compounds exists as a colourless gas of extremely disagreeable odour; it is however, a reagent of frequent application and considerable importance.

Preparation. To form sulphuretted hydrogen, the protosulphuret of iron (obtained by bringing a rod of iron, heated to whiteness, into contact with sulphur; or by heating together to bright redness, in a crucible, three parts of iron filings and

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* The Daguerrotype process is this: a plate of silvered copper is cleaned with dilute nitric acid, so that the surface of the silver shall be absolutely pure, and it is then exposed to the vapour of iodine, until a gold-coloured pellicle of iodine of excessive tenuity is deposited upon it. In this state it is very sensible to light. The plate so prepared, is placed in a camera obscura, and the image of the object required is allowed to remain on it for a space of time which varies with the brightness of the light. When it has been sufficiently exposed it is removed, and submitted to the action of the vapour of mercury, by which the picture is rendered visible. As there still remains, however, a general sensibility to the further influence of light, this is removed by dissolving away all the iodine and iodide of silver, by a solution of *hyposulphite of soda*. The shadows remain then marked by smooth amalgamated surfaces, and the lights, by the corresponding portions being of a dull grey colour, possessing only a power of diffuse refraction.

two of sulphur) is acted on by dilute sulphuric acid, with the assistance of a gentle heat. The gas readily passes over and may be collected over warm water, not in the large hydro-pneumatic trough, *Fig.* 34, but in a small one, which the student will find convenient to have at hand for the preparation of this gas, and chlorine, and some others requiring warm water. The sulphuretted hydrogen thus obtained, usually contains a small portion of free hydrogen; if required very pure, it may be generated from sulphuret of antimony and liquid muriatic acid.

Properties. Any one who has had the misfortune to meet with a putrefying egg, may form a pretty correct idea of the fetidly offensive character of sulphuretted hydrogen. It is very poisonous. Air contaminated with $\frac{1}{800}$ of it has been known to produce death, even to large animals. It is highly inflammable, but it extinguishes all burning bodies. It is soluble in water, and the solution is extensively used as a reagent for metals, from the solutions of most of which it precipitates metallic sulphurets of various colours, by which many metals may be recognised. Thus antimony gives an orange; manganese a flesh red; arsenic and cadmium, a canary yellow; lead, mercury, and bismuth, black or brown precipitates. The composition of sulphuretted hydrogen, is strikingly shown by pouring a little strong nitric acid into a bottle containing the gas; light and heat are liberated, the hydrogen being instantly oxidized, while sulphur is precipitated on the sides of the bottle. Chlorine also immediately decomposes it, in consequence of the powerful affinity which (as will be shown in the next Lecture,) this element possesses for hydrogen; hence, should any sulphuretted hydrogen accidentally escape into an apartment, its odour is soon destroyed by diffusing a little chlorine through it.

Sulphuretted hydrogen is a frequent constituent of mineral waters, being probably evolved by the action of water on the native sulphurets of iron at high temperatures: the class of spas which it forms are called sulphurous: such as those of Harrowgate, Lucan, and Golden-bridge.

Mr. Daniell has lately drawn attention* to the impregnation of the waters on the Western coast of Africa, with sulphuretted hydrogen, to an amount in some places, exceeding that of the most celebrated sulphur springs, to which impregnation, the rapid decay of the copper sheathing of ships employed on those stations is to be ascribed. This impregnation of the water with sulphuretted hydrogen, is undoubtedly to be ascribed to the *decomposition of the sulphates in the water, by the carbonaceous matter of vegetables;* and Mr. Daniell, with a high degree of probability suggests, that the existence of this deleterious gas in the atmosphere, which must necessarily accompany its solution in the waters, may be connected with that awful miasma, which has hitherto proved so fatal to the explorers and settlers on the deadly shores of Africa. He adds, "may not the jungle fever in India depend, for much of its malignity, upon the same cause? The soil, in many parts, abounds not only with the nitrates of potash and soda, but the *sulphates* of soda and magnesia; these become washed down by the periodical rains, and mingling with the decaying leaves, the mutual reaction takes place." Plentiful fumigations of chlorine would infallibly prevent these deleterious effects, as chlorine and sulphuretted hydrogen cannot exist together.

Persulphuret of hydrogen is generated when bisulphuret of potassium in solution, is poured into dilute muriatic acid. It is a heavy oily liquid, insoluble in water, but rapidly decomposed by contact with it.

Sulphur and carbon. Bisulphuret of carbon; CS_2. When vapour of sulphur is transmitted through a red-hot porcelain tube containing charcoal, a volatile colourless liquid is produced. The arrangement of the apparatus is shown in *Fig.* 72. When the stove is sufficiently heated, pieces of sulphur

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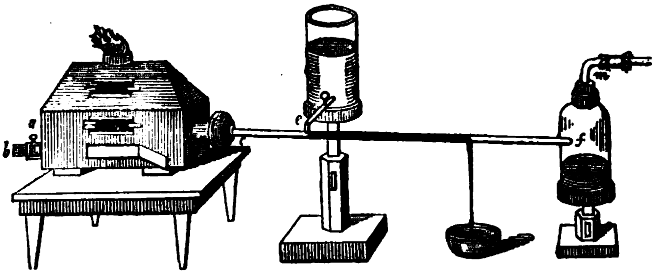
* See London, Edinburgh, and Dublin Phil: Mag: July, 1841.

are introduced at *a*, which instantly become fused and flow into the hottest part of the tube, which is placed in a rather inclined position. The sulphur enters into ebullition and is converted into vapour, which, passing over the heated charcoal, combines with it. The sulphuret of carbon is condensed in the long glass tube, *o*, from which it flows into the flask *f*, and sinks in the water which it contains; sulphuretted hydrogen is produced at the same time, in consequence of the presence of hydrogen in the charcoal; this escapes through *m*, which conducts it through a window into the external air. The tube *o*, is kept cool by cold water, which constantly trickles along it from the reservoir *e*.

Fig. 72.



Pure bisulphuret of carbon is very inflammable, burning with a blue flame, and producing by its combustion carbonic and sulphurous acids. It has a very disagreeable odour. When pure, it boils at 110°, and by its evaporation in vacuo, a cold of —80 can be produced. Its composition is pleasingly shown by throwing a few drops into a stout bottle containing oxygen, through which its vapour soon diffuses; on applying a light it burns with a brilliant flash, but without any violent explosion; sulphur is at the same time deposited.

Selenium; Se, Eq: 494·58. It will be unnecessary to dwell long on this substance, as it is very rare, and has never been applied to any useful purpose. It was discovered by Berzelius, in 1817, in the sulphur of Fahlun, who gave it the name selenium, from Σεληνὴ, the moon, on account of its strong analogy to *Tellurium*, which derives its name from *Tellus*, the earth. In its combinations it almost completely resembles sulphur, but it differs from that substance in combining with only one equivalent of oxygen, forming a colourless gas, which is remarkable for its pungent odour of horse-radish.

Phosphorus. P. Eq: 392.2. This singular substance has been known since the year 1660, when it was first obtained by Brand, of Hamburgh. It exists in nature, in the animal, vegetable, and mineral kingdoms, but in by far greater quantities in the former. It appears essential to the organization of the higher animals, being the basis of the solid structure of the bones, and existing in the fluids of the body, and in the pulpy material of the brain and nerves.

Preparation. To three parts of the earthy material of bones, (consisting of phosphate of lime,) ground to powder, thirty of water, and two of oil of vitriol are added; the liquor is evaporated to the consistence of syrup, the sulphate of lime produced by the reaction having been previously removed by straining through a cloth.

The thick liquid is then mixed well in a mortar, with charcoal powder, and completely dried at a temperature just below redness. It is then introduced into an earthen retort, adapted to a long copper tube, the free end of which dips into a receiver containing water. On applying heat gradually, the phosphoric acid becomes decomposed by the charcoal, phosphorus is set free in a vaporous state, is condensed in the copper tube, and flows in a liquid state into the receiver, where it collects on the surface of the water. It is again melted under the water, and being poured into glass tubes it solidifies, and thus gets the cylindrical form in which we meet with it in commerce. The disposition of the apparatus is shown in *Fig.* 73. This is the only good practical method of preparing phosphorus, and by it very considerable quantities are manufactured in London and Paris.

Fig. 73.

Properties. When pure, phosphorus is transparent and colourless; the red tint which it is found to possess in commerce arises from the influence of light. It is soft, and may be easily cut with a knife, though at 32° it becomes brittle, and even crystalline in its fracture: at 108° it melts, and at 550° it boils, forming a colourless vapour. It is absolutely insoluble in water, in which it is necessary to keep it, as it undergoes oxidation in the air, exhaling luminous fumes of a peculiar odour, something resembling garlic. It is remarkable, that the slow combustion of phosphorus does not take place in pure oxygen, at temperatures below 80°, though when diluted with nitrogen, hydrogen, or carbonic acid, or when the pure oxygen is rarefied by diminished pressure, the oxidation occurs below 60° Professor Graham has found that small admixtures of olefiant gas, sulphuric ether, naphtha, and oil of turpentine prevent its slow combustion. It is necessary to be exceedingly cautious in handling phosphorus, as the evolution of heat during its slow combustion, particularly if increased by friction and other causes, may cause it to burst into a flame which it is impossible to extinguish, and which occasions particularly painful and severe burns.

Phosphorus is soluble in the volatile oils, in ether, and in sulphuret of carbon. When dissolved in rectified sulphuric ether, and brought into contact with a large quantity of water, the solution undergoes decomposition. A pretty experiment in illustration of this is, to wet a lump of fine white sugar with the solution, and throw it into a basin of warm water; the whole of the surface will be illuminated, and by gently blowing it, beautiful undulations will be formed, resembling the occasional fiery appearance of the sea. When one part of phosphorus is gently heated with six of oil of olives, a solution is formed which becomes luminous when the cork of the phial in which it is contained is drawn ; so luminous is the solution that the hour may be seen at night, by holding a watch against the bottle. Luminous drawings may be formed by means of it, and it may be rubbed on the face and hands, so as to make them luminous, without injury.

Phosphorus with oxygen. Phosphorus combines with oxygen in four proportions, forming

Oxide of phosphorus.............	$2P+O$
Hypophosphorous acid............	$P+O$
Phosphorous acid................	$P+3O$
Phosphoric acid.................	$P+5O$

Oxide of phosphorus; P_2O, Eq: 884·6, is generated whenever phosphorus is incompletely burned: it may be formed in large quantity by melting phosphorus under water, and throwing a stream of oxygen gas on it; it burns brilliantly, and being present in excess, passes into the lowest degree of combination it can form. It is a powder, of a canary yellow colour, exceedingly inflammable, and insoluble in water, alcohol, and ether.

Hypophosphorous acid; PO. Eq: 492·3. This acid is very little known: it is formed by the action of a warm solution of an alkali or earth, on phosphorus.

Phosphorous acid; PO_3; Eq: 693·3. This acid is the principal product of the slow combustion of phosphorus. It absorbs oxygen with avidity, reducing to the metallic state, salts of mercury, gold, platinum, and silver. In the laboratory, it is occasionally used as a deoxidizing agent. It is obtained pure with difficulty; but in solution, it may be formed by passing a current of chlorine, through water containing pieces of phosphorus; inflammation takes place, chloride of phosphorus is formed and immediately decomposed by the water, giving rise to phosphorous and muriatic acids.

Phosphoric acid; PO_5; Eq: 892·3. There are three ways of forming this singular acid.* 1st. By decomposing by carbonate of ammonia the acid solution of superphosphate of lime, the result of the first part of the operation for preparing phosphorus; crystallizing and igniting the phosphate of ammonia, by which it is decomposed, and the phosphoric acid solidifies into a colourless glass, known as the *glacial phosphoric acid.* 2nd. By oxidating phosphorus by fuming nitric acid, diluted with an equal bulk of water; a process, in conducting which great care is required, to prevent the phosphorus from being projected in a state of ignition. And 3rd. By burning phosphorus in a metallic capsule, and covering it with a large bell glass: white flakes of phosphoric acid are deposited.

It is by the first of these processes that phosphoric acid is generally obtained; but the last is the most convenient, when it is required in a state of purity.

The glacial acid of phosphorus has so strong an affinity for water, that it can only be preserved in its *glassy* state in well-stopped bottles.

The hydrated phosphoric acid may be distinguished from all other acids, except the arsenious, by forming with nitrate of silver a yellow precipitate, even when neutralized by ammonia. A certain test, between phosphoric and arsenious acids is, that the former is neither changed in colour nor precipitated, when a stream of sulphuretted hydrogen is transmitted through it: while the latter first acquires a yellow tint, and then yields a yellow precipitate.

Phosphorus with hydrogen. This compound is obtained by heating about a quarter of an ounce of phosphorus in a retort,

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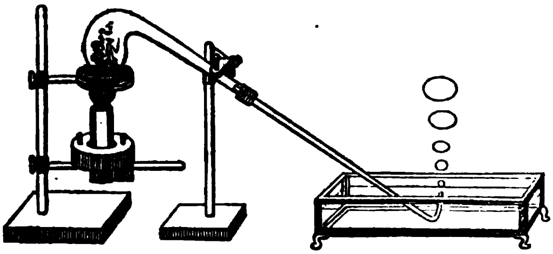
* Phosphoric acid is remarkable for forming three distinct compounds with water, and three classes of salts:—See the elaborate and important researches of Graham, in the Phil: Trans: 1833, page 253, or in the Phil: Mag: vol. 4, page 401. As we cannot spare the space to give a full detail of these researches, and as they could not be curtailed consistent with perspicuity, the advanced student is referred to the original papers in the periodical above referred to, or to the Elements of Chemistry, by the same Author.

capable of holding about four ounces of water, and completely filled with a moderately strong solution of caustic potash; each bubble of gas, as it bursts through the water of the pneumatic trough into the air, takes fire spontaneously, and burning with a beautiful white flame, forms a ring of phosphoric acid smoke, which, if the air of the room be still, will rise to a considerable height, widening as it rises, as shown in *Fig.* 74. The structure of this ring is very beautiful, consisting, according to Kane, of an amazing number of small rings, which revolve with great rapidity on their axes, and whose plane is perpendicular to that of the general ring which they produce. If the bubbles of gas be received into a jar of pure oxygen, the combustion is excessively brilliant;—altogether, this is one of the most splendid experiments in Chemistry. Care must be taken to have the retort *completely filled* with the caustic alkali, and when the gas is passed into oxygen, the operator must be careful that it is not generated too rapidly.

Fig. 74.



When hydrated phosphorous acid is heated, a variety of phosphuretted hydrogen is produced, which is *not* spontaneously inflammable, though analysis proves it to have the same composition as the other. Graham thinks, however, that the difference in properties may arise from the presence of small quantities of foreign substances not capable of being detected.

Boron;—B. Eq: 136·25. This elementary body is never found in nature in an insulated state, though in combination with oxygen in the form of boracic acid it is found in the small volcanic lakes or lagoons of Tuscany, and in the hot springs of Lipari. It is found also in the mineral kingdom, and as impure borate of soda, or tinkal, it is brought to Europe from India, and when purified, is commonly known as borax.

Boron was first discovered by Sir H. Davy, who produced it by submitting boracic acid to the action of a powerful galvanic battery; it is now obtained by a complicated chemical reaction which we will not describe, boron being an element of no utility in its insulated state.

Boracic acid; BO_3. By dissolving borax in four times its weight of water, filtering the solution while hot, and decomposing by one fourth its weight of oil of vitriol, boracic acid is obtained on cooling in thin shining crystalline plates, which after fusion in a platinum crucible and recrystallization, may be regarded as pure. It is the only compound of boron and oxygen known, and though feeble in its acid properties, on account of its fixity in the fire, it is capable of removing many of the stronger acids from their combinations. It is much used by Chemists as a *flux*, as, though it requires a very intense heat to convert it into vapour, it is very fusible, and forms fusible combinations with many of the metallic oxides. Boracic acid is distinguished by its property of communicating a green colour to the flame of spirits of wine.

Silicon; Si; Eq: 277·3. This is the base of the most extensively diffused body in nature,—*silica, silex,* or *silicic acid,* which constitutes at least *one sixth* of the total weight of the mineral crust of our globe. Quartz, crystallized flint, agate, and sand, are silica nearly pure: and when mixed with various metallic oxides, it forms a class of compounds termed silicates, which includes the great part of earthy minerals.

Silicon is only to be freed from oxygen with very great difficulty, and by a complicated process. It is a dull brown powder, which may be heated intensely in a covered platinum crucible without loss; but when heated in air or oxygen, takes fire and burns, forming silicic acid.

Silicic acid, S_2O_3, is the only known compound of silicon and oxygen. It exists in nearly a pure state, as has been observed, in colourless rock crystal, from which it may be obtained in a powder, by heating the crystal to redness and throwing it into water, after which it is easily pulverized. If required in a very fine state of division, it may be so obtained by projecting into a fused mixture of the carbonates of potash and soda, pounded flint, as long as effervescence takes place; the silica dissolves in the alkali, from which it may be separated by the addition of a stronger acid; it then appears in a gelatinous hydrate, and when quite dry, as a white powder, though it still feels gritty between the teeth. In this state it is quite insoluble in water; but in the gelatinous form it is soluble to a small extent; hence, its presence in mineral waters, and hence also, those beautiful silicious petrifactions, in which the most delicate vegetable tissues are faithfully preserved. There can be no doubt that much of the crystalline quartz in nature, besides all the agates, chalcedonies, &c., are deposited from aqueous solutions of silica.

The alkaline solution of silica, when decomposed by a *dilute* acid, does not precipitate the silica, though by evaporation to dryness, it assumes the insoluble condition.

Like boracic acid, silicic acid (though it has no acid reaction) is capable of displacing the most powerful of the volatile acids at a high temperature. It unites with metallic oxides by way of fusion, in a great variety of proportions. When it combines with potash and soda, so that the alkali be in excess, *fusible* silicates are formed; but when the silica is in excess the silicate is dissolved, and on cooling they solidify together and *glass* is the result.

Window glass (silicate of soda and lime,) is formed by fusing in a large clay crucible 100 parts of a quartzy sand, with 35 to 40 parts of chalk, 30 to 35 of carbonate of soda, and 180 of broken glass. When the mixture becomes thick and viscid it is fit to be worked, and may then be drawn out into extremely fine threads, and expanded by the blow-pipe into vessels of any form; but it is necessary that the vessels should be cooled very slowly, or *annealed* as it is called, otherwise they are brittle in the highest degree and quite worthless. To anneal glass it is placed in a situation at which it can be exposed to the highest degree of heat which it is capable of bearing without softening, and the temperature is progressively lowered to that of the atmosphere.

Plate glass was invented by Abraham Thwart, and was first manufactured in Paris, in 1688. It may be composed of 300 lbs. of fine sand, 200 lbs. of soda, 30 lbs. of lime, 32 oz. of black oxide of manganese, 2 oz. of cobalt azure, and 300lbs. of fragments of good glass. These materials, when in perfect fusion, are poured upon a hot copper plate; the mass is then rolled out, annealed, and afterwards polished by grinding with sand, emery, and colcothar. The difficulty of producing a perfect plate without specks, bubbles, or waves, together with the risk of breakage, render large plates very expensive.

The fusibility and density of glass is increased by oxide of lead, so that it is more easily worked and more brilliant, especially when ornamented by cutting: of this latter description is the glass called flint glass, used for decanters, drinking glasses, chandeliers, &c. It consists of about 52 parts of silica, 34 of oxide of lead, and 14 of potash. For the best crystal glass for optical purposes, the materials are 120 parts of fine sand, 40 of purified pearlashes, 35 of litharge or minium, and one of nitre. The presence of lead in glass, is at once detected by its surface acquiring a metallic lustre when heated to redness in the *reducing** flame. The beautiful Bohemian potash glass, of such extensive use to the chemist, from its infusibility, owes its property to the absence of oxide of lead.

The common wine-bottle green-glass is formed of the

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* In which there is excess of combustible matter. This will be particularly explained in the next Lecture.

cheapest materials, such as sand with soap-makers waste, lime that has been used to render alkali caustic, &c.

The application of glass to the glazing of windows is of comparatively recent introduction into dwelling-houses, though it was general in churches and other public buildings as early as the third or fourth century. In London, this manufacture was first begun in 1557. In Scotland, even in the early part of the last century, glass was seldom seen in the windows of country houses, and a few years previously, even in the royal palaces and the town houses of the nobility, the windows of the upper stories alone were furnished with it. Since that period, however, a mighty change has been effected: for now, even the windows of the meanest cottage in Great Britain, are almost without exception, supplied with glass, which, as Mr. Mc. Culloch has well observed, ought rather to be considered as a necessary of life, than as the most elegant and useful of conveniences.

The different colours are given to glasses, by fusing with them certain metallic oxides; thus, oxide of cobalt gives a blue; oxide of copper, a green; peroxide of manganese, a purple; peroxide of uranium, a delicate yellow; and arsenious acid and peroxide of tin, an opaque white, like enamel.

Chlorine. Cl: Eq: 442·65: The discovery of the elementary nature of this gas, by Sir Humphry Davy, in 1809, forms an important era in Chemical Science. It was previously thought to be a compound of muriatic acid and oxygen; but as it resisted the most powerful means of decomposition, Davy declared, that according to the true logic of Chemistry, it must be considered as an element. It was first discovered by Scheele, in 1774.

Chlorine is very abundantly diffused in nature; it constitutes more than one half the weight of common salt, and is the chief ingredient of sea water. It is found also combined with calcium, mercury, lead, silver, and some other metals, though these compounds are rare. It derives its name from χλωρος, yellow green, such being its colour.

Preparation. Muriatic or hydrochloric acid is, as will presently be shown, a compound of chlorine and hydrogen, and peroxide of manganese, has been proved to part freely with a portion of its oxygen; on heating therefore, about two ounces of the latter in coarse powder, in a flask, with six ounce measures of the former, diluted with an ounce or two of water, the reaction shown below in a diagram takes place.

BEFORE DECOMPOSITION.			AFTER DECOMPOSITION.	
455 hydrochloric acid	chlorine	442·5	chlorine	442·5
	hydrogen	12·5	water	112·5
546 peroxide of manganese	oxygen	100		
	manganese	346		788·5
	oxygen	100		
455 hydrochloric acid	chlorine	442·5		
	hydrogen	12·5		112·5
		1456·0		1456·0

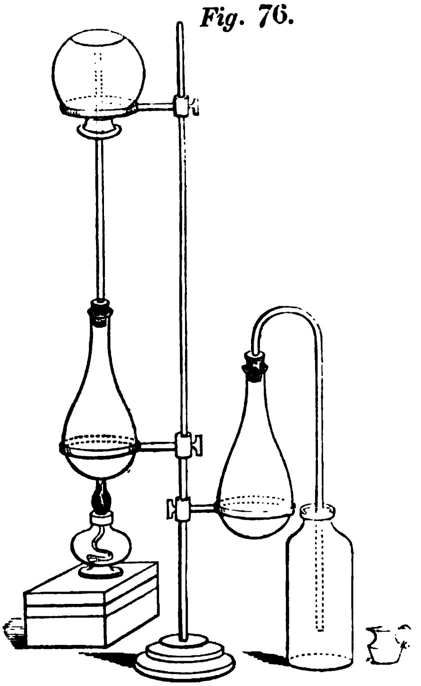
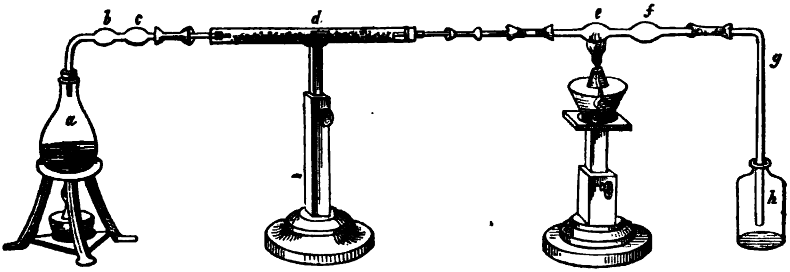


Fig. 76.

This is the most convenient method of preparing chlorine for the laboratory, and as it is soluble to a considerable extent in water, and cannot be collected and preserved over quicksilver, with which it combines, it should either be collected over water as hot as the receivers will bear, and the delivery tube made to reach to the top of the jar; or by displacement, as in the lower arrangement of apparatus, shown in *Fig.* 76. chlorine being much heavier than common air, and its colour showing when the bottle is full. By stopping the aperture with a *greased* stopple, the gas may be preserved unaltered for a long time.

The student is recommended to make himself familiar with the reaction explained in the above diagram by repeating the experiment. Into the flask *a*, *Fig.* 77, introduce a few ounces of fuming muriatic acid; connect it by means of a tube, in which two bulbs, *b*, *c*, are blown, and a caoutchouc connector, with a long tube, *d*, containing fused chloride of calcium; this is again to be connected with another tube, in which the bulbs *e*, *f* are blown; and lastly, with a bent tube, *g*, reaching to the bottom of the bottle *h*. Into *e*, some pounded and dry peroxide of manganese is placed. Muriatic acid gas is generated by applying heat to the flask *a*, its moisture is deposited in *b*, *c*, and the gas becomes thoroughly dried in its passage through the chloride of calcium in *d*; on arriving at *e*, it meets with the peroxide of manganese, heated by a spirit lamp, and suffers decomposition, its hydrogen uniting to the oxygen of the manganese and forming water, which is deposited in *f*; while its other constituent element, chlorine, passes into the bottle *h*, displacing the common air which it contains. A more satisfactory or a more easily performed analytical experiment could scarcely be made.

Fig. 77.



For the preparation of chlorine on the large scale, a cheaper process is followed. It has already been stated, that common salt is a compound of chlorine and sodium; about 8 parts are introduced into a large leaden vessel, with 6 parts of manganese, and 13 of oil of vitriol. The manganese furnishes the sodium with oxygen, converting it into soda, which combining with part of the sulphuric acid, forms *sulphate* of soda;—the manganese having parted with an equivalent of its oxygen, becomes *protoxide,* which unites with the remainder of sulphuric acid, and the results of the reactions are chlorine, and the sulphates of soda and manganese.

Properties. Chlorine is a greenish yellow gas, of a very suffocating odour, and irritating in a distressing degree, even when taken into the lungs much diluted.* Its specific gravity, as compared with air, is 2·470, and 100 cubic inches weigh 76·6 grains. Water, at 60° dissolves twice its volume, acquiring the colour, odour, and properties of the gas; at 32° chlorine and water combine, forming a crystalline solid: this compound is remarkable, as being that from which the first *liquefied gas* was obtained by Faraday. The aqueous solution of chlorine is resolved, by the agency of light, into hydrochloric acid and oxygen.

Chlorine is what is termed a *supporter of* combustion. Phosphorus takes fire in it spontaneously, burning with a feeble light; and many of the metals, in thin leaves or in powder, are suddenly inflamed when introduced into it. Arsenic and antimony, when sprinkled into a jar of the gas, in the state of powder, produce beautiful scintillations. Tin, brass, copper, and zinc-foil likewise, burn spontaneously in it.

The attraction of chlorine for hydrogen is exceedingly powerful; it decomposes most compound substances containing that principle, and is the cause of most of the changes it produces on organic bodies. Its power of decomposing water, merely by the action of light, is a striking example of its attraction for hydrogen; and hence also it happens, that chlorine is *indirectly* one of the most powerful oxidizing agents

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* The coughing and oppression on the chest, consequent on the inhalation of chlorine, may be partly relieved by breathing the vapour of ether or spirit of wine.

which we possess. In all these cases hydrochloric acid is formed. When a taper is plunged into a jar of chlorine, its flame is extinguished; but the column of oily vapour rising from the wick, is rekindled by the chlorine, which enters into combination with its hydrogen, leaving the carbonaceous part, which appears as smoke. A piece of paper dipped into oil of turpentine, which contains a large quantity of hydrogen, and immersed in a jar of chlorine, immediately takes fire, its hydrogen burning and its carbon being deposited.

There is scarcely any substance which, in its application to the arts, is more useful than chlorine. It is the discolouring agent of the modern process of bleaching, and is extensively employed as a disinfectant to remove the miasmata and infectious impurities by which the atmosphere of an hospital may be contaminated.

In the old process of bleaching, the goods are first well washed with water, to remove the weavers' *dressing or paste*; they are then *bucked* or boiled in a weak alkaline ley; and after having been well washed, are spread out upon the grass, so as to be exposed to the joint agencies of light, air, and moisture; the bucking and exposure are continued as often as necessary; the goods are then *soured*, that is, immersed in water slightly acidulated with sulphuric acid; and lastly, are thoroughly washed and dried. By these operations the texture of the goods is, to a certain extent, impaired, and much time is required to complete the process, which also cannot be carried on in the winter months. In the new process, the cloth, after being well washed, is boiled first in lime water, and then in caustic soda, which remove from it certain resinous matters. It is then steeped in a solution of *chloride of lime*, so dilute as just to taste distinctly, which has little or no perceptible effect in whitening it, till the cloth is steeped in dilute sulphuric acid, when a minute disengagement of chlorine takes place throughout the substance of the cloth, and it immediately assumes a bleached appearance; the operation is repeated as often as necessary, great care being taken to wash the cloth thoroughly when finished, to get rid of the acid, which, if allowed to dry in it, would injure its fibres. The theory of the operation of bleaching was, that it depended on the decomposition of water, the hydrogen of which was seized by the chlorine, while its oxygen being thrown on the organic substance, oxidized it, and formed a new body which was colourless. According to Kane, however, this is not the case, chlorine entering into the constitution of the new substance formed, sometimes replacing hydrogen, at others, simply combining with the coloured body, and at other times, occasioning very complex reactions.* The agency of chlorine in bleaching, results, nevertheless, from its disposition to unite with hydrogen.

When chlorine is employed as a disinfectant, some chloride of lime, diffused through water, is placed in a tea cup, and dilute sulphuric acid allowed to drop slowly upon it; by this means, a slow but continuous evolution of the gas is obtained.

Chlorine with hydrogen—hydrochloric acid; $Cl\,H$; Eq: 455. This highly important compound constitutes one of the three mineral acids so constantly called into operation in chemical processes. It is known by the various names of spirit of salt, marine acid,† muriatic acid, chlorohydric, and hydrochloric acid. The very powerful affinity of chlorine for hydrogen, has already been adverted to and illustrated. The experiment of proving that the result of their union is muriatic acid, is very easily performed. Fill a stout bottle half full of hydrogen, and then quickly pass in chlorine till it is full; expose it for a few minutes to a bright sun; or present to the open mouth a lighted taper; an explosion will ensue, and the bottle will become filled with white fumes: admit a little water, and agitate the bottle; the fumes will be absorbed, and the water will be found to have acquired a sour taste. A very striking method

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* See Kane's Elements of Chemistry.

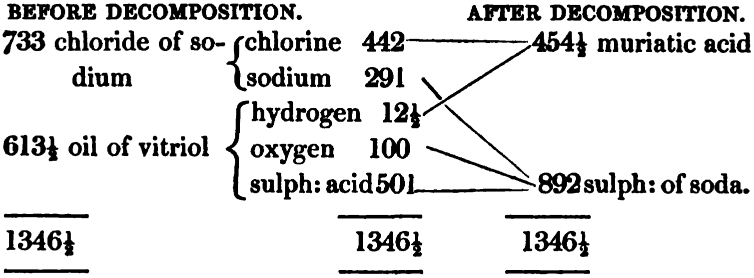
† From murias, sea salt.

of showing the composition of muriatic acid in the Lecture room, is to fill a large thin globular vessel with chlorine, (by displacement) and to allow a stream of hydrogen from a pipe at the end of the flexible tube, to burn inside the receiver; the flame will be so feeble as scarcely to be perceptible by day, the heat, however, will be intense, and the receiver will soon become filled with dense vapours of muriatic acid gas.

To prepare muriatic acid gas for examination, a little commercial spirit of salt may be placed in a flask, connected with the mercurio-pneumatic apparatus and heated: the gas is colourless and invisible. It is irrespirable, though it does not produce the suffocating effects of chlorine. It is condensed by a pressure of 40 atmospheres, at 50° into a liquid. It extinguishes combustion, and is not inflammable. Its most remarkable property is its powerful attraction for water; hence it is, that though the gas is invisible whilst in a jar over mercury, it forms heavy white fumes on escaping into the atmosphere in which it finds moisture, and condenses in minute drops of liquid acid. A few drops of water are sufficient to condense a large jar of muriatic acid gas. One cubic inch will absorb 418 cubic inches, according to Thomson. Considerable heat accompanies the condensation. A piece of ice let up into the gas over mercury, becomes instantly liquefied and the gas is absorbed.

The muriatic acid of commerce, is water saturated with the above gas. The materials usually employed, are equal weights of salt, water, and sulphuric acid; more acid being employed than is sufficient to form a neutral sulphate with the soda, so that the more perfect decomposition of the salt may be ensured. The acid, to prevent too violent effervescence at first, is mixed with one-third of the water, and when the mixture has cooled it is poured upon the salt, previously introduced into a glass retort. The distillation is continued to dryness, and the gas, as it escapes, is conducted into the remainder of the water. The apparatus, shown in *Fig.* 64, and used in the preparation of nitric acid, may be employed. The specific gravity of the acid obtained in this process is 1·170.

The following diagram represents the nature of the reaction; supposing single equivalents of oil of vitriol and salt to be employed.



The student has rarely any occasion to prepare this acid himself; the spirit of salt, of commerce, being easily purified by distillation. Liebig's condensing tube may be very conveniently employed for this purpose; the pure acid thus obtained is colourless, and besides being strong enough for almost every purpose, it has the advantage of not fuming in the air. The commercial acid has a yellow colour arising from iron, and perhaps also some organic matter; it also contains sulphuric acid, which may be detected by nitrate of barytes.

When, however, a *concentrated* and pure acid is required, the following process of Dr. Gregory* may be advantageously adopted for procuring it.

Into a common Florence flask are introduced, 4 ounces of the purest patent salt, and 5 ounces of sulphuric acid, of specific gravity 1·600; a gentle heat is applied, and the gas which is then generated, is conducted by a bent glass tube, into a four ounce phial, surrounded with snow or ice-cold water, and containing 2 ounces of distilled water. No safety-tube is required, as the tube is made to dip only about one-eighth of an inch into the water, so that should any absorption take place, the rise of a little water in the tube exposes the extremity of

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* Memoirs of the Chemical Society.

it, so as to admit the air; or, for greater security, a small bulb may be blown on the descending limb of the tube.

The gas is absorbed as fast as it comes over, and for the first hour and one quarter, the heat hardly requires to be increased; if the temperature of the surrounding water has been kept so low as 50°, the 2 ounces of distilled water will have increased in volume to 3 ounces of colourless hydrochloric acid, fuming strongly, and having a specific gravity of 1·20 to 1·21; the gas passing over so dry that no part of the tube becomes warm. This portion being removed, its place is supplied by 2 ounces more of distilled water, and the heat gradually increased and continued for an hour longer: by that time all the hydrochloric acid is expelled, with some water, and the 2 ounces of water will have become 3 ounces of hydrochloric acid, of specific gravity 1·10. Both portions are absolutely pure. If 3 ounces of water are used in the first instance, 4·5 fluid ounces of acid of specific gravity 1·165 are obtained; and then replacing the acid by 2 ounces of water, 3·5 ounces more, of specific gravity 1·065. If 5 ounces of water are used at once for condensing the acid, and kept till the distillation is complete, 7·5 fluid ounces of specific gravity 1·155 are obtained. Dr. Clark finds sulphuric acid, of a specific gravity of 1·65 to answer still better than acid of 1·60.

By using sulphuric acid of this degree of strength, (containing 25 per cent of water,) and *two* equivalents to *one* equivalent of salt, instead of one equivalent as usually prescribed, the whole of the hydrochloric acid may be expelled without a trace of sulphuric acid, and two-thirds distil over before water is volatilized.

Hydrochloric acid is a powerful acid, but less corrosive than sulphuric acid; it is not poisonous and is used in medicine. It is decomposed by substances which yield oxygen readily, such as metallic peroxides and nitric acid, which cause an evolution of chlorine by oxidating the hydrogen of the acid. When two measures of hydrochloric, are mixed with 1 of nitric acid; the mixture, though previously colourless, becomes deep yellow, and exhales a strong smell of chlorine and of nitrous acid. It is thus a source of chlorine in a very concentrated state, and hence its use in dissolving gold and platina metals not soluble in nitric acid, and in oxidizing metallic sulphurets. It is called *aqua regia.*

The strongest hydrochloric acid that can be easily formed, contains six equivalents of water, and when evaporated in the open air, it abandons a quantity of gas, and contains 12 equivalents of water to 1 of acid. The great use of muriatic acid in the laboratory is, as a solvent in inorganic analyses. It is distinguished by its odour and volatility, and by its giving, with nitrate of silver, a white curdy precipitate, insoluble in water and in nitric acid, but soluble in ammonia.

Chlorine with oxygen. These elements, though exhibiting but little disposition to combine together, form four distinct compounds, as under:—

Hypochlorous acid..........	$Cl\,O$:	Eq: 542
Chlorous acid.............	$Cl\,O_4$:	Eq: 842
Chloric acid...............	$Cl\,O_5$:	Eq: 942
Perchloric acid............	$Cl\,O_7$:	Eq: 1142

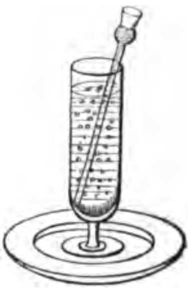
Hypochlorous acid. A solution of this acid in water, is obtained by agitating red oxide of mercury with a little water, in a large jar filled with chlorine. The proportions are, 6 drachms of the oxide, and 1½ ounce of water, in a two pound bottle of the gas. The chlorine takes part of the oxygen from the oxide of mercury, forming with it the acid in question, which is dissolved by the water, whilst another portion of the chlorine unites with the mercury, and forms with the undecomposed oxide, an insoluble oxichloride. It is obtained pure, and in a gaseous form, by passing nitrate of lime, in fragments, into the liquid acid, over mercury; the water is absorbed by this deliquescent salt, and the acid remains as a greenish yellow gas, very similar to chlorine.

This is a very unstable compound, and becomes resolved into its elements by very simple causes; a slight elevation of temperature, and even the act of transferring it from one vessel to another, causes it to explode with violence; many of the metals and elementary bodies act upon it with great energy, and are raised to their highest degree of oxidation, chlorine being evolved. Its composition is 2 volumes of chlorine and 1 volume of oxygen, condensed into two volumes.

Chlorous acid, ClO_4, cannot be obtained in a state of purity without very great danger; it is one of the results of the reaction of sulphuric acid on chlorate of potassa, and is an acid gas of a rich yellowish green colour. It is exceedingly unstable and dangerous, from the violence with which its elements separate from each other from the slightest causes. Brande says, that it may be conveniently obtained by putting a few grains of chlorate of potassa into the bottom of a tall narrow jar, about half an inch in diameter and 12 inches high, standing upon a foot, and carefully dropping upon it, so as not to soil the sides, a little sulphuric acid; the weight of the gas causes it to expel the air and fill the tube, from which, with a little management, it may be decanted into a tall glass containing copper leaf, upon which it exerts no action; but a hot wire dipped into the gas causes it immediately to explode, and the metal leaf burns in the oxygen and chlorine. A little jet of nitric oxide thrown in, produces the same effect without explosion. It is my duty, however, to warn the student to be *very careful* in repeating this experiment, which is not without considerable danger, and ought never to be attempted at the lecture table. The violent action of this compound on combustibles, may be shown in a beautiful manner and without the slightest danger, by throwing a drachm or two of crystallized chlorate of potash into a deep ale glass, *Fig.* 78, filled with cold water, to the bottom of which the salt falls without much loss by solution. Oil of vitriol is then conducted to the salt in a small stream from a tube funnel, the lower end of which has been drawn out into a jet with a minute opening.

A gas of a lively yellow colour is evolved with slight concussions, and immediately dissolved by the water, to which it imparts a yellow colour. If, while this is occurring, a piece of phosphorus be thrown into the glass, it is ignited by every bubble of the gas, and a brilliant combustion is produced under the water. If a few grains of chlorate of potash in fine powder, and loaf-sugar, be mixed upon paper *by the fingers*, and a drop of sulphuric acid allowed to fall upon it, an instantaneous deflagration takes place. It was in this manner that Captain Manby used to fire the small pieces of ordnance, which he proposed as a life preserver, to throw a rope over a stranded vessel, from the shore: and the same mixture was afterwards employed, with sulphuric acid, in various forms of the instantaneous light match; all of which, however, are now superseded by other mixtures ignited by friction, without sulphuric acid.—*Graham.*

Fig. 78.



Chloric acid; ClO_5. This acid may be prepared in solution, by transmitting a stream of chlorine through a strong solution of caustic barytes; chloride of barium and chlorate of barytes result from the reaction. The latter salt separates in a crystalline form, and by decomposing a solution of it in water, by a cautious addition of sulphuric acid, sulphate of barytes is precipitated, and a solution of chloric acid is obtained. In its strongest form, this acid is of an oily consistence, and is a powerful oxidizing agent. It produces a class of salts which is remarkable for a general solubility. Those that are fusible detonate with great violence with combustibles. The chlorate of potash, which is prepared in the same manner as the chlorate of barytes, is a salt of considerable importance in commerce, from its utility in making matches. It deflagrates with combustibles more violently than the nitrate. A grain or two rubbed in a mortar, with an equal quantity of sulphur detonates violently, and if a small piece of phosphorus be added, the explosion is very violent and dangerous. A mixture of chlorate of potash, sulphur, and charcoal inflames by percussion, and is applied to lucifer matches. Graham gives the following receipt for this percussion powder. Wash out the nitre from 10 parts of ordinary gunpowder, and mix the residue, *while moist*, with 5¼ parts of chlorate of potash in very fine powder. This mixture, when dry, is highly inflammable and dangerous to preserve in that state.

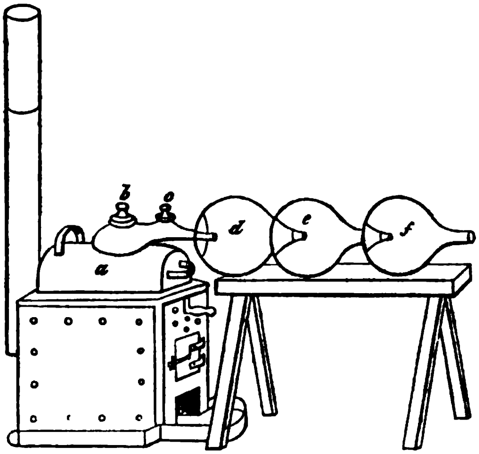
Hypochloric acid; ClO_7. A compound of this acid with potash, is obtained without danger or inconvenience, by gently heating nitric acid on chlorate of potash; the result of the reaction consisting of 3 equivalents of nitrate and 1 of hyperchlorate of potash; the latter salt may be separated in small shining crystals, by dissolving in a small quantity of boiling water and cooling. From the hyperchlorate of potash, the acid may be obtained by boiling it with an excess of fluosilicic acid, (to be described presently,) which forms with potash, a salt nearly insoluble. This acid is much the most stable of the oxides of chlorine, and is remarkable for the large quantity of oxygen which it contains, and for the very sparing solubility of its potash salt; it has hence been employed as a reagent to detect that alkali.

Chloride of nitrogen; NCl_3. This formidable compound is obtained by inverting a jar of chlorine over a basin containing a solution of sal ammoniac, at 90°. The gas is absorbed, and an oily substance gradually accumulates on the surface of the liquid, and precipitates to the bottom of the *leaden* saucer in which the solution of sal-ammoniac is contained. This is the chloride of nitrogen, and so dangerously explosive is it, that the bottle of chlorine must not be touched while it is forming, unless the face be protected by a wire mask, and the hands by stout gloves; a slight agitation is sufficient to resolve it into its elements, with a violence so great as to shatter to pieces vessels of glass or cast-iron. It produces, however, merely an indentation in lead, so that if every particle of it be allowed to settle in the saucer, its general character may be ascertained without danger. Most organic matters containing hydrogen decompose it; and it may be safely exploded, by touching it with a cane rod dipped into oil of turpentine.

Iodine. I: Eq: 1579: was discovered in 1811, by M. Courtois, a manufacturer of saltpetre, in Paris, in *kelp*, a substance from which he prepared carbonate of soda. Its properties were shortly after investigated by M. Clement, and its nature determined by Sir H. Davy and Gay Lussac.

It is from kelp that the greater part of the iodine of commerce is obtained, and the manufacture is conducted upon a large scale, at Glasgow. The concentrated solution of kelp, after it has deposited the soda salts which it contains, is allowed to cool in a shallow pan; crystals of chloride of potassium separate, and a dark dense-coloured liquid remains. To this, sulphuric acid is added in excess, and after standing a day or two, it is heated in the leaden retort, *a*, *Fig.* 79, to about 140°, and then peroxide of manganese is introduced, and the capital, in which are two openings *b*, *c*, closed with leaden stoppers, is luted on. Iodine immediately begins to come off, and is condensed in the receivers *d*, *e*, *f*. In this operation, hydriodic acid is decomposed, either by its hydrogen uniting at once with the oxygen of the manganese, or hydrochloric acid, (which is always present) may be supposed to be

Fig. 79.



first decomposed by the metallic oxide, its chlorine reacting on the hydriodic acid. Precautions to be attended to, and minute directions for performing this operation successfully, are given by Professor Graham, in his "Elements."

Properties. As met with in commerce, iodine is generally in crystalline scales, of a bluish black colour and metallic lustre. Its vapour is of a most beautiful violet colour, as may be seen to great advantage by throwing a scruple or two on a hot brick. Hence its name, from Ἰώδης, violet coloured. It stains the skin yellow, but the colour disappears in a few hours. Water dissolves about $\frac{1}{7000}$th of its weight of iodine, and acquires a brown colour; alcohol and ether dissolve it readily, forming dark reddish-brown solutions. Its vapour is the heaviest of the simple gaseous bodies. It bears a considerable resemblance to chlorine, though its affinities are much less powerful. One of the most remarkable properties of this substance is, that of its forming with starch, a deep blue insoluble compound, the production of which is an exceedingly delicate test of its presence; according to Stromeyer, a liquid containing $\frac{1}{450000}$th of its weight of iodine, receives a blue tinge from a solution of starch. It is only *free* iodine that gives this blue precipitate; if it be in combination as a soluble *iodide*, no change takes place till chlorine is added to liberate the iodine. The chlorine must not, however, be in excess. The best plan, according to Dr. A. T. Thomson, is to add starch, with a drop of sulphuric acid, to the liquid containing an iodide, and allow the *vapour only*, from a solution of chlorine in water to fall upon the liquid; the blue compound is immediately formed, and there is no danger of an excess of chlorine.

Iodine is used in medicine. It appears to have a specific action in causing the absorption of glandular swellings, and is also administered as a tonic. It was first successfully employed in the treatment of goitre, by Coindet, of Geneva, and it has since been found that most mineral waters, to which the virtue of curing that disease was ascribed, contain iodine.

Iodine combines with metals with nearly as much energy as chlorine. The compounds which it forms with mercury and lead are very beautiful. The iodide of mercury falls as a precipitate of a fine scarlet colour, when iodide of potassium* is added to a solution of bichloride of mercury, (corrosive sublimate.) When moderately heated, it becomes yellow; at a higher temperature it fuses, and sublimes in beautiful yellow rhomboidal crystalline plates. These yellow crystals generally, gradually change to scarlet when cold, and the change may be brought about at once by scratching or crushing the surface of a crystal. Now the forms of these crystals are totally different; hence, the iodide of mercury presents a remarkably clear example of *dimorphism*, or the capability of some bodies to assume different crystalline forms, their constitution being precisely similar. Iodide of lead is formed, when iodide of potassium is added to a salt of lead in solution; it falls as a beautiful lemon-coloured powder, soluble in 194 parts of boiling water, from which, on cooling, it separates in crystalline golden scales, of exceeding brilliancy.

Iodine appears to form three compounds with oxygen, namely, *iodous*, *iodic*, and *periodic* acids. It combines also with hydrogen, forming a compound analogous to hydrochloric acid, namely, hydriodic acid.

Of iodous acid very little is known. Iodic acid, IO_5, is prepared by digesting iodine in nitric acid; or by transmitting a current of chlorine through water containing iodine diffused through it, neutralizing the acid liquor by carbonate of soda, and repeating these two operations till the alkali ceases to precipitate iodine. The iodate of soda is then mixed with a salt of barytes, and the resulting iodate of barytes decomposed by sulphuric acid. Iodic acid is a powerful oxidizing agent, and

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* A salt procurable at any chemist's, being extensively used in medicine.

is remarkable for its action on morphia, which it decomposes, iodine being set free, by which property it may be recognized. Its salts resemble, in most respects, those of chloric acid.

Periodic acid; IO_7, is formed by transmitting a current of chlorine through a solution of iodate of soda, to which at least, three times as much caustic soda has been added, as there is of soda in the iodate. It is more stable than iodic acid, though at a high temperature it is resolved into iodine and oxygen.

Hydriodic acid; HI. Under ordinary temperatures and pressures, this compound exists as a gas, which may be obtained by introducing into a little tube retort, 9 parts of dry iodine and 1 of phosphorus, and filling it up with pounded glass. On gently heating the tube, the iodine and phosphorus combine, forming iodide of phosphorus; a little water is now allowed to filter through the pounded glass, which, when it comes into contact with the iodide of phosphorus, decomposes it with violence, its hydrogen uniting with the iodine and forming a gaseous substance, which may be collected by displacement. This gas is very soluble in water, and soon decomposes over mercury. It is colourless, though like hydrochloric acid, it fumes in the air. Its solution in water is best obtained by transmitting sulphuretted hydrogen through water in which iodine is suspended; the iodine combines with the hydrogen of that compound, and liberates the sulphur. The excess of sulphuretted hydrogen is expelled by warming the liquid, and it is rendered clear by filtration. In its strongest form, sp: gr: 1·700, it may be distilled unaltered. It is colourless, though, if exposed to the air, it soon becomes brown, and finally red, owing to its decomposition by atmospheric oxygen.

Iodide of nitrogen. This is a powerfully detonating compound; it explodes more easily than the chloride of nitrogen, though not so violently. It may be formed by digesting iodine in solution of ammonia, or, which is a better plan, by mixing great excess of ammonia with a saturated solution of iodine in alcohol, and afterwards adding water as long as the iodide of nitrogen precipitates. It may be collected on a filter, which, while moist, should be divided into a number of small pieces, or the whole may explode at once on drying. When the paper is dry, the slightest touch causes it to explode with violence, and if there be several pieces on the same table, the concussion in the air, produced by the detonation of one, generally causes all the others to explode. There is, however, no danger attending this experiment, which is a very striking one, at the lecture table. A small quantity of the iodide on a piece of filtering paper, if quite dry, will explode when dropped from the hand, before it reaches the ground.

Bromine. Br: Eq: 978·3. This singular element was discovered by M. Balard, in 1826. Its name is derived from Βρωμος, mal-odour, and was applied to it on account of its strong and disagreeable smell.

As it has not been found applicable to any important purpose of utility, I shall pass it over with very few words. It is found in an exceedingly minute quantity in sea-water, under the form of bromides of sodium or magnesium; also in the water of the Dead Sea, and in nearly all the saline springs of Europe, particularly in those of Theodorshall and Kreuznach, in Germany. It is detected by means of chlorine water, a few drops of which cause the colourless solution of a bromide to become orange yellow. Bromine in mass is opaque, and of a dark brown red colour, but in a thin stratum, transparent, and of a hyacinth red. It is strongly poisonous. In almost all its chemical properties, it is intermediate to chlorine and iodine, and its compound with hydrogen is obtained by a process precisely similar to that described for hydriodic acid.

Fluorine. F. Eq: 233·8. It is doubtful whether this body has ever been isolated; for so intense are its affinities, that no sooner is it liberated from its combination with one substance than it enters into union with some other. The only experiments in which its isolation is probable, are those of the

Messrs. Knox, in which they employed vessels of fluorspar, (fluoride of calcium) and decomposed fluoride of mercury, by means of chlorine; though it is not improbable that the gas which was produced, was a chloride of fluorine, and not fluorine itself.

There is no compound of fluorine and oxygen known. It combines, however, with hydrogen, forming, when pure and concentrated, the most intensely corrosive compound known; so much so, that it is not safe to have much to do with it, as, should a drop fall on the hand, it would produce a very painful sore, and one very difficult to heal.

The most remarkable property of hydrofluoric acid is its action on glass; hence, it must be prepared and kept in vessels of platina or lead. It is formed by distilling fluor-spar with twice its weight of oil of vitriol, a little water being put into the receiver.

Its corrosive action on glass, depends on its property of combining with the base of silica, (silicon) forming fluoride of silicon. Patterns or designs may, therefore, be etched upon glass by means of hydrofluoric acid. There are two ways of doing this. 1st. The glass is uniformly covered with wax, and the design traced on it with a graver, taking care to expose the glass perfectly in every part; a rim of wax is then formed round the edge of the plate, and the liquid acid poured on after a time, dependant on the judgment of the operator; the remaining acid is poured off and the the wax cleaned away. The etched portions of the glass are equally transparent with the others, and the design is therefore indistinct, except in certain incidences of the light. A glass plate, so prepared, may be used as a copper-plate to print from, but the risk of breaking is too great to allow of its introduction into practice. —*Kane.* 2nd. Pounded fluor spar and oil of vitriol are put into a leaden saucer, and the glass to be etched, covered as before with wax, is laid upon it; heat is then applied to the saucer, and the design etched by the hydrofluoric acid which rises. In this case, however, the lines have a rough and white appearance, and are easily visible in every direction; this arises from the regeneration of a quantity of *silica*, occasioned by the decomposition of the watery vapour which rises with the hydrofluoric acid.

Fluoride of silicon, fluosilicic acid; S_2F_3. The solution of this compound in water, is so valuable as a chemical reagent, and its preparation is so interesting that it must not be passed over. To form it, equal parts of powdered fluor spar and pounded sand or glass, are introduced into the flask *a*, *Fig.* 80, and six parts of concentrated sulphuric acid poured on, and well mixed; heat is then applied, and the gaseous matter which is immediately evolved, is conducted by the bent tube, *b*, into the receiver *d*, containing water, but covered at the bottom as far as *c*, with a layer of mercury, so that the extremity of the exit-tube shall be underneath the fluid metal. The reason for this arrangement is, that no sooner does the fluosilicic gas come into contact with water, than a reaction takes place, and *silica* is deposited, which, if the conducting tube touched the water would speedily choke it up. By the above arrangement, however this is prevented, and a singular appearance is presented; as each bubble of gas enters the water, it becomes invested with a white coating of *silica*, like a bag of tissue paper, which preserves its form, frequently for a considerable time: sometimes, in the course of the operation, the gas forms tubes or little chimneys of silica in the water, which reach to the surface, by which the gas escapes decomposition, if care be not taken to break them from time to time. When the water becomes thick the silica is removed, by straining with pressure in a fine linen cloth. The property of this acid, which renders it interesting to the chemist is, that of its form-

Fig. 80.

ing with neutral salts of potash, soda, and lithia, precipitates, which are at first so gelatinous and transparent, that they cannot be readily recognised in the liquor, but when collected on a filter and dried, appear like powdered starch; hence, this acid is used to detect the presence of these substances in solution. With salts of barytes, a white and crystalline precipitate is produced in a few seconds.

LECTURE TENTH.

CARBON WITH HYDROGEN—LIGHT CARBURETTED HYDROGEN —ITS NATURAL SOURCES AND PROPERTIES.—OLEFIANT GAS—ITS PREPARATION AND PROPERTIES—ITS ANALYSIS —RE-ACTION WITH CHLORINE.—COAL—ITS ORIGIN AND HISTORY—VARIETIES—COMPOSITION.—COAL GAS— DESTRUCTIVE DISTILLATION OF COAL—MANUFACTURE OF COAL GAS—QUANTITY ANNUALLY MADE AND CONSUMED IN LONDON—ŒCONOMY OF GAS ILLUMINATION—IGNITION OR INCANDESCENCE—DIFFICULTY OF ASCERTAINING THE PRECISE TEMPERATURE AT WHICH IT COMMENCES.— HEAT OF THE DIRECT RAYS OF THE SUN—EXPERIMENTS OF SAUSSURE, ROBISON, AND LAVOISIER—DE LA HIRE'S EXPERIMENTS ON THE LIGHT OF THE MOON— FORBES' EXPERIMENTS—EXPERIMENTS OF BOUGUER— LIGHT EMITTED BY BODIES DURING THEIR SPONTANEOUS DECOMPOSITION—THE PHOSPHORESCENCE OF THE HUMAN SUBJECT AFTER DEATH.—CANTON'S PYROPHORUS— IMPROVEMENT IN ITS PREPARATION BY DR. HIGGINS.— CONNECTION BETWEEN HEAT AND LIGHT.—FLAME— DAVY'S DEFINITION OF—TEMPERATURE OF FLAME— WEDGEWOOD'S EXPERIMENTS ON HEATED AIR—THEORY OF THE FLAME OF A CANDLE—STRUCTURE OF FLAMES —THE INTENSITY OF THE LIGHT OF FLAMES DEPENDENT ON THE PRESENCE OF INCANDESCENT SOLID MATTER— ILLUSTRATIONS—CIRCUMSTANCES WHICH DETERMINE THE MAINTENANCE OF FLAME.—INTERCEPTIVE POWERS OF

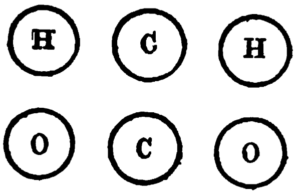
WIRE GAUZE—SAFETY LAMP—PLANS OF SIR JAMES LOWTHER, HUMBOLDT, AND DR. CLANNY, FOR LIGHTING COAL MINES—DAVY'S EXPERIMENTS ON FIRE DAMP—DETAIL OF THE INVESTIGATION WHICH TERMINATED IN THE INVENTION OF THE SAFETY LAMP—STRUCTURE OF THE "DAVY LAMP"—ITS INVALUABLE USE TO THE MINER—CIRCUMSTANCES UNDER WHICH IT CEASES TO BE SAFE—IMPROVEMENT BY MESSRS. UPTON AND ROBERTS—EXPERIMENTS WITH WIRE GAUZE.

The compounds of carbon with hydrogen. It would require a whole volume to give the history of the numerous and important compounds of these two elements, which with nitrogen, comprise the whole range of *organic chemistry.* I propose, therefore, to introduce into the present lecture those two gaseous compounds only, which have been known to chemists several years, and which must be described previous to the consideration of these two last divisions of the subject of heat; viz: *ignition and combustion.* In the twelfth lecture, (on the method of analyzing organic compounds,) some of the most important *hydrocarbons* will be described.

Light carburetted hydrogen; CH_2. This gas, which is also sometimes called *heavy inflammable* air, is formed during the spontaneous decomposition of dead vegetable matter, under water, and may be readily obtained by stirring the mud at the bottom of a stagnant pool and collecting the gas as it escapes in an inverted glass vessel. It always contains from $\frac{1}{12}$th to $\frac{1}{20}$th of carbonic acid, which may be removed by means of lime-water or caustic potassa; it contains also a small portion, (usually about $\frac{1}{20}$th) of nitrogen.

Dalton very ingeniously represents the formation of carburetted hydrogen, by many natural operations, in the manner shown in the diagram, *Fig.* 81. Two atoms of charcoal are interposed between two atoms of water, each consisting of an atom of oxygen and an atom of hydrogen: now, if we divide this diagram *vertically*, we have the original substances, but if it be separated horizontally, we have two new ones. This theoretical view is confirmed by the fact, that carburetted hydrogen, formed at the bottom of stagnant pools, is never accompanied by carbonic oxide, CO, but always by carbonic acid, CO_2.

Fig. 81.



This gas may also be obtained by decomposing acetate of potash in a retort, with an equivalent proportion of caustic barytes: (*Johnston.*) or by passing the vapour of alcohol, through a red-hot porcelain tube, though by this process it is not pure. It is the principal constituent of coal gas, and when free from all impurities it is tasteless and nearly inodorous, and has neither acid nor alkaline properties. Water, according to Dr. Henry, absorbs about $\frac{1}{60}$th of its volume. It is highly inflammable, burning with a yellow flame, and with a much stronger light than is occasioned by hydrogen gas. It is a very stable compound, though, when passed through a tube heated to whiteness, it is decomposed, being resolved into carbon and hydrogen. When mixed with twice its bulk of oxygen gas it detonates powerfully, either by the electric spark or the contact of flame; 100 measures are thus found to yield 100 measures of carbonic acid, and water is at the same time formed. When mixed with chlorine, the two gases do not act upon each other when quite dry, even when exposed to the direct solar rays, but if moist, decomposition follows the exposure of the mixture to sunshine, and carbonic and hydrochloric acids are produced.

Olefiant gas; $C_4 H_4$. This gas was discovered in 1796, by some associated Dutch Chemists, who gave it its name from the property which it possesses of forming an oily looking compound with chlorine. Olefiant gas is prepared by a very interesting and instructive reaction. Into a capacious retort, one measure of strong alcohol and three measures of oil of vitriol are poured, and the mixture immediately heated by means of an Argand lamp; effervescence ensues, and olefiant gas passes over in considerable abundance, mixed however with ether at the commencement of the process, which condenses spontaneously, and with sulphurous and carbonic acids, which may be separated by allowing the gas to stream through lime water or liquid potassa, before it is collected over either the mercurial or hydro-pneumatic trough. As the operation proceeds, the mixture gets darker in colour, and eventually becomes quite black. The formation of olefiant gas in this process, is owing to the strong affinity of sulphuric acid for water. Alcohol is composed of oxygen, hydrogen, and carbon, and from the proportion of its elements, it is inferred to be a compound of one equivalent of olefiant gas united to one equivalent of water; now the sulphuric acid combines with this equivalent of water, and the olefiant gas is set free. Other complicated changes ensue, and the products are numerous, and towards the close of the operation, carbonic acid is pretty freely formed, and charcoal deposited in considerable abundance.

Pure olefiant gas is a colourless elastic fluid, having no taste and very little odour. Water absorbs about one-eighth of its volume. Its specific gravity is about ·980, and 100 cubic inches weigh about 30 grains. It is inflammable, burning slowly, and with the emission of a beautiful dense white light, very superior to that of carburetted hydrogen. When mixed with oxygen it detonates very loudly and forcibly, and if fired by electricity in the eudiometer, small quantities should be employed, or there would be a danger of bursting the instrument. One volume requires three volumes of pure oxygen, and affords two volumes of carbonic acid; but to ensure perfect combustion, it should be mixed with five times its bulk of oxygen; for if too little of the latter be employed, charcoal is apt to be precipitated unburned, and it must be remembered that the purest oxygen obtainable, even from chlorate of potash, rarely contains more than from 90 to 94 per cent of pure oxygen. An excess of oxygen does no harm, but remains in the mixture; now, as for every measure of olefiant gas, three measures of oxygen disappear, and two measures of carbonic acid are produced, the composition of olefiant gas is easily found. The two measures of carbonic acid contain two measures of vapour of carbon, which must have been present in the olefiant gas, and two measures of oxygen. Two-thirds of the oxygen which disappeared are thus accounted for, the remaining third must have combined with two measures of hydrogen, to form water, and this hydrogen must likewise have been present in the olefiant gas. It has therefore been assumed that this gas consists of eight volumes of carbon vapour and eight of hydrogen, condensed into four volumes.

The following beautiful experiment renders the presence of a large quantity of carbon in olefiant gas strikingly apparent. Into a glass tube, three feet long and two inches in diameter, filled with warm water, introduce two-thirds of its capacity of chlorine, and fill it up with olefiant gas. Invert the tube, laying a glass plate over the mouth; now apply a light to the mouth, and a deep red flame will be seen gradually to descend through the mixture, leaving behind it a dense black cloud of carbon, part of which will rise into the atmosphere, and part be deposited on the sides of the tube; fumes of muriatic acid are at the same time formed, and a peculiar aromatic odour is evolved.

If, instead of inflaming the mixture of these two gases, they are allowed to remain at rest, a very different action ensues. The chlorine enters into combination with the olefiant gas, and a yellow liquid like oil is generated. This singular substance is called *chloric ether*, or *chloride of hydrocarbon*. It may be collected in quantity, by mixing large volumes of chlorine and olefiant gas, taking care to have an excess of the latter, and it may be purified by washing it with water, and then distilling it from dry chloride of calcium. It has an agreeable etherial smell, and not an unpleasant taste. It boils at 148°, and may be distilled without alteration. To obtain it perfectly pure, it should be agitated successively with solution of potassa, pure water, and strong sulphuric acid, and then redistilled. When its vapour is passed through a red-hot porcelain tube, it is resolved into charcoal, light carburetted hydrogen, and hydrochloric acid gas.

When olefiant gas is mixed with eight or nine times its bulk of chlorine, and exposed to the sun's rays, at first the fluid chloride of hydrocarbon is formed, and this, by continuing the exposure is changed into a crystalline compound of carbon and chlorine, discovered by Faraday, and called *perchloride of carbon*. The moment that chlorine is added to olefiant gas over water, a diminution ensues, and this effect takes place, even when the vessel is shaded from the light by an opaque cover. On this, a very excellent method of separating olefiant from light carburetted hydrogen gas was founded by Dr. Henry, a detailed account of which will be given in our next lecture on the analysis of gases.

Olefiant gas unites with iodine and bromine. Iodide of hydrocarbon was formed by Faraday, by exposing olefiant gas and iodine to the direct rays of the sun: it is a white, solid, crystalline body, having a sweet taste and aromatic odour. It burns if held in the flame of a spirit lamp, with the evolution of iodine and some hydriodic acid.

Bromide of hydrocarbon was formed by Serullas, by adding one part of iodide of hydrocarbon to two parts of bromine, contained in a glass tube. Instantaneous reaction ensued, attended with the disengagement of heat and a hissing noise, and two compounds, the bromide of iodine and a liquid bromide of hydrocarbon were generated.

Bromide of hydrocarbon is a colourless volatile liquid, of an ethereal odour and of an exceedingly sweet taste, which it communicates to water, in which it is soluble; both of these compounds appear to be composed of one equivalent of each of its constituents.

Coal gas. Before describing this important compound, it will be proper to direct attention to the substance from which it is derived.

Coal. This most valuable of all the mineral substances, from which Britain derives her prosperity, and which may be regarded as the main support of the whole system of British production, is found in beds or strata in that group of the secondary rocks which includes the red sandstone and mountain limestone formations, and which is commonly called the *carboniferous group or coal measures;* and also sometimes from the peculiarities of their deposition, *coal basins* and *coal fields.* Geologists appear to be nearly unanimous on these three points respecting the origin of coal. 1st. That it is exclusively of *vegetable* origin, having probably been formed from the destruction of immense forests. 2nd. That similar formations are not improbably going on at the present time in certain parts of the sea, since it is well known that prodigious quantities of timber are continually drifting, by some of the great rivers of the world, into the ocean; and 3rd; that the climate of these parts of Europe, judging from the nature of the preserved vegetables, was not merely tropical, but ultra-tropical. It may also be inferred that these strata were deposited in the neighbourhood, and probably upon the verge of extensive tracts of dry land; for the trees that are found in coal strata, are often like those of our submarine forests, or of the Portland dirt bed, as far as position goes; and finally, the deposits of coal appear afterwards to have been elevated, and often singularly dislocated and contorted by forces acting from below, and probably of a volcanic nature. Every thing, observes Mr.

Fairholme,* connected with coal, seems to tend to prove its vegetable origin. Its immediate and invariable contact with stony strata, in which vegetable substances of every size, from the minutest grasses to the tallest trees, are so beautifully displayed; its bituminous character; its colour; its combustible nature, which is found in no other mineral; its frequently displaying a distinct lignèous texture; and in corroboration of these, the conclusive experiments and reasoning of many able chemists;—all tend distinctly to prove that the arguments formerly maintained by some geologists, who considered it as an original chemical formation, entirely unconnected with a vegetable origin, may now be classed, amongst various other concessions which have of late years been made, to the Wernerian theory.

If we suppose coal to have been produced from woody fibre, it would not be difficult to show how the change has been effected. The process must have been one of decay and putrefaction. When damp saw-dust is confined in a close vessel, it undergoes the same change as when air is admitted, and is converted into a substance similar to that found in the interior of trunks of dead trees. Now, according to the analyses of Thenard and Gay Lussac, 100 parts of oak wood, dried at 212°, from which all soluble substances had been extracted by means of water and alcohol, yielded 52·53 parts of carbon, and 47·47 parts of oxygen and hydrogen, in the same proportion as they are contained in water, and 100 parts of white decayed wood, 47·11 carbon, 6·31 hydrogen, 45·31 oxygen, and 1·27 ashes. These numbers lead to the formula—

FOR OAK WOOD.	FOR DECAYED WOOD.
$C_{36} H_{22} O_{22}$	$C_{33} H_{27} O_{24}$

If there be added to the formula for oak wood the elements of 5 atoms of water and two atoms of oxygen, and if 3

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* See his remarks on the nature of coal, in the 3rd volume of the London and Edinburgh Phil: Mag: page 245.

atoms of carbonic acid be deducted, the exact expression for decayed wood will be obtained, thus :—

Oak wood	$C_{36}\ H_{22}\ O_{22}$
5 atoms of water	$H_5\ O_5$
2 atoms of oxygen	O_3
	$C_{36}\ H_{27}\ O_{30}$
Deduct 3 atoms of carb. acid.......	$C_3\ \ O_6$
	$C_{33}\ H_{27}\ O_{24}$

according to this view, the change of woody fibre into white mouldered wood, consists in the combination of the elements of water with the wood;—the absorption of a certain quantity of oxygen, and the disengagement of carbonic acid.

Wood coal is probably produced by the same sort of decomposition. Of two samples, analyzed in Liebig's laboratory, one was found to be composed of $C_{33}\ H_{21}\ O_{16}$, and the other, which was taken from a depth of 120 feet, of $C_{33}\ H_{15}\ O_9$; now on comparing these formula with that of oak wood, we find that the elements of carbonic acid, hydrogen, and in the second specimen, the elements of water have been separated, but both show an excess of hydrogen and less oxygen than is necessary to form water with that hydrogen; and it further appears, from the diminution in the original *quantity* of hydrogen, that though at such considerable depths below the surface, the action of air was not entirely excluded.

From the frequent occurrence of springs of water, impregnated with carbonic acid, in the vicinity of the layers of wood coal, it is probable that the peculiar process by which the decomposition of extinct vegetables has been effected: viz.—a disengagement of carbonic acid from their substance is still going on, at great depths, in all the layers of wood coal. According to the analyses of Richardson and Regnault, the composition of combustible materials, in splint coal from Newcastle, and cannel coal from Lancashire, is expressed by the formula, $C_{24}\ H_{13}\ O$; on comparing this with the composition of woody fibre, we find the difference to consist in the removal of a certain quantity of *carburetted hydrogen* and carbonic acid: thus—

	$C_{36}H_{22}O_{22}$ = wood
3 atoms of carburetted hydrogen C_3H_6	
3 atoms of water............. H_3O_3	
9 atoms of carbonic acid....... C_9O_{18}	$C_{12}H_9O_{21}$
	$C_{24}H_{13}O$ = mineral coal.*

Now, carburetted hydrogen is known frequently to accompany mineral coal, and various *hydrocarbons* are also known to be produced during its distillation. It seems clear then, that mineral coal is woody fibre in a still further advanced state of decay than in wood coal, it has lost more carbonic acid and more hydrogen; and should the putrefaction be extended still further, namely, till the whole of its hydrogen is removed, it would then be converted into *anthracite*.

In some coal-fields there are appearances which justify the term *coal basin*, indeed, Mr. Fairholme says, that there is no exception to the fact of their exhibiting this form in any part of the world where coal has been found, any more than to the coal fields being *invariably* situated in similar districts. In forming however, an idea of those basin-shaped hollows, in which the vegetable deposits have taken place, we must not, he says, be misled by attaching to them a great regularity, or roundness of form: on the contrary, the coal basins are found to be as diversified in form, as the various lakes and valleys now existing on the present surface of the earth. We find in some places such basins, of not more than a mile in diameter, and which in the hills of the West Riding of Yorkshire, are termed *swilleys*, filled, like the larger basins, with coal and its usual attendant strata. In other districts of greater extent, the basin obtains the name of a field, extending over many miles of country, but differing in no other material degree

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* Liebig. See his "Organic Chemistry, in its Applications to Agriculture."

from the basins already alluded to. These coal basins frequently dip as it were into a common centre, and consist of various beds of sandstone, shale, and coal irregularly stratified, and sometimes mixed with conglomerates, showing a mechanical origin.

That these deposits have taken place, and that the change of wood into coal has often been effected under great pressure, and often under pressure and heat, seems evident from the appearance of some of the vegetable masses, and also from the manner in which the carburetted hydrogen escapes in the form of *blowers* and eructations from the strata, as if pent up in their cavities under vast condensation, and even sometimes perhaps, in a liquid form.*

An opinion respecting the origin of coal, first advocated by De Luc, and more recently by Adolphe Brongniart, (the celebrated fossil botanist,) is, that coal beds have been extensive sheets of vegetable matter, resembling in that particular, *peat bogs*, which have, one after the other been submerged and covered by sand and silt. There are numerous facts in favour of this view, which has also been sanctioned by Mr. De la Beche, as upon the whole, more consistent with the phenomena presented by coal formations.

"In the present condition of the coal measures," remarks one of the most instructive geological writers, "we have opportunities of observing design, even where things are so disposed, as at first sight, apparently to preclude any such inference. The accumulation of vegetable matter, at a remote epoch in the history of the world, for the convenience and consumption of creatures which were long afterwards to exist upon its surface, must strike the least inquiring; but where the twisted, dislocated, upturned, and broken strata, so common in the coal districts, are before us, the design appears to the superficial observer to be frustrated, especially when the miner complains

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* See Brande's Dictionary of Science, Literature, and Art:—Articles Geology and Coal.

of them as interrupting, or even preventing his progress. So that this apparent confusion has sometimes been regarded as a bar to the ingenuity and industry of man in extracting the combustible so valuable and requisite. When, however, we contemplate the subject more closely, we find that these very irregularities and inconveniencies are in reality highly advantageous, for they often heave up seams of coal that would otherwise be beyond reach; and they perform the yet more important service of excluding the passage of subterraneous waters from one part of the workings to another; so that the miners in collieries, situated in one particular mass, have only to contend with the waters in it; whereas, if the strata were always unbroken and continuous, such would be the abundance of water flowing into the workings, that the utmost difficulty and expense would be incurred in proceeding, and it would often be necessary altogether to abandon the further extraction of the coal. The section of strata in Jarrow colliery, near Newcastle, shows how curiously they are sometimes fractured and dislocated: and in the coal measures at Little Haven, St. Bride's bay, Pembrokeshire, we have a good instance of their occasional contortions."

The following diagrams, *Figs*. 82 and 83, taken from Brande's Dictionary, represent a section of a coal basin, and the disturbance and dislocation of the strata by dykes or cross-courses. A A, in *Fig*. 82, are the dykes by which the shales and coal, B B B, are disturbed, and in *Fig*. 83, the seams of coal, B B, which in the first case was once continuous, has been dislocated by the intrusion of the dyke A.

Fig. 82.

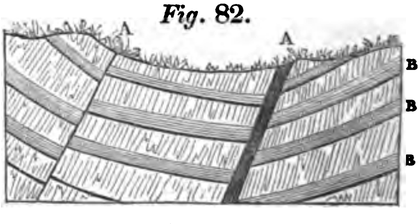
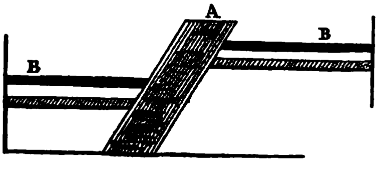


Fig. 83.



Though there may be many beds and seams of coal in one field, it is seldom that many of them are worked. They are generally of uniform thickness through a great extent, but are sometimes subject to irregularities. When less than two feet thick they are seldom worked to any great extent. The nature of the upper stratum or stony matter of the roof is very important; if compact, it is secure from falling and keeps out the water; if loose, the expense incurred in supporting it absorbs the profits of the coal. .

Coal, as an inflammable substance, appears to have been known to the Britons before the Romans visited this island, but owing to the abundance of wood, it was not used as a fuel. As population and civilization however advanced, when agriculture began to be studied, and the arts of civil life cultivated, then the working of coal became an object of importance; but it was not till the end of the twelfth century that it became an article of commerce.

The collieries of Great Britain are now upon the most extensive scale, and are of the first importance to the kingdom, both as regards its political and commercial interests; so much so, that it is evident, that without cheap coal, the manufactures of Great Britain could not be brought forward in competition with those of other nations of the world, where the price of labour is so much lower than in this country.

The great coal-field of Britain, which is composed of numerous subordinate coal-fields, crosses the island in a diagonal direction, the south boundary line extending from near the mouth of the river Humber, upon the east coast of England, to the south part of the Bristol channel on the west coast, and the north boundary line extending from the south side of the river Tay, in Scotland, westward by the south side of the Ochill mountains, to near Dumbarton, upon the river Clyde; within these boundary lines, North and South Wales are included. The area is about 260 miles in length, and on an average about 150 miles in breadth. Within these bounds all the chief coal-fields are found, upon which collieries have been established in Britain, and no coal-field of any consequence has been found, either to the north or south of the lines above mentioned, excepting some small patches of thin coals of inferior quality, and the coal-field of Brora, in Sutherlandshire, Scotland, which is far disjointed from any other coal-field. It is calculated, that many centuries must elapse before the supply of coal in Great Britain can be exhausted. The coal-fields of Durham and Northumberland alone, are estimated to furnish their present annual supply for more than 1700 years.

The annual consumption of coal throughout the British empire, is estimated at 28,575,000 tons. The coal trade gives occupation to nearly 200,000 persons. In 1838, the total quantity of coal shipped, was 7,190,433 tons; of which, from the Tyne and Wear, were 4,628,000; South Wales, 1,228,300; Whitehaven, 395,000 tons. The export was 2,449,417 tons, chiefly to Ireland, France, the Netherlands, Germany, Denmark, British America, and the United States. The imports into London, in 1831, amounted to 2,638,256 tons, brought by 7,500 vessels.—*Brande's Dictionary.*

The deepest coal mines of England are those of Northumberland and Durham, which are worked nearly 1000 feet below the surface. The thickest bed of coal, is said to be at Woodmill Hill colliery, in Staffordshire, and to exceed forty feet. From six to nine feet is the average thickness of the most productive seams.

There are three chemical varieties of coal. 1st. Brown coal. 2nd. Black, or common coal; and 3rd. Glance coal, or anthracite.

Brown coal is only imperfectly bitumenized, and is characterized by burning with a peculiar peaty odour. It is sometimes earthy, but the fibrous structure of the wood from which it is derived, is generally more or less distinct. In the mode of its combustion, as well as in its external appearance, it bears a considerable resemblance to half charred wood. It is found at Bovey, in Devonshire, and is used on the spot to heat the furnaces of a pottery, for which purpose it is admirably adapted from the clearness with which it burns; but the smell which it emits while burning, and the dust of its ashes, prevents its being employed in dwelling-houses. At Bovey, specimens are occasionally met with, having so exactly the appearance of wood, viz:—the fibres, knots, bark, &c., that it would be difficult, without touching it, to convince oneself that it is not *really* wood. This species of coal is likewise found in Iceland, where it is called *surterbrand*, and in several parts of the continent.

Black coal appears to be a compound of bitumen and charcoal, and according to the proportion of these two ingredients, its properties vary considerably. It shows no remains of the vegetables from which it has originated. The Wernerian arrangement divides black coal into six subdivisions, but Dr. Thomson proposes the following four only:—

1st. *Caking coal;* so called, because its fragments melt at a certain temperature, and unite into one mass. Such is the Newcastle and Manchester coal.

2nd. *Splint or splent coal;* which has received its name from the splintery appearance of its cross fracture. It has also been called hard coal, from the difficulty of breaking it. This is the sort best adapted for making coke, and extracting iron from its ores.

3rd. *Cherry coal.* This variety abounds near Glasgow and in Staffordshire. It has considerable lustre, both in its principal fracture which is slaty, and in its cross fracture, which is flat and conchoidal. It readily catches fire, and is consumed rapidly, burning with a clear yellow flame.

4th. *Cannel coal* is a very well characterized species. It is found of the best quality and in the greatest abundance, at Wigan, in Lancashire. Its great combustibility, and the vivid light which it emits, have occasioned its being sometimes substituted for candles. As it does not at all soil the fingers, and is easily turned by a lathe, it is made into snuff boxes, inkstands, and various trinkets. In Scotland it is known by the name of *Parrot coal.*

Dr. Thomson obtained the following results from the analysis of these four species of coal.

	Carbon.	Hydrogen.	Nitrogen.	Oxygen.	Total.
Caking coal	75·28	4·18	15·96	4·58	100
Splint coal......	75	6·25	6·25	12·50	100
Cherry coal.....	74·45	12·40	10·22	2·93	100
Cannel coal.....	64·72	21·56	13·72	0·00	100

The quantity of nitrogen given in this table is probably *greater*, and that of the oxygen *less* than the truth. Dr. Ure, in his analyses of splint and cannel coal, could find no nitrogen, but as *ammonia* is always one result of their distillation, it is fair to infer the existence of that element.

3rd. *Glance coal,* or *anthracite.* This differs from common coal, which it frequently accompanies, in containing no bituminous substances, and in not yielding inflammable gases by distillation. Its sole combustible ingredient is carbon, and consequently it burns without flame.

Coal gas. When coal is subjected to what chemists term *destructive distillation,* it yields a great variety of complicated products, and a carbonaceous residue, called *coke,* remains in the retort. The volatile substances are tar, acetic acid, water, hydrosulphuric acid, hydrosulphate and carbonate of ammonia, together with certain inflammable gases, consisting principally of a few well known compounds, mixed in different and variable proportions. In considering the nature of the products of the distillation of coal, they may be classed under three heads. 1st. The permanent gases: secondly, vapours which are condensible into the liquid or solid state by cooling; and thirdly, the fixed or residuary matter which remains in the retort.

The chief gaseous constituents are, light carburetted hydrogen and olefiant gas; but there are likewise found hydrogen, carbonic acid, carbonic oxide, and nitrogen: most of these gases are inflammable, but their illuminating power is very unequal. Thus, the carbonic oxide as well as the carbonic acid is positively hurtful, that is, more light would be emitted without them. The nitrogen, of course, from its negative properties, is of no service, and the hydrogen in burning, emits so feeble a light that its presence may also be considered prejudicial. The real illuminating agents are the carburets of hydrogen, and the degree of light emitted by these is dependent on the quantity of carbon which they contain. Thus, olefiant gas illuminates much more powerfully than light carburetted hydrogen, and for the same reason, the dense vapour of etherine* emits a far greater quantity of light than an equal volume of olefiant gas.

It thus becomes obvious, that the comparative illuminating power of different kinds of coal and oil gas, may be estimated by determining the relative quantities of the denser carburets of hydrogen which enter into their composition. The method of performing this will be given in our next lecture, on gaseous analysis. We will now proceed to describe the apparatus employed in effecting the destructive distillation of coal;—for separating the solid and liquid products;—and for rendering it sufficiently pure to be applied to the purposes of illumination.

The coal is subjected to heat in *retorts*, or cast-iron cylinders, which are usually about 7 ft. 6 in. long, and 1 foot in diameter, and in the shape of an arched cylinder: from five to eight of them are set in brick-work, so as to be heated red-hot by one fire. Each retort has what is called a mouth-piece, which projects from the front of the brick-work, and from which

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* A highly volatile liquid, first examined by Faraday, and obtained by subjecting oil gas to a pressure equal to 30 atmospheres.

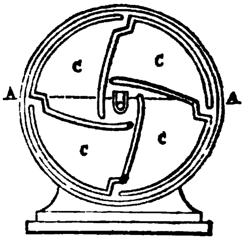
there rises an upright pipe, about 12 feet high and 3 or 4 inches in diameter, which carries the products of distillation into the hydraulic main. Each retort has a cover, which is kept in its place by hold-fast screws, and rendered air-tight by lime luting. The hydraulic main is a long horizontal pipe, 12 or 14 inches in diameter, into which the dip-pipe of each retort enters, so as to be filled up by the fluid which fills the lower half of the main, and which is allowed to run off at that level. This fluid is of a very complicated nature, but tar, and ammoniacal liquor are the terms applied to its chief component parts; these being condensed in the hydraulic main, serve to seal the ends of the dip pipes, and are constantly running off into what are termed the tar vessels. Those products of the distillation, which are not thus in the first place condensed, are conveyed by a pipe continued from the hydraulic main, through a series of tubes or other contrivances so as to expose a large and cold surface. This part of the apparatus is called the *condenser;* in it, the more volatile vapours are brought to the liquid state, and are collected in an appropriate receiver. The uncondensed gases then pass on to the *purifiers,* which are vessels so constructed as to expose them to the action of a very large surface of lime and water, or of slaked lime, by which carbonic acid and sulphuretted hydrogen are abstracted, and thence the gas, now purified, passes into the *gasometers,* where it is stored up for use.

In the largest gas manufactories of London, from 500 to 600 retorts are employed, each of which is charged four times a day with two bushels of coal. They are ranged in rows on either side of the retort-house, and the flues from their respective furnaces are generally so arranged as to meet in one central chimney; but as coke is the usual fuel used for heating the retorts, there is commonly little or no smoke. Each chaldron of coals submitted to distillation, yields on an average 24 gallons of tar, ammoniacal liquor, and other condensible products, and 12,000 cubic feet of purified gas: while there remains in the retort a chaldron and a quarter of coke. To purify these 12,000 cubic feet of gas, there is required about one bushel of lime, which after its removal from the purifying vessels, is used for making mortar, luting the retorts, and other similar purposes, while the fetid liquor which runs from it, is transferred to the ashpits of the furnaces, where it is consumed by evaporation, its vapour passing through the fire, and tending materially to preserve the bars of the furnaces by keeping them cool.

In a well-conducted gas establishment, two men are required for the management of sixteen retorts, which are charged four times in the 24 hours; during which time the retorts are kept perpetually at work, so that relays of men are required for the night-work. In small gas works, the *agitators* of the *purifiers* are worked by hand; but in the larger establishments, there are usually one or more steam-engines on the premises for this purpose; and for pumping water, lifting coals, and other heavy work.

Besides the apparatus already adverted to, which are essential to the manufacture; there are several other ingenious and beautiful contrivances in the larger gas works, which may be considered as auxiliaries. One of these is the *station meter:* a large instrument, through which the whole of the gas passes in its way to the gasometers, and by which its volume is registered, so that the quantity made during any given time can be immediately ascertained, and the weekly, monthly, or annual production accurately determined. The gas meter was invented by Mr. Clegg, formerly engineer to the Chartered Gas Company. It consists of a hollow cylinder, which is made to revolve upon its axis by the ingress and egress of gas into and from the compartments into which it is divided: the cylinder being partly immersed in water, and by a train of wheel-work connected with it, the number of its revolutions in a given time is registered, and the number of cubic feet of gas which traverse it in a minute, hour, day or year, shown upon separate dials.

Fig. 84.



The annexed section, *Fig.* 84, may perhaps, sufficiently explain the construction of this very ingenious instrument. A A, represents an outside cast-metal case, of a flat cylindrical form. Into the back of this casing a pipe is led from the gasometer, the opening of which turns up within the case; on the knee of this point a pivot is fixed, exactly opposite to another, fastened into the front face of the case, on which pivots a sort of drum, C C C C revolves. This drum carries vanes, which open at the circumference, as shown in the figure. The instrument is filled with water, up to the height marked by the dotted line, through an orifice in the side of the vessel in which a plug is fitted. The gas enters by the pipe A, and fills the cavity above with gas, causing the drum C C C C, to revolve from right to left, while the gas escapes from an orifice on the other side, into the pipes to be consumed. The wheel-work is fixed upon the axis of the drum. Should there be too much water in the meter, it is clear that the index will point out falsely, as there will be less consumed than there is registered.

The invention of this instrument forms an important epoch in the history of gas manufacture; for it is now constructed upon any scale, and is applicable to any case of the consumption of gas; so that by having a meter in each house, of a size appropriate to the number of burners employed, the companies are enabled to sell their gas by measure, and have an unerring check upon the quantity which each instrument consumes.

Another beautiful contrivance, adopted in most of our gas works, is that by which the pressure upon the gas in the main and service pipes is adjusted, so that when a number of burners are suddenly extinguished or suddenly lighted in any part of the district which is supplied, there shall be an intimation of the change at the works, so as to prevent either excess or deficiency of supply: or in other words, to prevent the lights which remain from flaring up on the one hand, or being nearly or quite extinguished on the other. This is effected by a small and nicely-adjusted gasometer, connected with the service main, and which, by its rising or falling by diminished or increased pressure of the gas within the main, points out the necessity of opening or shutting the valve by which the gas is admitted from the gasometers to a greater or less extent. This small regulating gasometer has a vertical rod connected with it, which carries a pencil made to bear on a paper cylinder properly ruled and divided, and which is made to rotate upon its axis by communication with a timepiece, so that every change of pressure which takes place, during the night for instance, is shown by the aberration of the line. This ingenious apparatus was the invention of Mr. Crossley.

The following particulars* may serve to give an idea of the quantity of gas annually consumed in London; of the quantity of coal required for its production; and of the general economy of this mode of illumination. It must also be borne in mind, that gas is an article of increasing consumption; and that in proportion as attention is paid to its manufacture, and more especially to the *fittings* as they are called;—that is, to the pipes, cocks, burners, and other arrangements required for its use and distribution in houses,—it will become more generally adopted in private dwellings, so as in all probability to supersede, ere long, all other sources of artificial light. Nor are the attempts which have been made to employ it as a source of *heat* unimportant. Gas stoves, though hitherto made upon very erroneous principles, are not without their advantages; and it has been promisingly applied to some of the operations of cooking.

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* See Brande's Dictionary of Science, Literature, and Art: article—Gas illumination.

The oldest of the London gas works, is the establishment belonging to the original Chartered Company. They have three stations; the largest situated in Peter street, Westminster; the second in Brick lane, St. Luke's; and the third in Curtain road, Shoreditch. This Company consumes annually 50,000 chaldrons of coal; the produce of which, in gas, may be estimated at about six hundred million cubic feet, or about eighteen million seven hundred and fifty thousand pounds *weight* of gas. It may be assumed that each chaldron of coals weighs 2880 lbs., and yields an average produce of 12,000 cubic feet of purified gas. The prime cost of gas is about four or five shillings per 1000 cubic feet; the usual retail price is from seven to ten shillings per 1000 cubic feet.

The Chartered Company probably supply about a fifth part of the whole of the gas consumed in London and the suburbs; so that the total annual consumption of coal, employed for this important manufacture in the London district only, probably exceeds two hundred and fifty thousand chaldrons, and the quantity of gas produced for the supply of this district, amounts annually to three thousand million cubic feet. The weight of this quantity of gas exceeds 75 millions of pounds, and the light produced by its combustion, may be considered as equivalent to that which would be obtained by the combustion of 160 millions of pounds of mould candles of six to the pound.

The operations of the London Gas Light Company, which was established in 1833, are on a scale of great magnitude. This Company was called into existence by the dissatisfaction which existed among gas consumers, at the defective supply both in quantity and quality previously afforded. Their works, situated at Vauxhall, are not only the most powerful, but the most complete in arrangement of any in the world. From this point, their mains ramify to a prodigious extent in Middlesex as well as Surrey, and by the admirable mode in which they are laid, aided by the power of their works, they are enabled to supply gas at Highgate hill, (several miles off,) with the same precision and in the same abundance as at Vauxhall. The extent of their pipes exceed 150 miles.

The œconomy of gas-illumination may be judged of by examining the value of the products of distillation of a chaldron of coals, the average cost of which may be considered as 25*s*. It should afford

	£.	*s.*	*d.*
1¼ chaldron of coke, at 13*s*.	0	16	3
24 gallons of tar, ammoniacal liquor, &c.	0	2	0
12000 cubic feet of gas, at 10*s*. per 1000 c. f.	6	0	0
	£6	18	3

These products are taken nearly at their lowest value, but they afford ample grounds for showing the advantage of gas-illumination, not merely for public purposes, but also in private establishments. It appears, that where about one hundred lights are required, a coal-gas apparatus will be found profitable.

	PER HOUR. *s.*	*d.*
The cost of a lamp, fed by gas, and giving the light of seven candles, will be	0	0¾
Of Argand's lamp, with spermaceti oil	0	3
Mould-candles	0	3½
*Wax-candles	1	2

The following table by Dr. Ure, shows the relative intensities of light afforded by the combustion of different candles.

Number in a pound.	Duration of a Candle.	Weight in Grains.	Combustion per hour: Grains.	Proportion of Light.	Œconomy of Light.	Candles equal to 1 Argand.
10 mould	5h.9m.	682	132	12¼	68	5·7
10 dip	4·36	672	150	13	65½	5·25
8 mould	6·31	856	132	10½	59½	6·6
6 mould	7·2½	1160	163	14¾	66	5
4 mould	9·36	1787	186	20¼	80	5·
Argand oil flame	..	..	512	69·4	100	..

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* Brande's Chemistry.

A pint of the best sperm oil, weighing about 13 ounces, burns in a well-trimmed Argand lamp about 10 hours.

Ignition. The commencement of ignition, or rather of incandescence, which is a better term, (as *ignition* may be confounded with the commencement of a totally different process, that of combustion,) may be placed at about 800° Fahrenheit. Sir Isaac Newton calculated the temperature at which iron begins to shine in the dark, to be 635°, but we know it must be much higher than this, because mercury is quite invisible at its boiling temperature, which is 632°. Daniell measured with his metallic pyrometer, the lowest point at which heated iron appears red-hot in *day light,* and found it to be 980° F. but antimony is distinctly luminous at its melting point, 810°, and it was shown by Davy, that fusible metal becomes luminous at 812°; so we cannot be far wrong if we place the commencement of ignition at 800°, a full red-heat at 1200°, and an orange heat at 1650°.

It is not surprising that there should be such uncertainty attending the exact temperature at which incandescence commences, when it is considered, that it is to the evidence of sight alone to which we have to appeal; and this is a very imperfect measure of illumination, as similarly illuminated objects, convey to different individuals very different ideas of brightness. Let two pieces of white paper be differently illuminated by common candles: let one be exposed to the light of a single candle, and the other to the light of ten candles, and let these be viewed by any number of individuals, it will be found that no two will agree in their estimates of the relative degree of illumination.* If, then, the eye be so imperfect a judge of the degree of illumination, it is extremely probable, that when the illumination becomes so faint as to be barely perceptible, it will begin to be perceived by different persons when it arrives at different degrees of intensity. It is extremely probable, if not certain, that the same object placed

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* Herschell on Light.

in a dark room, will be pronounced to be luminous by one person, and not so by another; and it is absolutely certain that an object may be luminous to the eyes of certain animals when it is perfectly invisible to the human eye. Sight, therefore, is by no means a certain test of the presence of light; and consequently, is an extremely inadequate means of determining the commencement of incandescence. If, however, incandescence be defined to be, the commencement of that state in which, whether light be actually emitted or not, sufficient light is emitted sensibly to affect the human eye; then the temperature of incipient incandescence must be taken as the average or mean of the results given by different observers.*

It is not easy to ascertain the degree of heat produced by the *direct* rays of the sun, because it is apt to be dissipated as fast as it accumulates. M. de Saussure made a little box, lined with fine dry cork, the surface of which was charred, to make it black and spongy, in order that it might absorb the greatest possible quantity of the sun's rays, and be as bad a conductor of caloric as possible. It was covered with a thin glass plate. When this box was set in the sun's rays, a thermometer laid in the bottom of it, rose in a few minutes to 221°, while the temperature of the atmosphere was only 75°. Professor Robison constructed an apparatus of the same kind, employing three very thin vessels of flint glass, which transmit more heat than any of the other species of glass. They were of the same shape, arched above, with an interval of $\frac{1}{8}$ of an inch between them. They were set on a cork base, prepared like Saussure's, and placed on down, contained in a pasteboard cylinder. With this apparatus, the thermometer often rose on a clear summer day to 230°, and once to 237°. Even when set before a bright fire, the thermometer rose to 212°†. But when the rays of the sun are concentrated by a burning glass,

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* Lardner on Heat.—Page 342.

† See Black's Lectures. 547.

they are capable of setting fire to combustibles with the greatest ease, and even of producing a temperature at least as great, if not greater than what can be produced by the most violent and best conducted fires. Lavoisier, by means of a powerful burning-glass, not only melted gold, but actually caused it to evaporate, for a piece of silver, placed at some height above the gold, was sensibly gilded. The utmost heat of a glass-house furnace, acting on gold for a *month*, produced no sensible evaporation.

The light of the moon, though concentrated by the most powerful burning glass, is incapable of raising the temperature of the most delicate thermometer. M. de la Hire, collected the rays of the full moon, when in meridian, by means of a burning-glass, 35 inches in diameter, and made them fall on the bulb of a delicate air thermometer. No effect was produced, though the lunar rays, by this glass, were concentrated 306 times.* Professor Forbes concentrated the moon's light by a lens, 30 inches in diameter; its focal distance being about 41 inches, and having a power of concentration exceeding 6000 times. The image of the moon, which was only eighteen hours past full, and less than two hours from the meridian, was brilliantly thrown by this lens on the extremity of a commodious thermo-pile, *Fig.* 29. Although the observations were made in the most unexceptionable manner, and (supposing that half the rays were reflected, dispersed, and absorbed,) though the light of the moon was concentrated 3000 times, not the slightest thermo-effect was produced. The whole sensitive extremity of the pile being larger than the moon's image, was not brought into action; but when their relative dimensions were compared, it was found that the direct light of the moon, did not probably produce sufficient heat to raise a thermometer *one three hundred thousandth part of a centigrade degree*, at least in this climate.†

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* Mem. Paris, 1705; p. 346.

† London and Edinburgh Phil: Mag: vol. vi. p. 140.

These facts do not, however, form exceptions to the general law, that when heat is accumulated in bodies to a certain amount, it causes them to emit light,—and that, on the other hand, when light is accumulated in them, it causes them to become hot. This is evident, when we consider the prodigious difference between the intensity of the solar and lunar rays.

It was shown by M. Bouguer, by a very simple and ingenious set of experiments, that the illuminating power of a solar ray, is 300,000 times greater than that of a lunar ray of the same size.* "Indeed," says Thomson, "we may satisfy ourselves by a very simple calculation, that this estimate of Bouguer, is not below the truth. During a part of every lunation, we have an opportunity of seeing the moon in the sky at the same time with the sun. If we compare the moon under such circumstances, with a white cloud, when any such happen to be in its neighbourhood, the brightness of the moon and the cloud, appear to the eye very nearly identical; so that the moon emits no more light than is emitted during the day by a white cloud of the same visual size. When the whole sky is covered with white clouds, the direct rays of the sun are intercepted; but the light of the day is very nearly the same as if the sky were unclouded and the sun shining. It follows from this, that the light emitted by the moon, is to that emitted by the sun, as the apparent size of the moon to that of the whole sky. Now the moon, when its usual diameter is at a maximum, does not cover one millionth part of the hemisphere of the sky. But let us take Bouguer's measurement, and let us admit that the direct rays of the sun are capable of elevating the thermometer 237°. The rays of the moon would only possess $\frac{1}{300000}$th part of this effect, or $\frac{1}{1250}$th part of a degree, so that when concentrated 306 times, the effect would scarcely amount to $\frac{1}{5}$th of a degree." But Dr. Thomson supposes that the light of the moon is, at least $\frac{1}{1000000}$ of times less intense than that of the sun; so that their heating

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* Mem. Paris, 1726; p. 12.

power, even when concentrated 306 times, could not amount to so much as $\frac{1}{20}$th of a degree.*

There are some bodies which appear to contain light as a constituent, and which, on their undergoing spontaneous decomposition they part with first. It has long been known, that different kinds of meat and fish, become luminous in the dark, just when putrefaction commences. This curious phœnomenon has been noticed in the whiting, the herring, and the mackerel.† If four drams of either of these be put into a phial, containing two ounces of sea water, or of pure water, holding in solution half a dram of common salt, or two drams of sulphate of magnesia, and if the phial be put into a dark place, a luminous ring will appear on the surface of the liquid within three days, and the whole liquid, when agitated, will become luminous, and continue in that state for some time. When these liquids are frozen the light disappears, but is again emitted as soon as they are thawed. A moderate temperature causes an increase in the luminous appearance, but a boiling heat extinguishes it altogether. This light produces no sensible effect on the thermometer.‡

It was shown by Beccaria and others, that there are many substances which become luminous after being exposed to light. This fact was discovered by carrying them instantly from light into a dark place; after a time they lose this property, but again recover it on being again exposed to light. We are indebted to Canton for some interesting experiments on this subject, and for the discovery of a composition which possesses the property of *phosphorescence* in a remarkable degree.§ He calcined some oyster shells in a good coal fire for half an hour, and then pounded and sifted the purest parts

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* Thomson on Heat and Electricity. p. 284.

† In vol. xii. p. 420, of the London and Edinburgh Phil: Mag: will be found an account of some observations and experiments, on the luminosity of the human subject after death, by Messrs. Cooper.

‡ See Thomson on Heat and Electricity. p. 288.

§ Phil: Trans: lviii.—327.

of them. Three parts of this powder were mixed with one of flowers of sulphur, and rammed into a crucible which was kept red-hot for an hour. The brightest parts of the mixture were then scraped off and kept for use in a dry and well-stopped phial. When this composition is exposed for a few seconds to the light, it becomes sufficiently luminous to enable a person to distinguish the hour on a watch by it. After some time it ceases to shine, but recovers this property on again being exposed to light. Dr. Higgins has added considerable improvements to the method of preparing Canton's pyrophorus. He stratifies the oyster shells and sulphur in a crucible, without pounding them; and after exposing them to a proper heat, they are put into phials furnished with ground-glass stoppers.

Heat and light are, therefore, evidently intimately connected with each other, and the conclusion may be drawn, that if a sufficient quantity of heat be supplied to any body, that body will at length become luminous; and therefore, that light is invariably a consequence of heat, when that heat attains a certain degree of intensity; the quantity of heat necessary for the production of light, differing, according to the nature of the body which contains that heat; those having a less specific heat, requiring a less supply of heat to render them luminous.

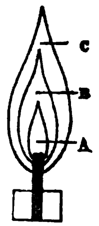
Flame. All the interesting phœnomena connected with flame, depend upon the gradual combustion of the various elastic compounds of carbon and hydrogen.

Sir H. Davy, defined flame to be the combustion of an explosive mixture of inflammable gas, or vapour with air, and when continuous, it is maintained by an uninterrupted flow of these elastic fluids into the atmosphere, with which they slowly mingle. The temperature of flame is, under certain circumstances, very intense, and not at all dependent on the degree of light emitted; perhaps, the purest flame which we can exhibit, is that of hydrogen gas, the illuminating power of which, is well-known to be exceedingly feeble; nevertheless, a piece of fine platina wire, becomes immediately white hot when held in it, and other metals are generally either melted or burned.

That the temperature of flame must be very high, considering it to be luminous gaseous matter, is proved by the fact, that gold will become red-hot in heated air, though no appearance of luminosity can be perceived in the air itself. Mr. Wedgewood took an earthenware tube, bent so in the middle that it could be sunk and make several turns in a large crucible filled with sand. To one end of this tube was fixed a pair of bellows; at the other end was a globular vessel, in which was a passage furnished with a valve, to allow air to pass out but none to enter. There was another opening in the globular vessel filled with glass, that one might see what was going on within. The crucible was put into a fire; and after the sand had become red-hot, air was blown through the earthen tube by means of the bellows. This air, after passing through the red-hot sand, came into the globular vessel. It did not shine; but when a piece of gold wire was hung at that part of the vessel where the earthenware tube entered, it became luminous; a proof that though the air was not luminous, it had been hot enough to raise other bodies to the shining temperature.

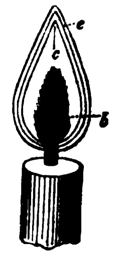
The nature of flame may be learned, by observing with attention the flame of a candle. It will be found to consist of three parts, as shown in *Fig.* 85. A, is the cone of vaporized combustible; B, the sphere of partial combustion; C, the sphere of complete combustion. When the candle is first lighted, a sufficient degree of heat is produced to liquefy the tallow, which rises in the wick by capillary attraction. It is there converted into vapour, and meeting with the oxygen of the atmosphere, undergoes decomposition. It is the hydrogen of the tallow or wax that principally burns in

Fig. 85.



the sphere B, while the carbon is rendered white-hot by the combustion, and is deposited:—upon this deposit of carbon the light entirely depends, and hence, luminous flame has justly been described by Davy, as always containing ***solid matter, heated to whiteness.*** The reason that the carbon does not combine with oxygen in B, is because the supply of air is limited, and hydrogen having a stronger affinity for oxygen than carbon, enters first into combination with that element. In the sphere B, there is consequently excess of inflammable matter, and it is often referred to as the deoxidizing or reducing flame; it takes oxygen from some metallic oxides, as arsenious acid and litharge, and developes their metals. The combustion in B then is incomplete, and it is in the exterior cone C, that the deposited carbon meets with abundance of oxygen to effect its entire consumption. This sphere contains excess of oxygen, and as its properties are, therefore, exactly the reverse of those of B, it is called the *oxidizing flame.* In *Fig.* 86, a more complete view of these parts of flame is presented; the dark part, *b*, is the magazine of inflammable vapour; *c*, is the luminous part, covering it like a mantle; and *e*, is the thin and slightly luminous covering where the oxidizing process is complete. Every person who has looked attentively at the flame of a candle, must have remarked that the lower part is *blue;* this arises from the cooling influence of the current of air, which enters the flame at this part, and is characteristic of carbonic oxide. It is very easy to demonstrate the nature of the chemical processes which are going on in flame. On presenting a piece of polished steel, as a pair of bright snuffers, to the side of the flame, about half an inch from it, it will speedily become covered with precipitated moisture, showing that water is formed and projected from all sides of the flame; and on presenting a drop of clear lime-water on the end of a glass rod, it will

Fig. 86.



very soon become milky, indicating the formation of carbonic acid.

Thus it appears, that flame is a superficial envelop of luminous gaseous matter, the interior of which contains no oxygen. By bringing a piece of thin glass down upon a flame, its structure is seen very clearly, and by bringing a thin sheet of platinum foil down upon the flame of a large spirit-lamp, and thus truncating it, a red-hot ring will appear upon the metal coincident with the edge of the flame, and testifying by its dark centre to the coldness of the interior. That the interior contains no oxygen is proved by plunging a piece of ignited phosphorus, in a metallic spoon, into the body of a large flame; it will be instantly extinguished: and in a very satisfactory manner also, by making a ring of tow, about two inches in diameter, and a quarter of an inch thick, moistening it with spirits of wine and setting it on fire, having previously placed in the centre of the ring, a small piece of lighted wax taper, which will be extinguished the moment that it is enveloped by the flame of the burning alcohol.

That the quantity of light emitted by flames, is dependent on the incandescence of minute particles of solid matter, is shown by a variety of interesting experiments. Thus, on sifting some calcined magnesia through the flame of hydrogen gas, its luminosity is increased to a surprising degree; now we know that there is no chemical action going forward here, magnesia being in no way acted upon by hydrogen; the increase of light is evidently, therefore, caused solely by the presence of finely divided solid matter. To what is the intense light caused by the action of the oxy-hydrogen blowpipe on lime owing? Evidently, in a great measure, to the separation of minute particles of the earth in an incandescent state, as is proved by the fact, that the top of the lantern, used with the oxy-hydrogen microscope becomes, after a little use, covered with solid lime, in an unaltered state. To what are we to ascribe the very great difference in the intensity of the light, caused by the combustion of phosphorus in oxygen on the one hand, and in chlorine on the other? In the former case, the light emitted is so exceedingly brilliant as to be painful to behold for any length of time, but in the latter, the light is so feeble as hardly to be perceptible in the light of day. Did the degree of luminosity depend on the intensity of the chemical action, then the combustion of phosphorus in chlorine ought to emit the most light, since that substance takes fire and burns spontaneously in chlorine, which it does not do in oxygen. The real cause is, that in the one case there is produced, as the result of combustion, *phosphoric* acid, which, at the moment of its production, is a *solid*, in a fine state of division, while in the latter case, a *liquid* chloride of phosphorus is generated. The light of hydrogen is very feeble, because it is a simple and pure gaseous substance; that of olefiant gas is very brilliant, because it contains a large proportion of carbon. The combustion of spirits of wine produces carbonic acid and water, the light consequently is very feeble though the heat is very great. By holding a cold body, such as a knife-blade, in the flame of a spirit-lamp, it will not even be stained, but if it be held in the luminous part, c, of the flame of a candle, it will instantly become covered with carbon, from which, by its conducting power, it abstracts the temperature necessary for the support of combustion. The luminous property of flame then, depends on the separation of solid matter, and in all ordinary flames this solid matter is carbon, which first becomes white-hot, and is then consumed.

When sufficient heat is abstracted from a burning body it is extinguished; by blowing on the flame of a candle, the current of cold air lowers the temperature of the burning matter to such a degree that it can no longer continue burning; and when a piece of white-hot iron is exposed to the atmosphere, the nitrogen absorbs so much of its heat, that it cannot combine with the oxygen with sufficient avidity to exhibit the phœnomena of rapid combustion. The same is the case with gases, for when those mixtures which burn briskly are mixed with other gases in which that property does not reside, they become cooled down below the temperature necessary for their combination. Hydrogen gas requires a temperature of about 700° to be enabled to combine with oxygen gas; and if both gases be mixed together and kindled, the burning parts communicate to the adjacent parts the temperature necessary for their combination. If the hydrogen be caused to burn in the atmosphere, it must create by its combustion, sufficient heat to raise the temperature of the nitrogen to 700°. By adding, however, more nitrogen to a mixture of hydrogen gas and atmospheric air, for instance, seven times as much as it naturally contains, then this excess of nitrogen absorbs so much heat that the oxygen and hydrogen no longer continue to burn. The same effect takes place by adding to one volume of a mixture of gases, consisting of one volume of oxygen, and two volumes of hydrogen, eight volumes of oxygen, or nine volumes of nitrogen gas. Of carbonic acid it is only necessary to add half as much. Phosphorus, on the other hand, which combines at common temperatures with oxygen gas, abstracts the last trace of that principle from a mixture of gases.

It is possible to extinguish a flame by bringing close to it a large surface of a good conducting substance: a jet of burning gas will have its volume considerably diminished by bringing down upon it a thick cylinder of brass, and a small flame of hydrogen will be extinguished if a large mass of copper be held close to it though it do not actually touch the flame. If a stout metallic wire be held in a flame, a dark ring may be observed all round it, and it will never appear to touch it. A second wire held by the side of the first, would increase the dark space, and the dark rings would coalesce. By multiplying the number of wires, or holding in their place a piece of wire gauze, the flame will appear to be entirely cut off on the top. The cooled gases would, however, still flow on in their course, and might be rekindled upon their upper side. *Fig.*

87, exhibits the appearance of a flame on which a piece of wire gauze has been brought down; the gaseous matter passes through the net-work, but its temperature is so reduced that it cannot burn; but on applying a flame it may be rekindled, as shown in *Fig*. 88.

Fig. 87.

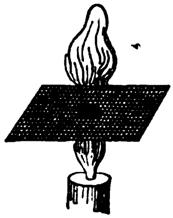
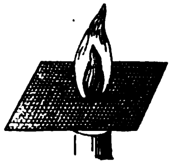
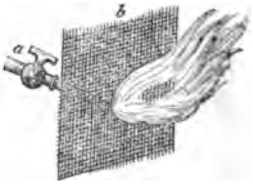


Fig. 88.



The gauze employed in these experiments should be made of copper wire, from $\frac{1}{40}$th to $\frac{1}{50}$th of an inch thick, and have at least 400 meshes to the square inch. By allowing light carburetted hydrogen gas (fire damp of coal mines,) to flow from a receiver, and holding before the cock, *a*, *Fig*. 89, such a kind of net, *b*, the stream of gas passes through the meshes, and burns when ignited *before* the netting, but not behind it; proving that the temperature of the flame is so reduced by the metal, that it cannot communicate to the gas on the other side of the gauze, the temperature necessary for the support of combustion. This property of metallic tissues to intercept flame was discovered by Sir H. Davy, and made by him the basis of one of the happiest and most intellectual inventions that falls to the lot of the scientific historian to record: viz.—the *safety lamp*.

Fig. 89.



The frequent tremendous explosions of the inflammable gas, spontaneously evolved in coal mines when it became mixed with atmospheric air and was accidentally inflamed, and the great destruction of human life consequent on such explosions, rendered it an object of the highest importance to devise some plan either for lighting the mines in such a way as to avoid the risk of inflaming the inflammable gas, or of destroying its explosive property. Several attempts were made to effect this. A mill for giving light by the collision of flint and steel was invented by Sir James Lowther, and used in the dangerous parts of many of the British collieries, but it was practically inconvenient, and sometimes occasioned explosions. In Flanders, amadou or fungus tinder was employed, but the light was too feeble to be of much use. In 1796, Humboldt invented a lamp which might be used in an explosive atmosphere, but it could only burn as long as the air it contained lasted. A lamp was contrived by Dr. Clanny, in 1813, but it required machinery to work it, and would not burn in explosive atmospheres. The subject was taken up by Davy, in 1815. He began by ascertaining the circumstances under which *fire damp* explodes, and the degree of its inflammability; he found that it required to be mixed with very large quantities of atmospheric air to produce explosion. When mixed with three or nearly four times its bulk of air, it burned quickly in the atmosphere and extinguished a taper; when mixed with between five and six times its volume of air, it exploded feebly; it exploded with most energy when mixed with seven or eight times its volume of air; and mixtures of fire damp and air retained their explosive powers when the proportions were one of gas to fourteen of air; when the air was in larger quantity, the flame of a taper was merely enlarged in the mixture, an effect which was still perceived in thirty parts of air to one of gas. *Davy also discovered that fire damp, or carburetted hydrogen was the *least* combustible of the inflammable gases; that it was not exploded or fired by red-hot charcoal or red-hot iron; and that it required iron to be white-hot, and itself in brilliant combustion for its inflammation. He found likewise, that the heat produced by it in combustion, was much less than that of most other inflammable gases, and hence in its explosion there was much less comparative expansion. In exploding a mixture, in a glass tube of one-fourth of an inch in diameter and a foot long, it was found that more

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* See Davy on the Safety-lamp, and Researches on Flame.

than a second was required before the flame reached from one end to the other; and that in tubes of one-seventh of an inch in diameter, explosive mixtures could not be fired when they were opened in the atmosphere; and that metallic tubes prevented explosion better than glass tubes. In reasoning upon these various phœnomena, it occurred to Davy, that as a considerable heat was required for the inflammation of fire-damp, and as it produced in burning, comparatively a *small degree* of heat, the effect of carbonic acid and azote, and of the surfaces of small tubes in preventing its explosion, depended upon their *cooling powers*: upon their lowering the temperature of the exploding mixture so much that it was no longer sufficient for its continuous inflammation. This idea led to an immediate result,—the possibility of constructing a lamp in which the cooling powers of the azote or carbonic acid formed by combustion, or the cooling powers of the apertures, through which the air entered or made its exit, should prevent the communication of explosion. A variety of lamps were constructed, all of which proved the correctness of the principle, and the conclusion was finally arrived at,—that a *metallic tissue*, however thin and fine, of which the apertures filled more space than the cooling surface, so as to be permeable to air and light, offered a perfect barrier to explosion, from the force being divided between, and the heat communicated to an immense number of surfaces, and a lamp was made in which the light was surrounded entirely by wire gauze, the same tissue being made to feed the flame with air and emit light. This lamp was found to be *safe*, for when it was plunged into an explosive mixture, Davy had the great satisfaction of perceiving the whole cylinder become quietly and gradually filled with flame, and the upper part get red-hot *without an explosion being produced.* The lamp was further protected by increasing the cooling surface in the top, and its efficacy further tested by placing it in a large receiver, through which there was a current of air, and, by means of a gasometer, filled with coal-gas, the current of air which passed into the lamp was made more or less explosive, and caused to change rapidly or slowly at pleasure, so as to produce all possible varieties of inflammable and explosive mixtures, and it was found, that iron-wire gauze, composed of wires from one-fortieth to one-sixtieth of an inch in diameter, and containing twenty-eight wires, or 784 apertures to the inch was safe under all circumstances, in atmospheres of this kind;—this material was, therefore adopted, and in January 1816, lamps, thus guarded, were introduced into coal mines.

Fig. 90.

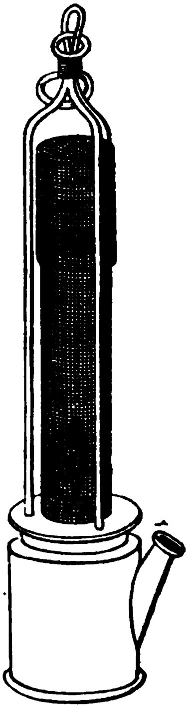

Fig. 90, represents the Safety-lamp. A cylinder of wire gauze, with a double top, is securely and carefully fastened down by doubling over to a brass rim, which screws on to the lamp. The whole is protected and rendered convenient for carrying by a frame and ring. If the cylinder be of twilled gauze, the wire should be at least of the thickness of one-fortieth of an inch, and of iron or copper, and 30 in the warp, and 16 or 18 in the weft to the square inch. If of plain wire gauze, the wire should not be less than one-sixtieth of an inch in thickness, and from 28 to 30 both warp and woof.*

When the miner is provided with one of these exquisite contrivances, he not only walks in safety and comfort, but is informed of the precise state of the atmosphere with which he is surrounded. The presence of fire-damp is indicated by the enlargement of the flame in the lamp, and if highly explosive, the mixture takes fire as soon as it has passed through the gauze and burns on its inner surface, while the light in

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* Davy on the Safety Lamp: p. 114, et. seq.

the centre of the lamp is extinguished. This should be a warning for the miner to withdraw; for though the flame may not be able to communicate with the explosive mixture outside of the lamp, as long as the texture of the gauze remains entire; nevertheless, the heat produced by the combustion would soon oxidate the wire, it would fall in pieces, and the enemy would triumph.

Since the introduction of the safety-lamp into coal-mines, those lamentable accidents which were so frequent, and which caused such deep distress amongst the families of the unfortunate sufferers, have become diminished to such an extent that the friends of humanity have good cause to venerate the name of that distinguished Chemist, to whose sagacity and perseverance this invaluable invention is due. Fatal accidents nevertheless, *have* occurred, even where the lamps have been employed; in many cases these have been traced to negligence on the part of the workmen, who, being perfectly ignorant of the principle of the lamp, and in the constant habit of witnessing its efficacy, use it carelessly, appearing to think that so long as they have the lamp in their hands they must be safe, paying no regard to the condition of the gauze, and not unfrequently trimming the wicks in the mine. But accidents also have occurred which cannot be traced to such sources; these are probably to be referred to the *conditions* under which the Lamp is safe. It has been shown by Messrs. Upton and Roberts, that if the lamp be exposed to a *current* of explosive mixture, the flame may pass so rapidly as not to be cooled below the point of ignition, and in that case, an accident might occur with a lamp, which would be safe in a calm atmosphere. These lamp-manufacturers have, therefore, constructed lamps, in which the gauze is surrounded with a glass cylinder, and the air allowed to enter solely at the bottom of the lamp, through wire gauze of extreme fineness, placed horizontally, and to escape at top by a similar contrivance. Lamps thus constructed, appear perfectly secure, and in the event of the fracture of the glass, they would be merely reduced to lamps of the usual construction; they give also more light, just as lamps in general burn better with a shade than without one.

The student is recommended to procure several squares of brass wire gauze of different degrees of fineness, and to try their interceptive powers with various flames; by thus experimenting for himself, he will learn more in five minutes than he would by reading for an hour. The following experiment is a very striking one. Place in the centre of a piece of rather fine gauze, about a foot square, a small piece of camphor; apply a light underneath the gauze; the vapour of the camphor will burn on the under side but the flame will not be communicated above.

LECTURE ELEVENTH.

ON THE ANALYSIS OF MIXED GASES: THE METALS: THEIR DISTINCTIVE CHARACTERS: THE METHODS OF SEPARATING THEM FROM EACH OTHER, AND OF QUANTITATIVELY ESTIMATING EACH.

FIRST:—GASES CONFINABLE BY MERCURY. SECOND:—GASES CONFINABLE BY WATER. GENERAL CHARACTERS OF THE DIFFERENT GASES, AND METHODS OF DISTINGUISHING THEM —HYDROGEN—ITS SEPARATION FROM OXYGEN AND NITROGEN—SEPARATION OF NITROGEN FROM OXYGEN—SEPARATION OF THE TWO GASEOUS COMPOUNDS OF CARBON AND HYDROGEN—ANALYSIS OF A MIXTURE OF THE CARBURETTED HYDROGENS, HYDROGEN, CARBONIC ACID, CARBONIC OXIDE, AND NITROGEN—SEPARATION OF HYDROGEN FROM PHOSPHORUS AND SULPHUR. THE METALS:—APPARATUS REQUIRED FOR GENERAL EXPERIMENTAL PURPOSES, VIZ:—FOR [illegible] TION.—FURNACES—KNIGHT'S, AIKIN'S.— [illegible] ENT OF A COMMON FIRE PLACE—KNIGHT'S [illegible] LANCES, FILTERING PAPER, ETC.—POTAS- [illegible] OF DISTINGUISHING IT WHEN IN SOLUTION, [illegible] TATIVELY ESTIMATING IT.—SODIUM—ME- [illegible] GUISHING IT—SEPARATION OF SODA FROM [illegible] IA—HOW DISTINGUISHED IN SOLUTION FROM [illegible] ALIES.—LITHIUM—ITS CHARACTERS—SE- [illegible] HIA FROM POTASH AND SODA.—BARIUM—

PREPARATION OF BARYTES—ITS QUANTITATIVE DETERMINATION—STRONTIUM—PREPARATION OF STRONTIA—ITS SEPARATION FROM BARYTES—CALCIUM—LIME—ITS EXTENSIVE DISTRIBUTION AND USES—QUANTITATIVE ESTIMATION OF LIME—ITS SEPARATION FROM BARYTES AND STRONTIA.—MAGNESIUM—ITS PREPARATION—MAGNESIA—ITS PREPARATION AND PROPERTIES—ITS QUANTITATIVE DETERMINATION—SEPARATION FROM LIME AND FROM THE ALKALIES.—ALUMINUM—ITS PREPARATION—EXTENSIVE DISTRIBUTION OF ALUMINA—ITS VARIOUS USES—METHOD OF OBTAINING PURE—METHOD OF DISTINGUISHING IT IN SOLUTION, AND OF QUANTITATIVELY ESTIMATING IT—SEPARATION FROM LIME AND MAGNESIA.—GLUCINUM—SEPARATION OF GLUCINA FROM ALUMINA.—YTTRIUM—SEPARATION OF YTTRIA FROM OTHER EARTHS.—CERIUM—LANTHANUM—THORIUM AND ZIRCONIUM.—MANGANESE—DIFFICULTY OF OBTAINING PURE—SOURCE AND USES OF PEROXIDE OF MANGANESE—COMPOUNDS OF MANGANESE WITH OXYGEN.—ŒCONOMICAL PREPARATION OF PURE SALTS OF MANGANESE—QUALITATIVE AND QUANTITATIVE ESTIMATION OF MANGANESE—SEPARATION FROM ALUMINA, MAGNESIA, LIME, ETC.—IRON—ITS GREAT VALUE AND EXTENSIVE DISTRIBUTION—PRINCIPAL SOURCES OF IRON—PROPERTIES—REDUCTION FROM ITS ORES—ITS COMBINATIONS WITH CARBON—WITH OXYGEN—FUCH'S METHOD OF EXAMINING IRON ORES—METHODS OF DISTINGUISHING IRON IN SOLUTION, AND OF QUANTITATIVELY ESTIMATING IT.—COBALT—ITS SOURCES AND CHARACTER—COMBINATIONS WITH OXYGEN—METHOD OF DISTINGUISHING IT—ITS PRECIPITANT.—NICKEL—ITS SOURCES AND PROPERTIES—ITS ALLOYS—COMPOUNDS WITH OXYGEN—TESTS FOR—ITS PRECIPITANT—SEPARATION FROM COBALT.—ZINC—ITS SOURCES AND PROPERTIES—ITS PRECIPITANT—SEPARATION FROM OXIDE OF IRON.—CADMIUM.—COPPER—ITS SOURCES AND PROPERTIES—COMPOUNDS WITH OXYGEN—TESTS FOR—ITS PRECIPITANT—SEPARATION FROM

IRON.—ALLOYS OF COPPER, BRASS, BRONZE, GUN-METAL, BELL-METAL, ETC.—ANALYSIS OF GERMAN SILVER.—LEAD—ITS SOURCES AND PROPERTIES—ITS COMPOUNDS WITH OXYGEN—TESTS FOR—QUANTITATIVE DETERMINATION OF—SEPARATION FROM NICKEL, COBALT, ZINC, IRON, MANGANESE, ETC.—BISMUTH—ITS SOURCES AND PROPERTIES—ITS COMPOUNDS WITH OXYGEN—TESTS FOR, AND QUANTITATIVE DETERMINATION OF—SEPARATION FROM LEAD.—TIN—ITS SOURCES, PROPERTIES, AND COMPOUNDS WITH OXYGEN—ITS COMPOUNDS WITH CHLORINE AND THEIR USES IN THE ARTS—ITS COMBINATION WITH SULPHUR—ALLOYS OF TIN—TESTS FOR AND QUANTITATIVE DETERMINATION OF.—TITANIUM—ITS PROPERTIES AND COMPOUNDS WITH OXYGEN—TESTS FOR—ITS PRECIPITANT, ETC.—CHROMIUM—ITS PROPERTIES AND COMPOUNDS WITH OXYGEN—TESTS FOR—METHOD OF QUANTITATIVELY ESTIMATING IT.—VANADIUM—TUNGSTEN—CURIOUS COMPOUND OF TUNGSTATE OF SODA AND TUNGSTIC ACID—MOLYBDENUM—TELLURIUM.—ARSENIC—ITS SOURCES AND PROPERTIES—ITS COMPOUNDS WITH OXYGEN—TESTS FOR ARSENIC—METHODS OF OPERATING IN CASES OF SUSPECTED POISONING—METHODS OF DISTINGUISHING ARSENIURETTED FROM ANTIMONIURETTED HYDROGEN—SEPARATION OF ARSENIC FROM COPPER—ANTIMONY—ITS SOURCES AND PROPERTIES—ITS COMPOUNDS WITH OXYGEN—TESTS FOR—METHOD OF QUANTITATIVELY ESTIMATING IT—SEPARATION FROM LEAD.—URANIUM.—CERIUM.—TANTALUM.—MERCURY—ITS SOURCES AND CHARACTERS—ITS COMPOUNDS WITH OXYGEN AND CHLORINE—TESTS FOR AND QUANTITATIVE DETERMINATION OF.—SILVER—ITS SOURCES AND CHARACTERS—SEPARATION FROM LEAD—FROM SULPHUR—ITS COMPOUNDS WITH OXYGEN—TESTS FOR AND QUANTITATIVE DETERMINATION OF—GOLD—ITS SOURCES AND CHARACTERS—METHODS OF ASSAYING—ITS COMPOUNDS WITH OXYGEN—TESTS FOR

AND QUANTITATIVE DETERMINATION OF—SEPARATION FROM PLATINUM—PLATINUM—ITS SOURCES, PROPERTIES AND COMPOUNDS WITH OXYGEN—TESTS FOR, AND QUANTITATIVE DETERMINATION OF—PALLADIUM, IRIDIUM, RHODIUM AND OSMIUM—THEIR DISTINCTIVE CHARACTERS AND COMPOUNDS WITH OXYGEN—ANALYSIS OF SILICEOUS MINERALS—DECOMPOSITION BY ACIDS—BY FUSION WITH CARBONATED ALKALIES—BY HYDROFLUORIC ACID—ANALYSIS OF CLOSELY AGGREGATED MINERALS BY FUSION WITH CARBONATE OF BARYTES—ANALYSIS OF SILICEOUS MINERALS CONTAINING PHOSPHORIC ACID.

It will not be worth while to enter very minutely into the difficult subject of gaseous analysis, for, there are only a few combinations that are likely to occur to the experimentalist, and the analysis of complicated mixtures, would not be undertaken by any but the experienced in Chemistry, for whom instruction is not intended here.

The following tables, (from *Henry's Chemistry,*) exhibit a view of the different gases, and the fluids best adapted for preserving them.

1. *Gases which are best confined by mercury.*

OXIDES.	COMBUSTIBLE.	ACID GASES.
Protoxide of chlorine.	Ammonia.	Hydrochloric acid.
Peroxide of ditto.	Cyanogen.	Hydriodic ditto.
		Sulphurous ditto.
		Fluoboric ditto.
		Fluosilicic ditto.
		Carbonic ditto.
		Chloro-carbonic ditto.

2. *Gases confinable by water.*

GASES THAT SUPPORT COMBUSTION.	COMBUSTIBLE GASES.	INCOMBUSTIBLE.
Oxygen.	Hydrogen.	Nitrogen.
Chlorine.	Carburetted ditto.	Carbonic acid.
Nitrous oxide.	Olefiant ditto.	
Nitrous gas.	Phosphuretted ditto.	
	Bi-hydruret of phosphorus.	
	Sulphuretted ditto.	
	Telluretted ditto.	
	Arseniuretted ditto.	
	Antimoniuretted ditto.	
	Selenuretted ditto.	
	Carbonic oxide.	

Most of these gases have been described in the preceding pages, and it will, consequently be unnecessary to advert again to their preparation.

To ascertain whether any gas has acid or alkaline properties, a slip of litmus paper may be introduced; if it be reddened it is a proof that the gas is an acid; if the colour be unchanged, a slip of turmeric paper may be passed up, which will be changed to brown, if the nature of the gas be alkaline.

To determine whether the gas is soluble in water, a portion of that fluid may be admitted to the gas, over mercury, in a graduated tube.

Of the gases soluble in water, the following are the most remarkable :—

Ammonia, of which 1 vol. water, absorbs	670 vols.
Fluoric acid	700 —
Hydriodic ditto	500 —
Hydrochloric ditto	480 —
Fluosilicic ditto	260 —

Sulphurous acid gas is soluble only to the extent of about 33 times its volume of water, so that if, on introducing the water the whole gas should rapidly disappear, it must have consisted of one or more of the above five gases.

All the gases are more or less absorbable by water; the best method of observing which, is to apply the water previously deprived of air by long boiling, by means of the caoutchouc bottle and tube, represented in *Fig.* 56, but the tube and bottle should be much larger than are commonly used for eudiometrical purposes. It is found that the absorbability of gases is much influenced by their purity, consequently, the information which is gained by observing the effect of water on a gaseous mixture, is of a general character only.

WATER ABSORBS.

Twice its vol. of	Chlorine gas. Sulphuretted hydrogen. Selenuretted hydrogen.
An equal vol. of..........	Nitrous oxide. Carbonic acid.
$\frac{1}{8}$th of its vol. of.........	Olefiant gas. Bihydruret of phosphorus.
$\frac{1}{18}$th to $\frac{1}{20}$th of its vol. of	Nitrous gas. Oxygen gas.
$\frac{1}{27}$th to $\frac{1}{40}$th of its vol. of	Phosphuretted hydrogen. Telluretted hydrogen.
$\frac{1}{50}$th to $\frac{1}{64}$th of its vol. of	Nitrogen. Hydrogen. Carburetted hydrogen. Arseniuretted hydrogen.

Two only of the gases, capable of existing at common temperatures over water, are distinguished by being coloured, viz.:—*chlorine*, which is yellowish green, and *nitrous acid gas*, which is deep orange red, the latter, however, being pretty rapidly absorbed by water, is only seen when first formed by the union of nitrous gas and oxygen.

Some of the gases are characterized by a peculiar *odour*; that of chlorine and nitrous gas is too marked to be mistaken. Most of the compounds of hydrogen have powerful and disagreeable odours; while oxygen, nitrogen, hydrogen, carburetted hydrogen, and olefiant gases have, if pure, no smell.

A short description of the method of separating some of the gases most commonly met with, from each other, and of estimating the quantity of each, will suffice for an elementary work like the present.

1st. *Hydrogen.* The method of separating this gas from oxygen, by detonation, in a graduated eudiometer, is fully described in the sixth Lecture. After the explosion has taken place and the instrument got cold, it is necessary to ascertain whether the gas which remains be oxygen or hydrogen: for this purpose its volume is accurately measured, and an additional quantity of oxygen, not less than half the volume of the gas in the tube introduced. The electric spark is then passed again through the mixture; if it produce no diminution of bulk, then the gas which remained, after the first explosion, was oxygen; if, on the contrary, a diminution of bulk should occur, then the gas which formerly remained, was hydrogen.

But it is possible that the gas under examination may be a mixture of oxygen and hydrogen, and yet no explosion take place on passing the electric spark; this happens when the volume of either gas is too large in proportion to the other; if, for instance, the oxygen should be to the hydrogen in the proportion of 12 to 1; or the hydrogen to the oxygen as 26 to 1; in either case the electric spark occasions no explosion, and the experimenter resorts to *spongy platina,* mixed with clay into a ball, and fastened to a platina wire, as described in page 175: by this means a combination of the gases can be effected, according to *Turner,* when the proportion of one to that of the other is as 1 to 100. This is a most useful method of freeing large quantities of oxygen from small portions of hydrogen, and vice versâ; but when detonation can be effected by the electric spark, this method should always be resorted to, as the results are more to be depended upon. The platina balls employed in these experiments, should be made with more platina and less clay than was recommended in page 175;

about 1 part of the metallic sponge and two of clay compose balls sufficiently active.

It may here be observed, that in all experiments with gases, it is quite necessary to pay attention to the barometer and thermometer. Rules for the correction for temperature and pressure are given in page 50, et seq.

In the account of the composition of atmospheric air, several methods of separating oxygen from *nitrogen* were given; when the gaseous mixture consists of oxygen, hydrogen, and nitrogen, the electric spark is first passed through the mixture without the previous addition of any other gas; after the explosion the nitrogen remains behind, together with the excess of either oxygen or hydrogen; a fresh portion of oxygen is then added, and the spark passed a second time; should an explosion occur, it proves that the gas remaining with the nitrogen after the first explosion was hydrogen, and in this case the composition of the mixture is easily calculated; but if no reduction in volume takes place, then it was oxygen which remained with the nitrogen; pure hydrogen must, therefore, be added, and another explosion produced, and in calculating the result, the quantity of oxygen gas previously added to the mixture must be deducted.

The only method by which the quantity of nitrogen gas, in a gaseous mixture is usually estimated, is by withdrawing the other gaseous substances with which it is mixed, as in the above examples; recently, however, a very valuable process has been introduced in which this gas is estimated, by first causing it to unite with hydrogen and form ammonia, and subsequently to make the ammonia enter into combination with chloride of platinum; a detail of this beautiful process will be given hereafter.

Separation of the two gaseous compounds of hydrogen and carbon:—

Numerous as are the compounds formed by hydrogen and carbon, there are only two existing in the gaseous form that the chemist is often called upon to separate and estimate: these are carburetted hydrogen, (gas of marshes or fire damp,) and olefiant gas. They occur in the gaseous products of the distillation of coal and oil, and are thus separated from each other. Into a graduated tube, standing over water, admit 30 or 40 measures of chlorine, and note its bulk when actually in the tube, which must be shaded by an opaque cover. Then add a known quantity (say 50 measures,) of the gas under examination, and after ten minutes, cautiously lift the outer cover till the surface of the water appears. If the volume of the gases has suffered no diminution, we may infer the absence of olefiant gas; but if the united bulk of the two gases be *less* than the sum of their separate volumes; divide the diminution by two, and the quotient will show how much olefiant gas has been condensed.* This method is founded on the fact, that in the dark, chlorine combines with olefiant gas, but not with carburetted hydrogen, though, in the sunshine, it combines with the latter also, producing hydrochloric and carbonic acid gases. One volume of chlorine combines with one volume of olefiant gas, to produce chloric ether: hence, one half of the observed diminution is the volume of olefiant gas in the mixture.

The proportion of these gases, when existing together in a mixture, may likewise be ascertained by detonation with oxygen, in the instrument shown in *Fig.* 49. It is not, however, a safe experiment, from the violence of the explosion, and when free hydrogen is present, it is by no means accurate.

Carbonic acid. The process for separating this gas, when it is the only acid gas present in the mixture, is very simple. The volume of the gases is first accurately measured in a graduated tube, standing over mercury, and a small stick of caustic potash introduced, having previously moistened and fixed it to an ignited harpsichord wire. The carbonic acid is absorbed by the potash, and the difference in the measurements of the volume of the mixture indicates its quantity.

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* See Henry's Chemistry.

When the compound under examination, consists of the two sorts of *carburetted hydrogen, hydrogen, carbonic oxide, carbonic acid, and nitrogen,* the analytic process is exceedingly difficult and complicated. The following method, given by Rose, affords a pretty close approximation to the truth, but those who would work the problem with all the accuracy which the refinement of modern Chemistry affords, I must refer to Dr. Henry's Essay, in the Philosophical Transactions for 1824, for the fullest information we possess on the subject.

Rose's method:*—The volume of the mixture is first measured over mercury. The carbonic acid is then removed by caustic potash, and its quantity estimated. Potassium is then introduced into the upper part of the tube, which must be held in an inclined position and heated; by this means the carbonic oxide gas is decomposed, its carbon being deposited upon the potassium, and its oxygen absorbed by the same metal. The diminution of the bulk of the mixture shows the proportion of this gas. A measured volume of the residual gas is then treated over water, in the dark, with chlorine, in the manner before described. The olefiant gas is thus removed. The residue is then exposed, with chlorine, to day-light, *not* to the direct rays of the sun, or an explosion might take place: hydrochloric and carbonic acid gases are produced, the former by the combination of the chlorine with the hydrogen of the carburetted hydrogen, and with the *free* hydrogen:—it is absorbed by the water. The residual gas is shaken with mercury, which separates the excess of chlorine, and the carbonic acid is absorbed by caustic potash, and its volume ascertained; this is equal to the volume of the carburetted hydrogen. The remainder consists of nitrogen, which is now measured, and the volume of the hydrogen is calculated from the loss. This method has no pretension to great accuracy, it is, however, sufficiently correct for merely technical purposes.

Separation of hydrogen from phosphorus. The gas is passed

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* Manual of Analytical Chemistry, Part 2. p. 410.

over a weighed quantity of dry chloride or sulphuret of copper, exposed to a gentle heat; phosphuret of copper is formed, from which the composition of the phosphuretted hydrogen is calculated.

Separation of hydrogen from sulphur:—If no other acid gas be present in the mixture to be examined, sulphuretted hydrogen may be absorbed by caustic potash; but when the contrary is the case, a concentrated solution of acetate of lead, mixed with acetic acid may be employed, and the quantity of sulphuretted hydrogen calculated from the absorption; if hydrochloric acid gas be present, it may be completely separated from sulphuretted hydrogen, by borax, which easily absorbs all the acid gases, even when it is employed in lumps.

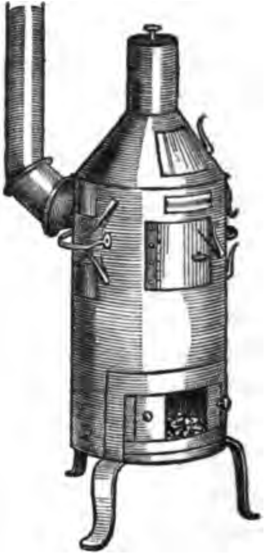
When sulphuretted hydrogen is dissolved in a liquid, as in sulphurous mineral springs, it is best to decompose it by a solution of *nitrate of silver*, or of *chloride of copper*; the resulting sulphuret must be collected on a filter, and completely oxidized by means of fuming nitric acid; it is thus converted into a sulphate: a salt of barytes is then added, and from the insoluble sulphate of that earth which is produced, the quantity of sulphuretted hydrogen is easily calculated.

For fuller details on the subject of the analysis of gaseous mixtures, the student is referred to the second volume of Dr. Henry's Elements of Chemistry.

The metals. Before commencing a general description of the metals, and a brief sketch of the methods of quantitatively estimating them, it may be useful to say a few words on the apparatus required. For general purposes this is sufficiently simple. Digestions and solutions may be very well performed in cleansed Florence oil flasks, the thinness of which enables them to bear a boiling temperature without breaking. Berlin ware digesting vessels, of various shapes and sizes, may be obtained at the philosophical instrument makers; they are very cheap, and from the high temperature to which they may be exposed without danger, they are invaluable in the laboratory:

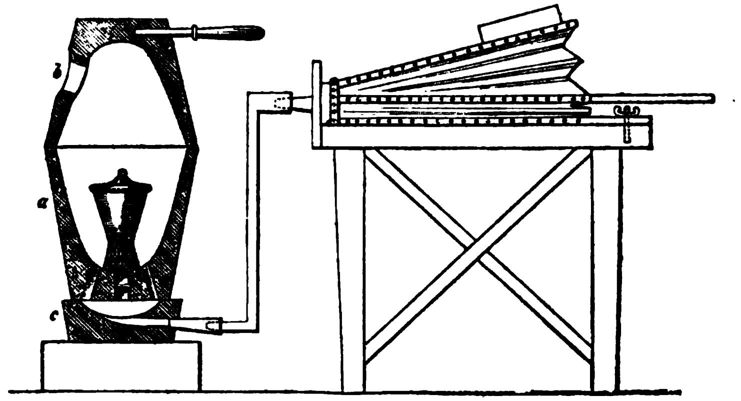
crucibles are made of the same material, and are exceedingly convenient and serviceable. There are so many forms of chemical furnace, all of which have their peculiar advantages, that it is difficult to know which to recommend. When the laboratory is on a small scale, none will probably be found more generally useful than Knight's portable furnace, *Fig*. 91. It is composed of strong iron plate, lined with fire lute, the inside diameter being about six inches; it is furnished with a sand bath (not shown in the figure,) and with various contrivances for heating retorts, tubes, &c. The fuel may be coke, or a mixture of coke and charcoal, and when urged by a pair of double bellows, a very considerable degree of heat may be obtained. Not among the least of the advantages of this furnace are, its portability, and the readiness with which it is lighted.

Fig. 91.



When a very intense heat is required, Mr. Aikins' portable blast furnace may be used. It is made out of the fragments of broken blue pots, and consists of several parts. *c*, *Fig*. 92, is the bottom of one of these pots, cut off so low as only to leave a cavity of about an inch, and ground smooth above and below. The outside diameter over the top, is five and a half inches. The middle piece or fire-place, *a*, is a larger portion of a similar pot, with a cavity about six inches deep, and measuring seven and a half inches over the top, outside diameter, and perforated with six blast holes at the bottom. These two pots are all that are essentially necessary to the furnace for most operations; but when it is wished to heap up fuel above the top of a crucible contained within, and especially to protect the eyes from the intolerable glare of the fire when in full heat, an upper pot, *b*, is added, of the same dimensions as the middle one, with a large opening in the side,

Fig. 92.



cut to allow the exit of the smoke and flame. It has also an iron stem, with a wooden handle, for removing it occasionally.

When this furnace is used, it is raised on a stand, and the nozzle of a pair of double bellows, brought towards the aperture in the lower piece, but not inserted. The fire is lighted by a piece of brown paper and a little small coal, and is sustained either with coke or small coal, or with coke alone. The coke is sifted of two sizes, and preserved in boxes with a ladle to supply it to the fire. In this little furnace cast-iron can easily be melted.*

A roomy sand-bath is so desirable, that much should be done to secure one; but where a proper sand-bath furnace cannot conveniently be constructed, a common fire-place may be-arranged as in *Fig.* 93, taken from Dr. Reid's Practical Chemistry. From the manner in which the grate is here set; a sand-bath may be placed immediately above the fire. For this purpose, an iron plate is fixed in the chimney, a funnel-pipe conveying the smoke from the fire into the vent, a constant draught is thus

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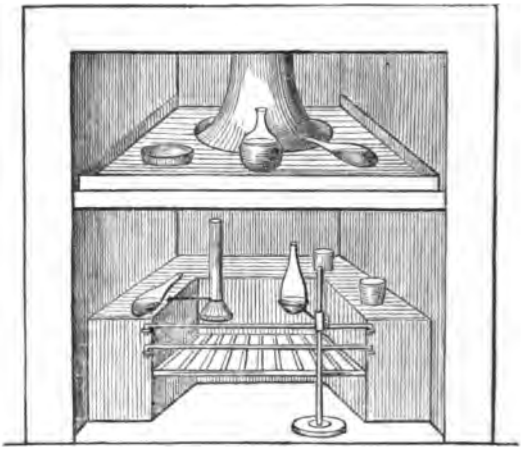
* These small blast furnaces may be had complete, with the bellows, of Messrs. Knight & Sons. For a description of other forms of chemical furnaces, Faraday's "Chemical Manipulation," and Dr. Henry's "Chemistry," may be consulted.

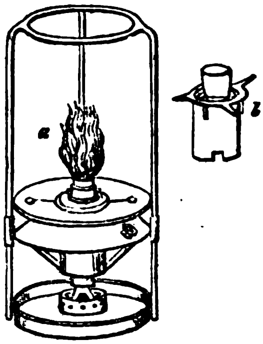
maintained, and a temperature of from 500° to 600° may be communicated to sand, placed on the plate to the depth of about one inch and a half. Digestions, slow evaporations, and a variety of other operations requiring a moderate heat, may be thus very conveniently carried on.

Fig. 93.



Many analytical operations may be very completely and elegantly carried on over a lamp. In *Fig.* 94 is shown the assay lamp of Messrs. Knight, by means of which, the fuel being rectified pyroligneous spirit, a sufficient degree of heat is speedily produced to assay, with a platina crucible of one ounce capacity, supported by platina wires on the chimney, as at *b*. It is likewise very serviceable for sublimation, &c. and is capable of heating a small sand-bath. To keep the spirit cool during long operations, the body of the lamp is protected from the influence of the burner by means of a cork or wooden jacket.

Fig. 94.



But of all the implements of the Chemist, there is none he can so ill dispense with as a good balance; it is at the same time his most important instrument, and the one to which he will have most frequently to appeal,—for what would the most exact and elaborate analysis be worth without the means of ascertaining the quantitative result? No expense should, therefore, be spared to secure a good balance. In addition to a pair of scales, that will weigh from one ounce up to three or four pounds, or more, and turn with two or three grains, a pair should be at hand for general laboratory purposes, capable of weighing from half a grain to two or three ounces, and turning with about one-third of a grain, when fully loaded. Messrs. Knight construct a very useful laboratory balance, fitted up with convenient arrangements for determining specific gravities, capable of weighing two or three ounces, and of turning with $\frac{1}{10}$th of a grain. This is sufficiently delicate for almost every purpose that the beginner in Chemistry requires; but much more sensible and highly-finished instruments are required in the laboratory of research,—one, for instance, which will weigh from 600 to 1000 grains downwards, indicating distinctly and certainly differences equal to $\frac{1}{5000}$th or $\frac{1}{8000}$th part of the weight in the scale.* It is hardly necessary to observe, that the greatest care should be taken to preserve the delicate scales from exposure to the vapours which are constantly escaping in the progress of operations, and from the dust and dirt inseparable from the laboratory.

Particular care must be taken in the selection of filtering paper. It should be sufficiently porous to admit the free and ready passage of fluids; strong enough to bear the weight of a considerable quantity of fluid; close enough to retain the finest solid particles; and so pure as to give nothing to the solution; or if heated with the substance retained upon it to occasion no admixture of ashes. Some Chemists reject the use of filters altogether; others use them but never burn them with the substance retained, removing as much as possible, and calculating the remainder, by bringing the filter, before and after the operation, to the same degree of dryness: others, always burn the filter with the substance, and where the purity of the paper can be relied upon, this is undoubtedly the most correct

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* In Faraday's Chemical Manipulation, much useful information respecting the verification of weights and scales will be found.

method of proceeding. In order to ascertain the purity of filtering paper, a piece should be burnt and its ashes examined; the fewer it yields the better it is adapted for filters. Paper may now be procured in London, a sheet of which does not yield more than half a grain of ashes, and which is, therefore, admirably adapted for any case of investigation however minute. For further details in manipulation, the reader is referred to Faraday's useful work, already so frequently quoted.

Potassium:—K: (Kalium) Eq: 490. This alkaline metal has been described in a former lecture. Its compound with oxygen—*potash* is distinguished from soda and all other substances, 1st: by a strong solution of tartaric acid, which produces a precipitate of crystalline tartrate of potash, in a liquid containing one per cent of any potash salt; this precipitate does not appear immediately, but is speedily determined by stirring the liquid briskly with a glass rod. 2nd: by hyperchloric acid, which occasions a similar precipitation. 3rd: by hydrofluosilicic acid, which throws down a gelatinous precipitate, the double fluoride of silicon of potassium sparingly soluble. 4th: by chloride of platinum. To apply this latter test, which is the one generally preferred, the solution containing potash should be neutralized by muriatic acid, the chloride of platinum then added, and the whole evaporated to dryness by a steam-heat. Water, with an admixture of alcohol being digested on the dry residue, takes up every thing but the double chloride of platinum and potassium.

Sodium:—Na: (natrium) Eq: 291. This alkaline metal has also been described. Its compound with oxygen—*soda*, is easily distinguished from all other salts when in solution by its own carbonate, which produces a precipitate with all salts but those of the alkalies: from potash it is distinguished by the tests above enumerated, and by the yellow colour it communicates to flame. With sulphuric acid it forms the well-known Glauber's salt, crystallizing in large efflorescent prisms.

If a solution be suspected to contain both potash and soda, a portion should first be tested by chloride of platinum, and another portion evaporated to dryness, and heated before the blowpipe;—if potash be indicated by the first test, and the colour of the outer flame of the blowpipe tinged *violet* colour, then potash alone is present, but, if the flame be tinged *yellow*, then the presence of both alkalies may be inferred.

To separate soda from potash, Berzelius converts both salts into chlorides, and after heating to incipient redness, mixes with them 3¾ times their weight of crystallized double chloride of sodium and platinum; he then dissolves in a very small quantity of water, and evaporates by a gentle heat to dryness. The residue is treated with spirits of wine, which dissolves the chloride of sodium, and the excess of chloride of sodium and platinum, while the chloride of potassium and platinum resulting from the double decomposition remains behind undissolved; this salt is washed with spirit of wine, and dried at a very gentle heat, and the calculation made accordingly. The quantity of chloride of sodium is found by deducting the weight of the chloride of potassium from the weight of the mixed chlorides.

Ammonia. When free, this compound is easily distinguished from the other alkalies by its odour; it is eliminated from all its combinations, by gently heating with caustic potash:—with chloride of platinum, it forms a yellow double salt, which may be mistaken for the double chloride of platinum and potassium, but when heated to redness, nothing is left but spongy platinum, whereas, the chloride of platinum and potassium leaves all its potassium in the state of chloride mixed with the platinum.

Lithium;—L: Eq: 80·33. This is the metallic base of the rare alkaline oxide, lithia:—it was discovered by Arfwedson in 1818. The claim of lithia to be ranked amongst the alkalies, is derived from the alkaline reaction and solubility (though sparing) of its carbonate. It tinges the flame of the blowpipe of a brilliant red colour, by which it is distinguished from soda.

It may be separated from potash and soda, (provided no other bases are present,) by phosphoric acid and phosphate of soda, a neutral double salt of sparing solubility, containing 15·08 per cent. of lithia being formed.*

Barium:—Ba: Eq: 856·9. The metallic base of the earth *barytes*, discovered by Sir H. Davy in 1808, by the voltaic decomposition of moistened carbonate of barytes in contact with mercury. Barytes exists abundantly in nature, principally in the states of sulphate and carbonate. It is obtained pure by calcining its nitrate, or, which is better its iodate. Kane recommends mixing the nitrate of barytes with twice its weight of the sulphate before ignition, by which the swelling up of the melted salt is much diminished. Caustic barytes is also very conveniently prepared by exposing a mixture of powdered sulphate of barytes, with one-fourth of its weight of charcoal powder, to a strong heat for about two hours; carbonic oxide gas is evolved and sulphuret of barium remains, which is to be dissolved in water, and boiled with black oxide of copper till a drop of the solution occasions no discoloration in solution of acetate of lead; insoluble sulphuret of copper is formed, and caustic barytes remains in solution.—*Mohr.*

There is no difficulty whatever with regard to the quantitative determination of barytes, when it exists in solution with the alkalies, its sulphate being completely insoluble not only in water, but in all dilute acids; it is only necessary, therefore, to add to the solution dilute sulphuric acid, and after the precipitate has subsided, filter, wash, dry, and ignite it; 100 parts consist of 34·37 sulph: acid, and 65·63 barytes.

Strontium: Sr: Eq: 547·3. The preparation of this metal is similar to that of barium, to which it bears a very strong resemblance—its compound with oxygen; *strontia* may be obtained in the same way as that described for the preparation of barytes. It is not so heavy an earth as barytes, nor is it so caustic. It is said not to be poisonous, whereas, all the

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* Berzelius.

salts of barytes are highly so. Strontia is not precipitated by sulphuric acid so completely as barytes, sulphate of strontia being soluble to a slight extent in water; it is, however, insoluble in spirits of wine, and if strontia be combined with an acid which is soluble in spirits of wine, it may be precipitated as sulphate with very great accuracy, by adding alcohol and washing with the same.

The separation of strontia from barytes may be effected by a solution of the neutral chromate of potash; (Mr. J. D. Smith.) To a neutral solution of the two earths in hydrochloric acid diluted with water, a dilute solution of chromate of potash is added, the chromate of barytes is precipitated alone, and, after its separation the strontia may be thrown down by sesquicarbonate of ammonia, or better, perhaps, by carbonate of soda. Hydrofluosilicic and hyposulphurous acids likewise, precipitate barytes but not strontia, and if to a neutral and rather concentrated solution of these earths in hydrochloric acid, solution of ferrocyanuret of potassium be added, the barytes is precipitated but not the strontia. According to Liebig, iodate of soda is an excellent reagent for separating barytes from strontia; the latter is not at all precipitated by it, while the former is completely thrown down by it from neutral solutions, so that no remaining trace of it can be detected. The precipitate is flaky.

Calcium: Ca: Eq: 256. This is the base of lime; its metallic character was demonstrated by Davy, who obtained it by the same method as that described for barium. Lime is the only compound of calcium and oxygen; it may be said to be the most important of the earths, and is most extensively diffused in nature, in the form of carbonate and sulphate; as the former, it forms the basis of lime-stones, marbles, marles, chalk, shells, coral reefs, &c., and as the latter, it forms that well-known salt, gypsum, or plaster of Paris.

At a red heat, carbonate of lime loses its carbonic acid; on the large scale, *quicklime* is obtained by burning the ordinary limestone in kilns; but for chemical purposes, the earth is obtained pure by strongly heating calc-spar or Carrara marble in a loosely-covered crucible. Lime has a strong affinity for water, and is much used by the Chemist to deprive certain liquids, such as alcohol, of the water they contain. Considerable heat is evolved during the combination of lime with water, and instances have been known of ships at sea, laden with lime, being burnt, by water penetrating to the hold.

The uses of lime in the formation of mortar, and as a manure are well known; we shall have an opportunity of adverting to the latter of these applications in our next Lecture; with respect to the former, we may observe, that the action of lime is purely mechanical, acting solely by the attraction of aggregation, and uniting the stones between which it is placed in the same manner as glue unites two pieces of wood. The absorption of carbonic acid by lime, in the state of mortar, is exceedingly slow, and never complete even in the oldest buildings. Some limestones are found containing 20 per cent. of clay or silicate of alumina; these afford lime, which forms with water, a mass which becomes solid in a few minutes, and which is, therefore, admirably adapted for hydraulic mortar. When clay and chalk are mixed and calcined, or when puzzolano,* ground to fine powder, is added to hydrate of lime, an hydraulic mortar is formed which is known by the name of Roman cement.—*Graham.*

Lime enters largely into the composition of the animal frame, it is the basis of the bony or testaceous skeleton, that of the vertebrated animal, consisting principally of phosphate, and the shell of the invertebrated animals of carbonate of lime. The teeth also consist of phosphate of lime; and in all these cases the phosphate of lime is associated with fluoride of cal-

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* A volcanic substance, composed principally of pumice, of which a stratum is excavated in the neighbourhood of Pozzuoli, near Naples.

cium. The supply of lime in the mineral state, arises from the destruction of its animal sources, the densest and hardest limestone to the softest chalk, resolving itself ultimately into a congeries of animal remains, and all the great geological formations which contain carbonate of lime, consisting of the aggregated shells of myriads of the tribes of invertebrated animals, which had existed in some former period of the world's history. "Notwithstanding, therefore," observes Dr. Kane, "the vast extent of its distribution over the surface of the globe, it is questionable whether lime should not be looked upon as rather a characteristic of the animal than of the mineral kingdom of nature."

Sulphate of lime not being altogether insoluble in water, *oxalate of ammonia* is generally employed in the quantitative estimation of this earth; the oxalate of lime being quite insoluble in water, though it is dissolved by oxalic acid. It is not, however, usual to estimate the quantity of lime in the state of oxalate, but to convert it into carbonate, after being well washed, and dried by ignition in a platinum crucible, taking care to add a small fragment of carbonate of ammonia to prevent the lime from becoming caustic. 100 grains of carbonate of lime consist of 55 lime and 45 carbonic acid.

When lime is to be separated from strontia and barytes, the following process is recommended by Rose. Precipitate the barytes by hydrofluosilicic acid; then mix the filtered solution with sulphuric acid. Upon evaporating the mixture to dryness and igniting the dry mass, a mixture of sulphate of strontia and sulphate of lime is obtained. This is mingled in a platinum crucible, with three times its weight of carbonate of soda, or carbonate of potash, and the mixture is melted. After the fusion, water is poured over the melted mass, and an insoluble substance is obtained, which consists of carbonate of strontia and carbonate of lime. These carbonates are then dissolved in nitric acid very carefully, so as to avoid all excess of acid, and employing a gentle heat; the solution is evaporated to dryness in a flask which is closed immediately that the saline mass is dry, and when cold, *absolute* alcohol* is poured in and well agitated; the nitrate of lime dissolves completely in the alcohol, but the nitrate of strontia remains undissolved; the latter is then collected on a filter and washed with absolute alcohol, with as little access of air as possible; it is then dried and weighed. The solution of nitrate of lime is diluted with water; the alcohol driven off by heat, and the lime precipitated by oxalate of ammonia.

Magnesium: Mg: Eq: 158·3. Bussy gives the following process for obtaining this metal. Into the bottom of a tube of hard glass, place a few fragments of potassium, and on them a small quantity of anhydrous chloride of magnesium; heat the latter to its fusing point by means of a spirit lamp; then convert the potassium into vapour, and cause it to come into contact with the heated chloride; vivid ignition takes place, chloride of potassium is formed which may be dissolved by water, and metallic magnesium of a silvery whiteness remains. This metal is malleable and fusible at a red heat, but in dry air, or even in dry oxygen gas it undergoes no change, but when heated it burns brilliantly, forming magnesia.

Magnesia, the only known oxide of magnesium, is an earth well known in pharmacy in three states, as *magnesia usta, magnesia alba,* (the hydrated carbonate,) and *sulphate of magnesia,* or Epsom salt. The carbonate of magnesia occurs native, and is known as *magnesite,* and a compound of the carbonates of lime and magnesia, or the magnesian limestone, (dolomite) is very extensively diffused. Pure magnesia is prepared by exposing the carbonate of magnesia of commerce to a full red heat, by which the carbonic acid is entirely expelled.

Magnesia is a substance, the quantitative determination of which is attended with considerable difficulties, particularly when the fixed alkalies are present. The *presence* of magne-

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* Alcohol, free from water, obtained by distilling rectified spirit of wine at a moderate heat, from carbonate of potash, or chloride of calcium.

sia in a solution, is best ascertained by rendering the liquor alkaline by ammonia, and then adding phosphate of soda; a crystalline double salt, the phosphate of ammonia and magnesia is formed. In a solid compound magnesia may be detected by igniting a small portion on charcoal before the blowpipe, moistening the ignited assay with a solution of *nitrate of cobalt*, and again strongly heating it,—the mass acquires a pale red colour if magnesia be present: this reaction is, however, prevented by the presence of metallic oxides, alkalies, or earths.

When the object is to determine the quantity of magnesia *alone* in a solution, it may be done by boiling for a long time with a considerable excess of carbonate of potash; evaporating carefully to dryness, and pouring boiling water over the residue, carbonate of magnesia remains undissolved, and the small quantity of the earth that has escaped precipitation as carbonate, may be removed from the solution, and estimated by adding, first, a solution of phosphate of soda, and then ammonia; the crystalline deposit which subsides after a time must be ignited, by which it is decomposed, phosphate of magnesia remaining, which may be calculated to contain 40 per cent. of magnesia. When magnesia is to be separated from lime, the best plan is to dissolve both earths in muriatic acid; evaporate to dryness, and heat in a platina capsule till acid fumes cease to rise, then raise the heat to redness and add chlorate of potash in successive portions as long as chlorine is evolved; digest the residual mass in water, and wash dry and ignite the insoluble residue, which will be magnesia; the lime may then be separated from the solution, by adding carbonate of soda in excess. This method gives very accurate results, and is less troublesome than the plan proposed by Lewis Thompson, viz: Dissolve the combined earths in dilute nitric or muriatic acid and precipitate the filtered solution by excess of carbonate of soda; dry the precipitate, and place it in a coated green glass tube; heat to redness, and pass well washed chlorine through the tube for a few minutes; the lime will thus be converted into chloride of calcium, but the magnesia remains unacted upon. The lime is precipitated as above by carbonate of soda.

When alkalies are present and have to be estimated, the separation of magnesia is attended with very great difficulties. Rose gives the following method. Convert the magnesia and fixed alkalies into sulphates; ignite, and mix with acetate of barytes, by which the sulphuric acid is separated, the acetates produced are then to be ignited, by which they are converted into carbonates, those of the alkalies being soluble, may be removed by hot water from the carbonates of barytes and magnesia. The alkaline carbonates may then be ignited, and converted into sulphates, and estimated as such; the carbonates of barytes and magnesia are then to be dissolved in muriatic acid, and the barytes separated by sulphuric acid; the magnesia remains in solution as sulphate of magnesia, as which it is to be estimated.

Aluminum: Al: Eq: 171·2. This metal is obtained from its chloride by the action of potassium, in the same manner as magnesium, but the decomposition must be conducted in a platinum or porcelain crucible. Alumina is the only known oxide of aluminum; it is not, however, a protoxide like magnesia, its composition being

Aluminum.................	53·3
Oxygen....................	46·7
	100

It is, therefore, to be considered as a sesqui-oxide, being represented by the formula, Al_2O_3.

Alumina is a very extensively diffused earth, more so even than lime. There are few rocks of which it is not the principal ingredient, and it constitutes the great mass of ordinary clays and soils. In the arts it is applied to a variety of important uses, as in the manufacture of earthenware, tiles, bricks, &c.; in dyeing, as a basis or mordant for which it is very extensively used. Alumina is found in nearly a pure state in two precious stones,—the sapphire and the ruby. It is obtained pure in the laboratory, by adding carbonate of potash to a solution of alum* in boiling water, thoroughly washing the precipitate thereby produced, which is very bulky and gelatinous, re-dissolving in dilute hydrochloric acid, and re-precipitating by carbonate of ammonia. It is necessary to be very particular in washing these precipitates in order to get rid of every portion of the liquids in which they were precipitated. Alumina shrinks very considerably in drying, being reduced to a few hundredths of its bulk, when moist: it is, however, even then combined with water, from which it can be entirely freed by exposure to a white heat; it is then dissolved by acids with great difficulty. Alumina is remarkable for its tendency to unite with organic matters. If a cotton cloth be immersed in a solution of acetate of alumina, the earth will deposit itself completely on the fibres of the cotton, and leave the acetic acid free, *(Kane,)* hence the application of the salts of alumina to dyeing, calico printing, &c.

Alumina in solution, is distinguished from the alkaline salts by producing a white precipitate with ammonia, from barytes, lime, and strontia, by producing no precipitate with sulphuric acid, and from magnesia by its solubility in caustic potash, and its subsequent precipitation by muriate of ammonia.

When a solid compound containing alumina, is heated on charcoal and then moistened with solution of nitrate of cobalt, and strongly heated by the blowpipe; a fine *blue* colour is communicated to the assay.—*Berzelius.*

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* The double sulphate of alumina and potash. This salt is extensively manufactured for the use of the dyer. The clay-slate found under beds of coal, and which contains bi-sulphuret of iron, is exposed to the action of air and moisture; oxygen is absorbed and sulphate of iron is formed, with excess of sulphuric acid, which reacts on the clay and combines with alumina. The process is quickened by the application of heat. When the calcined mass has become quite cold, it is lixiviated, and the sulphate of iron separated by crystallization. A solution of some salt of potash is then added, and alum is formed, and separated from the other matters by crystallization.

The quantitative determination of alumina is effected by precipitating it by ammonia, or carbonate of ammonia,—carbonate of potash should not be employed, it being almost impossible to free the precipitated alumina entirely from potash; the alumina is thrown down in a bulky gelatinous state, and requires a considerable affusion of hot water to render it pure.

When alumina is to be separated from lime and magnesia, M. Anthon recommends to add to the solution of the earths, ***tungstate of soda,*** which precipitates the lime and alumina, but not the magnesia, the addition of tartaric acid prevents the precipitation of the alumina.* If this plan be effectual, it will entirely supersede the usual method, which is as follows. Muriate of ammonia is added to the solution, and the alumina precipitated by caustic ammonia: the lime is then thrown down by oxalate of ammonia, and the magnesia precipitated by carbonate of potash. But a portion of the magnesia is carried down with the alumina, with which it appears to enter into combination, as it is very difficult, if not impossible to separate the earths by caustic potash.

When the quantity of lime is small, compared to that of the other two earths, another method of separation may be adopted, viz:—to add to the solution bi-carbonate of potash, which precipitates the alumina alone, converting the lime and magnesia into soluble bi-carbonates.—*Rose.* The alumina may then be separated by filtration, and the carbonates of lime and magnesia, dissolved in hydrochloric acid, and separated as already described.

Glucinum. The metallic base of glucina, an earth rarely met with, but existing in combination with alumina as a silicate, in the emerald or beryl; glucina, when precipitated from its solution, has much the appearance of alumina, from which it is separated by carbonate of ammonia, in which it is soluble. Glucinum derives its name from the Greek word γλυκυς, sweet, its salts being remarkable for their sweet taste.

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* Journal de Chem: Med: June, 1839.

Yttrium. The metallic base of yttria, a very rare earth, discovered in a mineral called godolinite. Yttria is separated from other earths by caustic alkalies, in which it is insoluble. Yttria has been discovered by Professor Apjohn, to be present in the Bohemian garnet.—*Kane.*

Cerium, Lanthanum, Thorium, and Zirconium. These are metals found in a few rare minerals; from their scarcity, little more is known of them than that they exist, and must be classed at present among elementary bodies.

Manganese: Mn: Eq: 345·9. This metal is reduced from its oxide and fused with very great difficulty. It is necessary to expose the artificial oxide, obtained by calcining the carbonate in a close vessel, made into a paste with oil to the strongest heat of a wind furnace for an hour and a half, in a carefully luted crucible, lined with charcoal. It is a greyish-white metal, resembling cast-iron, and so susceptible of oxidation that it is necessary to keep it, like potassium, in a bottle of naphtha.

Manganese is pretty extensively diffused through nature; it is found in the ashes of plants, in the bones of animals, and in many minerals. The native peroxide, which is well-known in commerce, is its most abundant source. It is much used in the arts for preparing chlorine, and in the laboratory it is a useful source of oxygen gas. For the following convenient method of preparing pure salts of manganese, we are indebted to Mr. Everitt. The impure solution of manganese, the result of the process for the preparation of chlorine, is evaporated to about one-fifth of its bulk, to drive off the excess of hydrochloric acid, then filtered, and its original volume restored by distilled water; one-fourth of the solution is then decomposed by carbonate of soda; carbonate of manganese, contaminated with much oxide of iron is precipitated; this must be washed well, and boiled with the remaining three-fourths of the solution; all the oxide of iron is by this means precipitated in combination with the carbonate of manganese, and a clear colourless solution of *pure* chloride of manganese is obtained, which gives, with ferrocyanate of potash, a pale pink precipitate, without any trace of blue. The chloride of manganese may then be decomposed by carbonate of soda, and from the carbonate thus obtained, any of the other salts of the metal may be formed.

Manganese is remarkable for the number of compounds which it forms with oxygen. There are five, viz:—the protoxide, $Mn\,O$, the sesqui-oxide, Mn_2O_3, the per-oxide, MnO_2, manganic acid, MnO_3, and permanganic acid, MnO_7. The *protoxide of manganese* is a greyish-green powder, very susceptible of further oxidation; it may be obtained by exposing to a red heat in a platinum crucible, a mixture of chloride of manganese with twice its weight of carbonate of soda, and a small quantity of sal-ammoniac; chloride of sodium and carbonate of manganese are formed, but the carbonic acid of the latter is driven off by the heat, and the hydrogen of the sal-ammoniac prevents the manganese from passing to a higher state of oxidation.—*Graham*—*Kane*. It is not, however, easy to ensure success in this experiment. A more pleasing method of making this oxide, is to pass a stream of dry hydrogen gas through a hard glass tube containing some artificial peroxide,* and heated to redness.

The sesquioxide of manganese is found in nature pure in the mineral *braunite*, and combined with water, in the mineral *manganite*. It possesses the property of staining glass purple or violet.

The peroxide of manganese occurs pure and crystallized in the mineral *pyrolusite*, and combined with water, in the mineral *wadd*. It is met with in considerable abundance, in an impure form, in Devonshire, Aberdeenshire, and Somersetshire. This oxide is used to give a black colour to earthenware, to remove the brown colour which glass derives from peroxide of

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* Obtained by decomposing the proto-chloride by solution of chloride of lime.

iron, and sometimes also to sweeten foul water at sea, or to prevent its becoming so.—*Brande.*

Manganic acid is incapable of existing in an isolated form. Manganate of potash is obtained by strongly heating the peroxide with nitrate, carbonate, or caustic potash; a green fused mass is obtained, which, in consequence of its solution passing rapidly through several shades of colour has obtained the name of *mineral chameleon.* Dr. Gregory gives the following convenient process for preparing this singular compound. Mix 4 parts of peroxide of manganese in fine powder, with 3½ parts of chlorate of potash, and add 5 parts of hydrate of potash dissolved in a small quantity of water; the mixture is to be evaporated to dryness, powdered, and afterwards ignited in a platinum crucible, but not fused, at a low red heat. Digested in a small quantity of cold water, this affords a deep green solution of the alkaline manganate, which may be obtained in crystals of the same colour by evaporating the solution over sulphuric acid in the air pump.—*Graham.*

Permanganic acid may be obtained in solution by decomposing manganate of barytes with a proper quantity of sulphuric acid; it is of a deep crimson colour. Manganate of barytes is obtained by fusing peroxide of manganese with nitrate of barytes.

Besides these oxides of manganese, there are two other complex oxides, viz:—the *red oxide,* which forms the mineral *hausmanite,* and which is produced when any oxide of manganese is strongly heated in the air; and *varvacite,* a mineral discovered by Mr. Phillips:—the formula for the first is Mn_3O_4, or $MnO + Mn_2O_3$, and for the latter, Mn_4O_7, or $Mn_2O_3 + 2MnO_2$.—*Graham—Kane.*

Protosalts of manganese in solution, are recognized by giving with yellow prussiate of potash a white, or pale-red precipitate; with red prussiate of potash, a brown precipitate; and with hydrosulphuret of ammonia, a yellow or flesh-red precipitate. Before the blowpipe on charcoal, they give, with borax or microcosmic salt* in the outer flame, a bead of an amethyst colour, which disappears in the inner flame, and with soda, a bead of a green colour. When the manganese is not in the state of protoxide, the solution is always coloured either red or green.

When manganese in solution is to be quantitatively estimated, it may be precipitated by carbonate of potash in the same manner as magnesia; the resulting carbonate, after being well washed, must be converted into the brown oxide by ignition, in a platinum crucible. When it is to be separated from magnesia, the solution containing the two substances must be rendered acid, or treated with muriate of ammonia, hydrosulphuret of ammonia is then to be added, and the resulting sulphuret of manganese filtered and washed without interruption with water, to which hydrosulphuret of ammonia has been added. The sulphuret of manganese is then to be dissolved in muriatic acid, and precipitated as above by carb: potash. When alumina, magnesia, and lime are present in a solution with manganese, and when the quantity of the latter is small, the solution must first be treated with muriate of ammonia, the alumina then precipitated with caustic ammonia, and the lime by oxalate of ammonia; the magnesia and manganese may then be separated as above described; but if the quantity of manganese be larger, it should be precipitated by hydrosulphuret of ammonia, immediately after the separation of the alumina, and the lime precipitated afterwards, taking care to acidulate the liquor with hydrochloric acid and heat it till it ceases to smell of sulphuretted hydrogen. There is no difficulty attending the separation of manganese from the alkalies, since, after rendering the solution alkaline by ammonia, it may be completely precipitated by hydrosulphuret of ammonia.

Iron: Fe: (*ferrum*) Eq: 339·2 or 349·4. Whatever artifi-

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* The ammonia-phosphate of soda, formed by dissolving five parts of crystallized phosphate of soda, with two of crystallized phosphate of ammonia, and evaporating.

cial value may be attached to the rarer metals and minerals, iron is unquestionably the most important of all the inorganic productions of the earth. Without it, it is impossible to imagine that civilization could have advanced to its present condition, or that we should have arrived at our present state of national intelligence and industry. Iron may be considered not merely as being useful, but as absolutely essential to man; as has been well observed, "on its employment and applications is founded every important step which marks the gradual progress of the human race from barbarism to civilization.

In the short sketch we are giving of the nature and properties of the metals, space cannot be afforded to enter into a detail respecting the method of reducing iron from its ores; more systematic works must, therefore, be referred to for full information on this head. Iron exists in nature in a variety of forms. In the primary formations, the most abundant ore is the black oxide or *magnetic ore,* from which the valuable Swedish iron is obtained. In the secondary and tertiary formations it occurs in considerable quantity, as *red and brown hematite,* (the anhydrous and hydrous peroxide of iron,) but by far the greatest source of iron is the *clay iron stone* of the coal measures, the proportion of iron in which averages about 30 per cent. The sulphurets of iron are likewise found in abundance, and the metal is also found combined with arsenic and phosphoric acid.

Pure iron is nearly infusible, its reduction from its ores would, therefore, be extremely difficult but for a fortunate peculiarity of the metal, viz:—that of forming a fusible compound with carbon. During the process of smelting, carburet of iron is formed, and from this compound the carbon, amounting generally to about five per cent. is removed by fusing in a reverberatory furnace, exposed to a current of air; the metal becomes less and less fusible, and ultimately breaks up into an incoherent granular mass; by increasing the heat the grains agglutinate, and after being worked up into large balls, the metal is removed from the furnace and compressed into a cylindrical form by a few blows of a loaded hammer; it is then quickly converted into bars by pressing it between grooved rollers. In this state it constitutes *malleable iron.*

Besides cast and malleable, iron exists in the arts in another important form—that of *steel,* a compound of iron and carbon, containing about 1·5 per cent. of the latter element. The best qualities of malleable iron are selected for conversion into steel. The process is termed *cementation,* and consists in exposing bars of iron imbedded in powdered charcoal, for some hours to a full red heat. Steel is harder and more fusible than iron, from which it differs in its invaluable property of becoming excessively hard and elastic when heated to redness and suddenly cooled by plunging it into water or oil, and from its susceptibility of regaining any portion of its original softness, by heating it up to particular temperatures, which are judged of by the colour of the film of oxide upon its surface, which passes from pale yellow at about 430°, through straw-yellow, brown-yellow, and red-purple, to deep blue at 580°.

Iron is especially remarkable for its property of obeying the loadstone; for its becoming pasty when strongly heated, whence its remarkable power of welding, and as being the strongest of all the metals. It combines with oxygen in two proportions, forming protoxide, FeO, and sesquioxide or peroxide, or ferric oxide, Fe_2O_3. The protoxide combines so rapidly with oxygen that it cannot be obtained pure in a dry state. It is the basis of the sulphate and all those salts of iron, formed when the metal dissolves, with the evolution of hydrogen. The peroxide exists in nature in great abundance; it may be prepared artificially, by precipitating a solution of any of the persalts of the metal by ammonia, and subsequently igniting. A compound of the protoxide and peroxide of iron, the magnetic oxide, exists native in great abundance, it constitutes the common loadstone, and the scales of iron which form in forges, during the successive heatings and hammerings to which the metal is subjected.

We are indebted to Professor Fuch for a simple and œconomical method of determining the quantity of metal in ores of iron and other ferruginous bodies, and for ascertaining at the same time the proportions in which the protoxide and peroxide of that metal occur. This method is founded on the fact, "that when air is excluded, hydrochloric acid is quite incapable of dissolving copper, but that on the addition of oxide of iron, or, when that substance is already at the outset contained in the mixture, the hydrochloric acid does dissolve a quantity of copper corresponding thereunto." The perchloride of iron becomes protochloride, and protochloride of copper is formed, and the equivalent of copper is to that of the peroxide of iron as the quantity of copper dissolved is to X, that is, to the quantity of peroxide of iron we wish to ascertain. If the object is to ascertain the quantity of metallic iron, all that is necessary is to substitute the equivalent of the metal for that of the peroxide, and make the calculation as before.

The following is the plan of proceeding. The specimen is to be dissolved in strong and pure hydrochloric acid and peroxidized, either by cautiously adding crystals of chlorate of potash,* or by passing a current of chlorine through the liquor till a drop of it, let fall into solution of red prussiate of potash, gives no tinge of blue. It is then to be boiled for a few minutes to expel the excess of chlorine, and a weighed quantity of pure copper† introduced, the boiling is to be continued without intermission, till the liquor passes off to a pale yellow green:—when no further change of colour is observed to take place, the flask must be filled up with hot water, and the copper removed, washed in cold water, dried, and weighed.

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* Particular care must be taken to avoid inhaling the fumes hereby evolved.

† I find voltaic copper, that is, copper revived from a solution of the sulphate by voltaic electricity, answers the purpose exceedingly well.

Example :—25 grains of good English iron were dissolved in hydrochloric acid, peroxidized by a current of chlorine, and the solution boiled for 1½ hours, with 42 grains of voltaic copper. 14·5 grains remained undissolved, consequently 27·5 had been taken up: therefore,
as 395·7 (eq: of copper) : 349·4 (eq: of iron) ::27·5 : 24·28 = the quantity of iron in the specimen examined, which is 97·12 per cent.

Again :—25 grains of black cast iron, digested for several hours at a gentle heat in hydrochloric acid, and treated as above, left 15·5 grains of copper undissolved, showing 23·4 grains, or 93·6 per cent. of iron in the specimen.

If we take the number 339·2 for the equivalent of iron, according to Berzelius, the calculation will not give us the actual amount of metal; but several Chemists prefer the number 349·4, or 28 on the hydrogen scale, with which the calculation agrees very closely.

Professor Fuch finds that the success of this method of analysis is not interfered with by the substances ordinarily met with in iron ores, such as silica, alumina, magnesia, lime, oxide of titanium, protoxide of manganese, phosphoric acid, sulphuric acid, &c., and as it is conducted without much trouble and with very little expense, it must certainly be regarded as a very valuable addition to analytical Chemistry.

Protosalts of iron are immediately recognized when in solution, by giving, with *ferrocyanide of potassium,* (yellow prussiate of potash) a precipitate, which, if the air be excluded is white, but which is usually of a light blue colour, becoming dark blue by exposure to the air, and with *ferricyanide of potassium,* (red prussiate of potash,*) an immediate dark blue precipitate, insoluble in acids. When fused in microcosmic salt, protosalts of iron communicate to it a green colour, which disappears when cold. Persalts of iron are known

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* Formed by transmitting chlorine gas, through a solution of *ferrocyanide*, till it no longer gives a precipitate of Prussian blue, with a persalt of iron.

in solution by producing an immediate dark blue precipitate with yellow, and none at all with red prussiate of potash; a deep blood-red colour, but no precipitate with sulphocyanide of potassium; and a deep violet or black with tincture of galls.

In whatever state iron is contained in a substance, it is always estimated as peroxide, the precipitant for which is caustic ammonia. When peroxide of iron is to be separated from protoxide of manganese, lime, alumina, magnesia, and a fixed alkali, muriate of ammonia is first added to the solution; it is then supersaturated with ammonia, the precipitate which falls contains the peroxide of iron and the alumina, together with small portions of manganese and magnesia. This mixture is then digested with caustic potash, by which the alumina is dissolved, and the peroxide of iron is separated from the small quantities of magnesia and manganese, by redissolving in hydrochloric acid, and precipitating by succinate of ammonia.

Cobalt: Co: Eq: 360. This metal is obtained from the impure oxide, known in commerce as zaffre; it is reduced in a spongy form, but may be fused into a button at a heat inferior to that required to melt cast iron; it is then a brittle metal of a reddish grey colour. It forms, with oxygen, two compounds,—CoO and Co_2O_3, corresponding with the two oxides of iron. The protoxide is obtained by adding caustic potash to any salt of cobalt; as a hydrate, it is of a fine blue colour, but after ignition it is ash grey. The peroxide is formed when chlorine is passed through water in which the protoxide is suspended; it is black, both as a hydrate and when free from water.

In solution, cobalt is recognised by producing, with ammonia, a blue precipitate, which is redissolved by excess of the alkali, changing colour on exposure to the air, eventually becoming of a fine rose-red colour, (*Kane,*) if the cobalt be pure, but brown if nickel be present. Before the blowpipe, cobalt salts are detected with the greatest ease, the smallest portions colour borax and microcosmic salt strongly blue. The use of cobalt in the arts is founded on this property; glass is coloured deep blue by cobalt, and when ground to an impalpable powder it constitutes *smalt*, which is used to give to writing paper and linen a delicate shade of blue. The blue colours on porcelain and stone-ware are also produced by cobalt; and alumina, coloured strongly blue by cobalt, is used in commerce as a pigment, *cobalt blue*, in place of ultramarine.

The best precipitant of oxide cobalt is caustic potash.

Nickel. Ni: Eq: 369·7. This metal is extracted either from the native arseniuret, or from a metallic substance, which collects at the bottom of the crucibles in which smalt is prepared; it is an artificial arseniuret, and is known by the name of *speiss*. Nickel is a metal of a silvery white colour, rather more fusible than cast iron. It has little tendency to rust even in damp air. It is remarkable for being magnetic nearly as much so as iron. It is highly ductile. The alloys of nickel are very white and brilliant, hence, when added to brass in the proportion of one to five, it is employed as a substitute for silver, constituting German silver, nickel silver, argentine, as well as the packfong long used in China. Nickel forms with oxygen, two compounds, $Ni\,O$, and $Ni_2\,O_3$, corresponding to the oxides of cobalt and iron. Protoxide of nickel may be obtained either by igniting the nitrate or carbonate, or by precipitation from its salts by an alkali; when free from water, it is an ash-grey powder, but as a hydrate it is apple-green. The peroxide is obtained in the same manner as peroxide of cobalt, which it much resembles in properties.

Nickel is distinguished in solution by giving, with potash, an apple-green precipitate, not soluble in excess of the precipitant; and with ammonia, a pale green precipitate, soluble in excess of the alkali, forming a blue solution; with yellow prussiate of potash, a very pale green precipitate; and with hydrosulphuret of ammonia, a black precipitate, communicating at the same time a black colour to the supernatent fluid.

Like oxide of cobalt, the best precipitant of nickel is caustic potash.

When oxide of nickel is to be separated from oxide of cobalt, and both quantitatively estimated, the best method is the following, recommended by Phillips. The solution, prepared by muriate of ammonia, is to be supersaturated with ammonia, and then diluted with a considerable quantity of water, which has been previously boiled to free it from atmospheric air; the hot solution is then treated with a considerable quantity of caustic potash, which, if the solution contains a sufficient quantity of ammoniacal salt, will precipitate the whole of the oxide of nickel, and leave the oxide of cobalt in solution, which may be known by the colour of the liquor, changing from blue to bright red. After removing the precipitated oxide of nickel, the oxide of cobalt is to be precipitated by hydrosulphuret of ammonia, washed with water, mixed with hydrosulphuret of ammonia, then digested with nitro-hydrochloric acid, by which it is decomposed, and having removed the sulphur by filtration, the oxide of cobalt is to be precipitated by caustic potash.

Zinc: Zn: Eq: 403·2. This metal is extracted from the native carbonate, (calamine,) or sulphuret, (zinc blende,) by the assistance of carbonaceous matter, in large earthen retorts of a peculiar construction. It is of a blueish-white colour, brittle when impure, but capable of being beaten out into leaves when pure. When exposed to the air, its surface acquires a grey film of suboxide, which protects the metal from further change, hence, its application to domestic and technical purposes.

Oxide of zinc, ZnO, is formed by the combustion of the metal in a stoneware crucible: to obtain it, fragments of zinc may be thrown in a red-hot crucible, and another crucible inverted over it; the oxide is deposited on the outside of the upper vessel, as a loose cottony mass, of a fine canary colour when hot, but pure white when cold. It is supposed that other oxides of zinc exist, but they have not yet been studied.

Oxide of zinc is precipitated when in solution by long boiling with great excess of carbonate of potash, or it may be precipitated, first, as sulphuret of zinc by hydrosulphuret of ammonia, and then, after digesting with strong hydrochloric acid, to separate the sulphur, it may be precipitated by carbonate of potash; from peroxide of iron, it may be separated by caustic ammonia, which precipitates the former but not the latter, unless it greatly preponderates.

Cadmium: Cd: Eq: 696. This metal is found in small quantities, in ores of zinc, from which it is separated by sulphuretted hydrogen. It is white, like tin; very ductile and malleable. It fuses considerably under a red heat, and is nearly as volatile as mercury. It is a metal of no importance.

Copper: Cu: Eq: 395·7. This most valuable and extensively diffused metal is found native and crystallized, but the ore from which it is extracted for purposes of commerce, is *copper pyrites*, a double sulphuret of copper and iron. Much skill and experience is required in reducing this ore, for, as neither copper nor iron are volatile, it is necessary to oxidate and convert the iron into a fusible slag by roasting the ore in contact with siliceous matter, and then by repeated calcinations and additions of small portions of sand, gradually to expel the sulphur and the remainder of the iron. Much copper is obtained by throwing fragments of old iron into reservoirs in which the drainage water of copper mines is collected. This water holds much sulphate of copper in solution.

The general characters of copper are well known. It ranks in hardness next to iron, and is one of the most malleable of the metals. It is incapable of decomposing water, except at a bright red heat. At ordinary temperatures, if air be excluded, the generality of the acids are without action on copper, but its oxidation is promoted in a remarkable manner when air has access to it; under these circumstances, the feeblest acids act upon it, and hence it is, that the metal has occasionally found its way into culinary preparations with fatal effects, the soluble salts of copper being highly poisonous.

Copper forms with oxygen, suboxide, Cu_2O, and protoxide, CuO. The suboxide of copper exists in nature, constituting *ruby copper ore*: artificially, it may be prepared by igniting five parts of black oxide with four of copper filings, or by fusing three parts of subchloride of copper,* and two of dry carbonate of soda. It is a reddish-brown powder, and as it resists the action of air and moisture much better than the metal itself, it is usual to convert the surface of the vessels of copper into suboxide, or bronze them as it is termed. This is effected by covering them with a paste of red oxide of iron, which, when heated, is reduced to protoxide, and by digesting in a boiling solution of acetate of copper, the vessels are freed from the protoxide of iron and cleaned.

Protoxide of copper, which is the base of the ordinary salts of copper, is best prepared by the ignition of the nitrate. It is remarkable for the facility with which it is reduced, at a low red heat, by carbon and hydrogen, a property which renders it exceedingly useful in the analysis of organic substances, as will be seen in the next lecture.

When ammonia is added to solution of oxide of copper, a greenish precipitate is produced, soluble in an excess of ammonia, producing a fine blue solution. Oxide of nickel has been stated to behave in the same manner with this reagent, but the two metals are easily distinguished by yellow prussiate of potash, which, with copper, produces a fine chocolate-coloured precipitate. The surest way of detecting slight traces of oxide of copper in solution, is to precipitate it in the state of metallic copper by clean iron, as the blade of a knife.

Organic substances do not interfere with this test, though they do in a remarkable manner with others. Ammonia, for instance, does not communicate a blue colour to a solution of copper, contaminated by non-volatile organic substances, un-

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* Prepared by heating copper filings with twice their weight of corrosive sublimate.

less the oxide of copper be present in considerable quantity, and the colour of the liquor may be too dark to allow the detection of the poisonous metal by yellow prussiate of potash, when, for instance, it is contained in red wine.

When the object is to detect the presence of copper, in food which has been boiled in copper vessels; or in bread, which has been adulterated with very small quantities of blue vitriol, the best method of performing the operation is as follows:—mix the substance into a paste with water, and heat it first gradually, and then for a quarter of an hour at a full red heat in a Hessian crucible, with twice its weight of pulverized crystals of carbonate of soda. When the mass is cold, moisten it with water and pulverize very finely in an agate mortar, then pour on more water, and after stirring well, pour it off with the charcoal powder in suspension; continue this till all the charcoal is removed, and if any copper be present it will be found at the bottom of the mortar in the state of minute copper coloured scales. A portion of the substance, unmixed with the alkaline carbonate, should be laid at the bottom of the crucible, to prevent any accident which might arise from the action of the alkali on the crucible.

The best precipitant of oxide of copper, in quantitative determinations, is caustic potash. From iron it is separated by sulphuretted hydrogen, the sulphuret of copper being subsequently oxidized by nitric acid, converted into sulphate by sulphuric acid, then precipitated by caustic potash. In weighing oxide of copper, it must be remembered that it attracts moisture very eagerly, it should, therefore, be ignited in a platina crucible, and put into the scale the moment it is sufficiently cooled, the crucible being closely shut with its cover.

Many of the alloys of copper are of considerable importance. With gold, it forms a fine yellow ductile compound, used for coin and ornamental work. Standard gold consists of 11 gold + 1 copper.—*Brande*. With silver, it forms a beautiful white compound, used also for coin. With zinc, it forms a great number of alloys, the most important of which is brass:* with tin, it forms bronze, gun-metal, bell-metal, and speculum-metal.† It has been before stated, that an alloy, consisting of one part of nickel to five of brass, is much employed as a substitute for silver, under the name of German or nickel silver. Mr. J. D. Smith gives the following method of analyzing this compound, which I have found to answer well. The alloy is dissolved in nitro-muriatic acid, the solution strongly acidified with muriatic acid and diluted with water; the copper is then precipitated in the usual manner by sulphuretted hydrogen, and after its separation, the solution containing the zinc and nickel is carefully evaporated to dryness, and redissolved in water acidulated with acetic acid. It is then diluted, and sulphuretted hydrogen again passed through in excess; by this means, the oxide of zinc is completely separated from the oxide of nickel in the state of sulphuret of zinc, and the nickel is then thrown down as a hydrate from the remaining solution, (which is previously heated, to expel the sulphuretted hydrogen,) by caustic soda. The hydrate of nickel is reduced by strong ignition to protoxide, and weighed.

Lead: Pb: (plumbum) Eq: 1294·5. For purposes of com-

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* The best brass consists of four equivalents of copper to one of zinc, and by changing the proportions of the metals, a variety of shades of gold lustre, used in counterfeit jewellery are obtained. *Hard solder*, used in uniting together surfaces of brass and copper, consists of copper and zinc in equal parts. In the analysis of brass, it is not advisable to attempt the separation of the oxide of copper from its solution by caustic potash, as a portion of oxide of zinc always falls with it. The complete separation of the two metals is, however, perfectly effected by sulphuretted hydrogen, passed through the acidulated solution.

† The bronze used in the earliest ages, as a substitute for steel, is found to have the same composition as that now employed in the casting of statues and monuments, namely, 90 of copper and 10 of tin. Gun-metal is an inferior bronze, containing less tin. The best bell-metal consists of 80 parts of copper and 20 of tin; this is also the composition of the Indian gongs, but in common bells there is less tin, and in place of it some lead and zinc. The beautiful speculum-metal, used for the mirror-surface in reflecting telescopes, is formed of 127 parts of copper and 59 of tin; the whiteness is improved by the addition of a little arsenic. The analysis of alloys of tin and copper may be performed by digestion in nitric acid, which dissolves the copper and converts the tin into an insoluble peroxide, consisting of 78·4 tin, and 21·6 oxygen.

merce, this metal is extracted from *galena,* the native sulphuret. The ore is heated to redness in a current of air, by which part of the sulphur is burned, the remainder, with the lead, becomes oxidized, sulphate of lead being formed; more ore is then added, and at the same time *lime,* which assists the reduction of the sulphate of lead by combining with the sulphuric acid, leaving oxide of lead, which is reduced by the fuel. The general characters of lead are well known. It melts at 612°. When in mass, it is not disposed to combine rapidly with oxygen, but its surface, which when newly cut is very brilliant, rapidly tarnishes. Pure or rain water cannot be kept in vessels of lead without becoming impregnated with the hydrated oxide, which is highly poisonous; spring water does not, however, become affected, in consequence of the sulphates and chlorides, which it usually contains, converting the oxide of lead into an insoluble salt.—*Christison.*

Lead forms, with oxygen, two direct compounds, PbO, and PbO_2, besides an intermediate oxide, Pb_2O. Protoxide of lead may be prepared as a hydrate, by decomposing a soluble salt of the metal by caustic potash, taking care to avoid great excess of the precipitant, which redissolves the oxide. The *litharge* of commerce is prepared by exposing metallic lead at a red heat to a current of air; protoxide of lead is produced which fuses and crystallizes on cooling: *massicot* is the same oxide produced at a lower temperature. This oxide of lead combines with most of the alkalies and earths, forming compounds more or less soluble. When lime and litharge are boiled together, a crystallizable compound is formed, which, when applied to the hair, dyes it black, in consequence of the formation of a *sulphuret* of lead, from the *sulphur naturally* existing in the hair.—*Kane.*

Peroxide of lead is of a dark earthy brown colour. It is obtained by digesting the protoxide in chlorine water, or in a solution of chloride of lime.

Minium or red-lead, is formed by heating *massicot* to incipient redness; oxygen is absorbed till one-third of the metal is converted into peroxide, and the compound has the constitution $2PbO+PbO_2$.

Dilute sulphuric acid is an excellent test for lead in solution, it produces a white precipitate, readily distinguished from the earthy sulphates by its solubility in caustic potash, and by its instantly becoming black when moistened with hydrosulphuret of ammonia.

Iodide of potassium forms, with soluble salts of lead, a yellow precipitate, which, by boiling, assumes the appearance of scales of gold leaf.

Salts of lead, when mingled with soda, and heated on charcoal, before the blowpipe, in the inner or deoxidizing flame, are reduced to metallic globules, which may be known to be lead by being easily flattened by the hammer.

When mixed with organic matters in solution, lead may be detected by passing a current of sulphuretted hydrogen through the liquor, and the metal itself demonstrated by subsequently fusing the sulphuret with soda, on charcoal, before the blowpipe; but when lead is mingled with solid organic substances, it is detected by fusion in a Hessian crucible, with carbonate of soda, as directed for copper.

In quantitative determinations the best precipitant for oxide of lead is oxalate of ammonia; the oxalate of lead being subsequently converted into protoxide, by ignition, in a platina crucible. From oxides of nickel, cobalt, zinc, iron, manganese, and from the earths and alkalies, it is completely separated by sulphuretted hydrogen, and from oxide of copper it is separated by converting the solution of both oxides in nitric acid, into sulphates, evaporating to dryness and pouring water over the remainder, which dissolves the sulphate of copper, leaving the sulphate of lead undissolved; should a small portion of sulphate of lead, however, be dissolved, it may be precipitated by oxalate of ammonia, after the sulphate of copper has been decomposed and removed by caustic potash.

According to Gustavus Switzer, (see L. & E. Phil: Mag: vol. 8, page 267,) many chemical preparations, such as the bicarbonates of potash and soda, the sub-carbonates of magnesia and ammonia, &c., are contaminated with lead. The source of this impurity is to be traced, partly to the employment of leaden vessels, and partly to the *white glass bottles* used in this country, which, according to Faraday, contain 33·28 per cent. of oxide of lead. Alkaline substances, and particularly caustic alkalies, act very powerfully on white glass, hence, bottles made of this glass, are not fit either for chemical or medical purposes.

When an alkaline fluid contains lead, the best test that can be applied, is the hydrosulphuret of ammonia, as this reagent will detect $\frac{1}{500000}$ gr. of crystallized acetate of lead. Chromate of potash is also an excellent test, it will indicate traces of lead when sulphate of soda ceases to do so.

Bismuth: Bi: Eq: 886·9, or 2660·7. This metal is found in the metallic state, and is separated from the rocks through which it is disseminated by simple fusion. It is a white metal with a peculiar reddish shade, and highly crystallizable. It is very brittle and easily oxidizable, for though sulphuric acid acts on it with difficulty, it decomposes nitric acid with violence. It is employed extensively in the formation of stereotype plates. Its alloys are remarkable for their fusibility, and its amalgam is highly liquid. An alloy of 8 parts bismuth, 5 lead, and 3 tin, melts at 202°, and one of 2 bismuth, 1 lead, and 1 tin, at 200·75.

Bismuth combines with oxygen in two proportions, forming BiO, and BiO_2. The first, or protoxide, is a straw-yellow powder, formed either by the combustion of the metal, or by the ignition of the subnitrate. The peroxide is a dark brown powder, formed by boiling the anhydrous protoxide, finely levigated with chloride of soda. All the soluble salts of this metal are decomposed by water, which combines with the acid and throws down the oxide.

In solution, bismuth is recognized by the milkiness produced on the addition of water, and by the dark-brown precipitate occasioned by liquid sulphuretted hydrogen. Heated with soda in the inner flame, before the blowpipe, salts of bismuth are reduced, the charcoal becoming coated with a yellow powder; the metallic globules are brittle and spring to pieces under the hammer.

Carbonate of ammonia is the best precipitant of oxide of bismuth, even when the solution has been rendered milky by the addition of water. From lead it is separated by sulphuric acid, the sulphate of bismuth being soluble; but as the sulphate of lead is not quite insoluble, it is better to add to a *cold* solution of the two metals, carbonate of lime, by which the oxide of bismuth alone is precipitated. If carbonate of lime be *boiled* with a solution of lead and bismuth, both oxides are completely precipitated.—*Liebig*. Another method of separating lead from bismuth is, to add to a solution of both metals in nitric acid, potash or soda in excess and boil for some time;—the oxide of bismuth is precipitated in the state of a hydrate, which loses its water during ebullition and becomes yellow; after washing, it is only necessary to dry it, as it would not lose more weight by calcination. The lead is then determined by supersaturating the alkaline solution by acetic acid, and precipitating by oxalate of ammonia. It is absolutely necessary that neither the nitric acid nor the potash should contain any muriatic acid, for in that case a sub-chloride would be precipitated, which the alkalies do not decompose, whilst they completely decompose the nitrate and sulphate.

This method is founded on the fact, that oxide of bismuth is quite insoluble in the caustic alkalies, whereas, the oxide of lead is completely soluble.—*Stromeyer*.

From those metals whose acid solutions give no precipitate with sulphuretted hydrogen, it is separated by that reagent, and from copper it is separated by excess of carbonate of ammonia.

Tin: Sn: (stannum) Eq: 735·3. This metal appears to have been known from the earliest ages. The ore from which it is extracted is found abundantly in Cornwall, and is reduced with the greatest ease. The tin is purified from any admixture of foreign metals by *liquation*, a process which consists in gently heating the ingots until they begin to melt, taking care to prevent the temperature from rising too high; the pure tin is first melted, and the less fusible alloys, containing the foreign metals, remain. The purer portion is well-known as *grain tin*, the other as *block tin.* The purity of the metal is known by its splitting into irregular prisms when let fall in a melted state into water. Tin is a silver-white, very soft and malleable metal, fusing at 442°, and but slowly acted upon by water, hence its great use for culinary vessels, and for covering the more oxidable metals. When a bar of tin is bent backwards and forwards rapidly, it emits a characteristic grating sound and becomes hot. Tin forms three compounds with oxygen, SnO, Sn_2O_3, and SnO_2.

Protoxide of tin is formed by heating in a retort, filled with carbonic acid gas, the hydrated oxide produced on adding ammonia to a solution of the protochloride. It is a black powder, remarkable for its tendency to unite with more oxygen. Solutions of protoxide of tin, convert peroxide of iron into protoxide, and throw down mercury, silver, and platinum in a metallic state from their solutions. If the black protoxide of tin be touched with a red-hot coal, it inflames and burns like tinder, forming peroxide.

Deutoxide or sesquioxide of tin is prepared by boiling peroxide of tin in a neutral solution of the protochloride.

Peroxide of tin is readily prepared artificially, by pouring strong nitric acid on metallic tin in foil or powder. The hydrated peroxide is obtained as a transparent gelatinous precipitate, by decomposing a cold solution of the bichloride by an alkaline carbonate, and washing with cold water; in this state it is soluble in hydrochloric acid.

When tin is dissolved in strong hydrochloric acid, a crystallizable protochloride is formed, which is extensively used in dyeing as a mordant; it is remarkable for its affinity for oxygen, reducing the salts of silver, mercury, and gold to the metallic state, and deoxidizing indigo. It is extensively used in calico-printing, for reducing to a lower state of oxidation, and discharging the peroxide of iron and manganese fixed upon cloth.

Another compound of tin, much used in dyeing is, the bichloride or nitro-muriate, prepared either by oxidizing crystallized protochloride of tin by nitric acid, or by dissolving tin in a mixture of hydrochloric and nitric acid, avoiding any considerable elevation of temperature.

When peroxide of tin, sulphur and sal-ammoniac, are ignited in a covered crucible, *aurum, musivum,* or *mosaic gold* of the alchemists is formed. It is a bisulphuret of tin, SnS_2. The best method of preparing it is the following. Twelve parts of pure tin are to be melted, with six parts of mercury, and rubbed up in a glass mortar, with seven of flowers of sulphur and six of sal-ammoniac. This mixture is to be placed in a glass flask, and heated in a sand-bath, until no more fetid white vapours are given off. The heat is to be then raised to dull redness, sulphuret of mercury and chloride of tin sublime and the mosaic gold remains in the bottom of the vessel, in metallic looking scales of a brilliant gold colour.

Tin, alloyed with small quantities of copper, antimony, and bismuth, forms the best kind of pewter, possessing peculiar whiteness. When tin is dissolved in a mixture of one part of nitrate of potash, two of alum, two of common salt, and a certain quantity of water, a mixture is formed which is used to tin pins.

Hydrosulphuret of ammonia produces, in protosalts of tin, a brown, and in persalts a golden yellow precipitate, soluble in excess of the precipitant; a bar of metallic zinc precipitates tin from solutions of its protosalts in a metallic state, and in the form of small greyish-white spangles. But solutions of protosalts of tin, are best known by their behaviour with solution of gold, a reddish-purple colour being produced in dilute solutions, and a dark purple precipitate, insoluble in muriatic acid, in concentrated solutions.

Tin is usually quantitatively estimated by converting it into peroxide by means of nitric acid; if hydrochloric acid be present it must be expelled by heat. When combined with those metals that are not precipitable from acid solutions by sulphuretted hydrogen, or with the earths and alkalies, tin may be separated by that reagent; from oxides of cadmium, lead, bismuth, copper, silver, and mercury, all of which are precipitable by sulphuretted hydrogen, it is best separated by supersaturating the concentrated solution with ammonia, and precipitating by excess of hydrosulphuret of ammonia: if the tin be in the state of protoxide, the hydrosulphuret of ammonia employed, must be mixed with a little sulphur, and the resulting sulphuret of tin converted into peroxide by nitric acid.

Titanium: Ti: Eq: 303·7. This metal is found in the form of titanic acid in a great variety of minerals; it is reduced with great difficulty, being nearly infusible; it is of a bright copper colour. It combines with oxygen in two proportions, forming TiO, oxide of titanium, and TiO_2, titanic acid, which is a white powder resembling silica, and characterized by its solution in muriatic acid, giving, with tincture of galls, an orange precipitate, and by the immersion of a slip of zinc, a fine purple powder. When titanium exists in solution as titanic acid, it is best precipitated by ammonia, the precipitate must be weighed in a closed platina crucible, as titanic acid has a great attraction for moisture.

Chromium: Cr: Eq: 351·8. This metal derives its name from χρῶμα, colour, being distinguished for the variety and beauty of the colour of its compounds. It is a greyish-white metal, very infusible, and reduced with very great difficulty. It combines with oxygen in two proportions, forming Cr_2O_3, oxide of chromium, and CrO_3, chromic acid.

Oxide of chromium may be obtained by heating chromate of mercury* to redness. It is a fine green coloured powder, insoluble in acids after ignition. As a hydrate, oxide of chromium is obtained by adding to a boiling solution of bichromate of potash, hydrochloric acid and alcohol alternately in small quantities, till the colour of the solution passes from red to green; the oxide is then precipitated by ammonia; it is of a pale blueish-green colour, soluble in acids, and forming an extensive class of salts.

Chromic acid is prepared by treating a warm solution of bichromate of potash by hydrofluosilicic acid gas, till the potash is completely separated, which may be ascertained by testing a few drops of the solution with chloride of platinum; the solution is evaporated to dryness by a steam-heat, and the chromic acid re-dissolved by water; it gives an opaque dull red solution.

Alkalies give a green precipitate with solutions of oxide of chromium. Before the blowpipe, the compounds of chromium are readily detected by the beautiful emerald-green colour which they communicate to fluxes. Oxide of copper produces with microcosmic salt, a green bead in the outer flame only, but with oxide of chromium, the colour is equally green both in the inner and outer flame.

Oxide of chromium in solution is best precipitated by caustic ammonia; it should be ignited in a covered platina crucible, as it is apt to become suddenly incandescent when heated to a particular point, and be projected from the vessel. When chromium exists in solution, in the state of chromic acid, it may be quantitatively estimated by precipitating it by solution of nitrate of barytes or nitrate of lead; or it may be reduced to oxide of chromium by means of hydrochloric acid and

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* Prepared by mixing chromate of potash and nitrate of mercury in solution.

alcohol as above, and then precipitated by caustic ammonia.

When chromic acid and oxide of chromium exist together in solution, they may be separated by acetate of lead, chromate of lead being precipitated, and oxide of chromium and the excess of oxide of lead remaining in solution; a solid compound of chromic acid and oxide of chromium may be examined, if recently precipitated, by digesting with solution of acetate of lead, oxide of chromium is thereby obtained in solution, while chromate of lead remains undissolved.

Vanadium: V: Eq: 856·9. This is a very rare metal, discovered by Sefstrœm, in 1830. Its combinations closely resemble those of chromium and manganese; of its properties as a metal little is known.

Tungsten or *Wolfram:* W: Eq: 118·3. In the form of tungstic acid this metal exists in several minerals. It derives its name from the density of its preparations, the word *tungsten,* signifying in Swedish, heavy stone.

Tungstic acid, WO_3, is reduced by heating it to redness in a glass tube, in contact with hydrogen; the metal, as thus obtained, is in the state of a dense dark grey powder, extremely infusible, more so even than manganese.

Tungstic oxide, WO_2, is formed when tungstic acid is reduced by hydrogen, at a temperature not exceeding low redness.

When to fused tungstate of soda, there is added as much tungstic acid as it will take up, the mass being then exposed at a red heat to hydrogen gas, there is left, after the undecomposed tungstate of soda is washed out by water, a compound, in golden yellow scales and regular cubes, bearing so striking a resemblance to gold, that had it been discovered when the rage for alchymy was prevalent, there is no doubt it would have lent plausible support to the belief in transmutation.

Molybdenum: Mo: Eq: 598·5. This metal is closely allied to tungsten; it exists combined with sulphur, and also with oxygen in some minerals. Its oxides, of which there are three, molybdous oxide, MoO, molybdic oxide, MoO_2, and molybdic acid, MoO_3, are easily reduced when exposed to a strong heat in a crucible lined with charcoal, but the metal itself is very refractory. It derives its name from the Greek term for plumbago, from which its native sulphuret was first distinguished by Scheele, in 1778.

Tellurium: Te: Eq: 801·8. Although from its lustre and power of conducting electricity, tellurium is classed with the metals, it ranks naturally with sulphur and selenium; like these elements, it dissolves to a small extent in concentrated sulphuric acid, and communicates to it a fine purple colour. It is silver white and very brilliant. It has been found lately in considerable abundance in Schemnitz, in Hungary, combined with bismuth; and in the silver mine of Sadovinski, in the Altai, united with silver and lead; it was first described by Klaproth. It is only separated from foreign bodies by a very complicated process, hence, in its pure state it is very rarely met with. It combines with oxygen in two proportions, forming tellurous acid, TeO_2. and telluric acid, TeO_3. It combines also with hydrogen, forming a compound analogous in constitution and properties to sulphuretted hydrogen.

Arsenic: As: Eq: 940·1. In combination with other metals, particularly with nickel and cobalt, arsenic is found in considerable abundance. It is obtained in the form of arsenious acid, by roasting the ores containing it in a furnace, so constructed that a powerful oxidizing action shall be produced by a current of air streaming over the ignited ore. The metal itself is obtained in the form of a metallic crust, of a steel-grey colour and a bright metallic lustre, by heating common arsenious acid with three times its weight of black flux,* in a crucible, over which a larger crucible is inverted; the metal condenses on the inside of the upper vessel. Arsenic is very volatile, rising in vapour at 56°, and emitting a disagreeable

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* Prepared by deflagrating together equal parts of nitre and cream of tartar.

odour resembling garlic, which arises from the formation of a peculiar oxide, produced by a low degree of combustion which occurs, but which does not belong to the pure metal.—*Kane.*

Arsenious acid : AsO_3, is well known in commerce as white oxide of arsenic. It is equally well known as the poison by which more deaths have been occasioned, probably, than by any other substance. Its recognition is, therefore, one of the most important analytical problems, and one on which a corresponding degree of attention has been expended. In a solid and unmixed state, arsenious acid is known as a white, heavy, and nearly tasteless powder, entirely volatile by heat, and diffusing a garlic odour in the reducing flame of a lamp.

In cases of poisoning by arsenious acid, when the aid of the chemist is called in, his object should be directed to the isolation and exhibition of the metal itself: as collateral evidence, the indications of tests are useful, but they should never, in so important an investigation, be regarded as alone decisive, for although in solutions of arsenious acid prepared for illustration, their action may be very satisfactory, their indications become complicated and uncertain in the organic and discoloured liquids obtained from the stomach and intestines.

The following are the methods recommended.

1st. The contents of the stomach, and the ejected matter is to be boiled well in distilled water for half an hour, with the addition of a few drops of nitric acid, then strained through calico, and the animal matter precipitated by excess of nitrate of silver, and the subsequent addition of common salt; then filtered through paper, and a current of sulphuretted hydrogen sent through the liquid for half an hour; after which the liquid must be boiled, and the precipitated substance received on a filter, washed well with water, slightly acidulated with hydrochloric acid, and dried at a temperature not exceeding 300°. If, previous to the straining through calico, the matter experimented upon be thick very and coloured, it may be convenient to coagulate the animal matter by a current of chlorine, the excess of which must afterwards be expelled by boiling.

2nd. The dried precipitate is mixed with twice its weight of black flux, and ignited in a small tube of hard glass, of the form, and about the size of the tube shown in *Fig.* 17. If any arsenious acid was present in the liquid operated upon, it will sublime as metallic arsenic, forming a steel-grey crust, brilliant on the side next the tube, but dull and crystalline on the inside. This metallic crust may then be removed carefully, and slowly heated in a test-tube, in size and shape such as is represented in *Fig.* 7; a white crystalline sublimate of arsenious acid will be formed, which may be dissolved in water, and the solution divided into three portions. Through the first, a current of sulphuretted hydrogen should be slowly passed; a rich yellow precipitate will fall,—this is sulphuret of arsenic or orpiment. Into the second portion, ammonio-nitrate of silver* should be dropped, arsenite of silver of a fine *canary yellow* colour will be precipitated, which is re-dissolved both by acids and ammonia; to the third, a few drops of ammonio-sulphate of copper should be added, when a fine apple-green precipitate, soluble in excess of acid and ammonia, will be produced.

The presence of arsenic in the subject of the experiment is, by the combined evidence thus adduced, placed beyond doubt, but the test results are not alone decisive, for 1st; sulphuretted hydrogen produces yellow precipitates with cadmium, antimony, and persalts of iron and tin; 2nd: ammonio-nitrate of silver produces a yellow precipitate with phosphate of soda; and 3rd: there are many basic compounds of copper, which very much resemble the arsenites.

We are indebted to Mr. Marsh for the following simple and elegant mode of detecting small quantities of arsenic. It is

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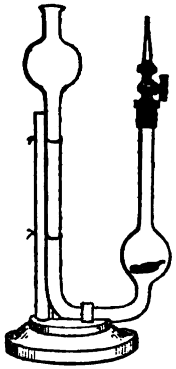
* This is an exceedingly delicate test; it is prepared by adding diluted ammonia to a solution of nitrate of silver, till the oxide of silver, which is first thrown down, is again redissolved.

founded on the fact, that whenever hydrogen gas is generated in contact with any soluble or insoluble preparation of arsenic, a portion of the metal is dissolved, and arseniuretted hydrogen formed.

Fig. 95.



Having removed the stop-cock from the little arrangement, shown in *Fig.* 95, a fragment of zinc is introduced into the lower bulb, and diluted sulphuric acid poured upon it; the stop-cock is now replaced, and the lower bulb soon becomes filled with hydrogen gas, the acid liquor being forced into the upper bulb. It is necessary to test this hydrogen for arsenic, before the suspected substance is introduced into the apparatus; with this view it is ignited at the apex of the jet, attached to the stop-cock, and a stone-ware plate depressed upon the flame and allowed to remain for a few seconds; if any arsenic was present in the zinc, or in the sulphuric acid, a black spot of a steel-grey colour and bright metallic lustre will be formed upon the plate; or if a cold object of glass be held over the flame at a small height above it, a white sublimate of arsenious acid will condense upon the glass. If no arsenic be present in the zinc or acid, neither of these effects will be perceived. The suspected liquor is now introduced into the lower bulb, together with the acid and zinc, and the hydrogen burned as before. It is desirable previously to remove as much as possible of the organic matter in the liquor to be tested by means of chlorine or nitrate of silver, but when it is, notwithstanding, thick, the operation may be conducted in a flask, provided with a horizontal tube, and the liquor rendered very feebly acid, so that the gas shall be generated very slowly; a portion of the tube may be kept red hot for two or three hours, so that all the arsenic dissolved by the hydrogen gas may be arrested in its passage along the horizontal tube, and fixed in a metallic form on the tube, at a little distance beyond the heated portion; or if the operation is to be allowed to go on for a considerable time, the end of the horizontal tube may be allowed to dip under the surface of a dilute solution of nitrate of silver, or sulphate of copper, and all the arseniuretted hydrogen being then absorbed and decomposed, metallic arseniurets are produced, which easily yield by the application of heat—arsenic, in a metallic form.—*Graham, Kane, Liebig, Clark.*

In testing for arsenic, particular care must be taken to ascertain, beyond the possibility of doubt, that the poisonous metal does not exist in any of the reagents employed. It has been before remarked, that traces of it are met with occasionally in the oil of vitriol of commerce, and as the ores of zinc contain orpiment, that metal should be distilled before it is regarded as pure. To avoid all chances of error, a jet of hydrogen, generated from the zinc and oil of vitriol alone, should be passed for a quarter of an hour through ammonio-nitrate of silver, and if no yellow deposition occur, the suspected liquor may be employed with confidence. The operator should also be careful not to allow the hydrogen to be generated too fast, as a portion of zinc or zinc salt may, perchance, become carried up in the steam and deposited upon the plate or glass.

Another source of error is not a little remarkable. It was discovered by Mr. L. Thompson, that hydrogen combines with antimony, forming a gas, which when heated in a glass tube, gives the metal and a white sublimate in the same circumstances as arsenic. It is not, however, difficult to distinguish between the two.

1st. The deposition of antimony occurs on the *heated* portion of the tube, that metal being far less volatile than arsenic.

2nd. The metallic crust is not volatilized at any temperature that can be applied to glass.

3rd. If the white sublimate from antimony be dissolved in water, containing a drop of ammonia, and the arsenic tests applied, the proper indications of the latter metal will not be afforded.

Mr. Marsh gives the following method of distinguishing between these two metals in cases of suspected poisoning. "After the common arrangements have been made for testing for antimony or arsenic, the piece of glass or porcelain on which the metallic crusts are generally received, is to have a drop of distilled water placed on it; the glass or porcelain is then to be inverted, so that the drop of water is suspended undermost. The gas as it issues from the jet is to be inflamed in the usual manner, but the piece of glass with its drop of water is to be held about an inch above the jet, or just above the apex of the cone of flame. The arsenic by this arrangement is oxidized at the same time that hydrogen is undergoing combustion, and coming in contact with the drop of water held above, forms with it a strong or weak solution of arsenious acid, according to the quantity of arsenic present. A very minute drop of Hume's test, (ammonia-nitrate of silver) being now dropped on the solution so obtained, if arsenic be present, the well-known characteristic lemon-yellow colour is immediately produced; antimony, under these circumstances, from being insoluble, produces no change."

When much arsenic is present, Mr. Marsh uses a glass tube, six inches long and half an inch in diameter, slightly moistened in the interior with distilled water, and held vertically over the apex of the jet of burning gas; by this means a strong solution is obtained.

If a drop of ammonia-nitrate of silver be placed upon a slip of glass, and held over the flame of hydrogen, containing arsenic, the well-known characteristic lemon-yellow colour is produced: if antimony alone be present, a *curdy-white* precipitate is obtained.

In cases of poisoning by arsenic, where tartar-emetic* has been given to produce vomiting, it is very possible that both

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* Tartrate of potash and antimony.

metals may be detected together in the matter found in the stomach; they may be separated by converting both into the hydrogen compounds and decomposing the mixed gases by igniting the tube through which they pass. The antimony is deposited close to the heated part, and the arsenic at a little distance.—*Kane.*

When arsenic is to be separated from copper, as in the examination of Scheele's green, a portion of the precipitate from the muriatic solution, by sulphuretted hydrogen, is to be mixed with four times its weight of carbonate of potash, and eight times its weight of nitre, and heated in a glass vessel until it melts. The resulting mass (which will probably be of a dark blue colour,) is to be boiled for some time in water, pure oxide of copper will remain undissolved, and the arsenic may be separated from the solution in the usual manner, or the solution, after the separation of the copper, may be supersaturated with muriatic acid, and the quantity of sulphuric acid ascertained by a salt of barytes. The quantity of sulphur added to the metallic copper, and that deducted from the weight of the combined sulphurets, gives the quantity of the sulphuret of arsenic, from which the weight of the arsenic may be calculated.—*Buckner, Annalen der Physik and Chemie.*

The best antidote to arsenious acid, is the hydrated peroxide of iron, which should be taken as it is obtained by precipitation, without drying. It may be prepared by adding bicarbonate of soda in excess, to any tincture or red solution of iron. The arsenious acid takes a portion of oxygen from the peroxide of iron, and becomes arsenic acid, which uniting to the protoxide of iron, gives rise to an insoluble protarseniate of iron.

Arsenic acid: AsO_5, is obtained by boiling eight parts of arsenious acid, with two of strong hydrochloric, adding in small quantities at a time, twenty-four parts of nitric acid, sp: gr: 1·25. The mixture is evaporated to dryness and heated in a platina capsule till all the nitric acid is expelled. The compounds of arsenic acid bear a very close analogy to those of phosphoric acid, indeed, so remarkable is the resemblance of function between phosphorus and arsenic, that the latter element may replace the former in the bones, arseniate of lime being substituted for phosphate of lime, and even in the blood it is possible that arsenic salts may replace those of phosphoric; the discovery of arsenic, therefore, out of the alimentary canal ought to be received with very great caution as evidence of its having been intentionally administered.

Antimony, Stibium: Sb: Eq: 1612·9. This metal is reduced from the native sulphuret by projecting in small quantities at a time, into a red-hot crucible, a mixture of four parts of the sulphuret, three of crude tartar, and one and a half of nitre. It is a white and brilliant metal, possessing a highly lamellated structure. It undergoes no change in the air, but at a red heat it burns and emits copious fumes of oxide. It combines with oxygen in three proportions, forming oxide of antimony, SbO_3, antimonious acid, SbO_4, and antimonic acid, SbO_5. It combines also with hydrogen, forming a compound which has been already described. It is prepared by dissolving zinc in dilute sulphuric acid, to which tartar emetic has been added.

Oxide of antimony is formed by dissolving prepared sulphuret of antimony in four times its weight of concentrated hydrochloric acid, and precipitating by solution of carbonate of potash added in excess: it is white, but when heated it acquires a yellow tinge.

Antimonious acid is a white powder, formed by oxidating metallic antimony by nitric acid. Antimonic acid is a pale yellow powder, prepared by oxidating *oxide* of antimony by nitric acid, driving off the excess of nitric acid by a heat short of redness.

Antimony in solution is detected by sulphuretted hydrogen, which precipitates an orange-yellow sulphuret, easily distinguished from orpiment by not being volatile, and from sulphuret of tin by the formation of the gaseous compound with hydrogen.

Antimony may be quantitatively estimated as sulphuret by precipitating it from its acid solution by sulphuretted hydrogen: in drying it, care must be taken not to employ too high a heat.

When antimony is to be separated from lead, as in the analysis of the colour, known in commerce by the name of *Naples yellow*, about 30 grains of the compound are to be carefully mixed with 75 grains of sulphur and 150 of recently heated carbonate of potash, and the whole melted in a glass retort; as soon as it is uniformly liquid and the dark brown mass cool, the retort is to be filled with water. The sulphuretted solution contains all the antimony, and the undissolved residue all the lead as a sulphuret. The latter may be dried and the quantity of lead calculated.

The solution containing the antimony must be carefully neutralized by dilute hydrochloric or acetic acid, and the precipitate collected on a weighed filter, dried, weighed, and a portion reduced to the metallic state by means of a stream of dry hydrogen gas, in the apparatus shown in *Fig.* 77. The quantity of each metal being thus ascertained, the state of the oxidation of the antimony may be ascertained by calculating the lead found as an oxide, adding its weight to the weight of the antimony, and deducting the combined weight from that of the sample examined; the difference gives the quantity of oxygen, combined with the antimony.—*Brunner Poggendorff's Annals, No.* 5, 1838, p. 135.

Uranium: U. Eq: 2711·4. The mineral *pitchblende*, consists principally of protoxide of uranium, and from it the metal is extracted by a complex operation. It is of a dark grey colour and with great difficulty fusible. It forms two compounds with oxygen, protoxide, UO, and U_2O_3, peroxide, the latter is a yellow powder, and is employed to colour glass.

Cerium: Ce: Eq: 574·7 *Lantanum.* These two metals are found in a few rare minerals, and have only recently been distinguished from each other; the latter was lately discovered by Mosander in the oxide of cerium usually made, he gave it the name of *lantanum*, from the Greek *λανθανω*, because it was so long hidden in the oxide of cerium.

Tantalum, or *Columbium:* Ta: Eq: 2307·4. This metal was discovered by Mr. Hatchett, in an American mineral. It was extracted with very great difficulty. It is a black powder and is not acted upon by any acid but the hydrofluoric. It combines with oxygen in two proportions, forming TaO_2 and TaO_3.

Mercury: Hg: (hydrargyrum,) Eq: 1265·8. This metal, which, from the importance attached to it by the ancients, in consequence of its remarkable properties, was very minutely studied in the infancy of Chemistry, is extracted from *cinnabar*, the native sulphuret. Its purity may be known by its fluidity, which is remarkably impaired by the admixture of foreign metals, and it is not unfrequently fraudulently adulterated with tin, lead, and bismuth, which it is capable of dissolving in considerable quantities; from these it may be purified by digesting it with a small quantity of nitric acid, or with a solution of chloride of mercury.

Mercury is well known to be distinguished from all other metals by being liquid at ordinary temperatures; it does not assume the solid form till cooled 39 degrees below zero; it then crystallizes in regular octohedrons. At 662° it boils, but it emits a sensible vapour at 68°. When pure, it is quite unaltered in the air at ordinary temperatures, but when heated near its boiling point it absorbs oxygen and forms crystalline scales of red oxide. It is not dissolved by boiling hydrochloric or diluted sulphuric acid, but it is readily acted upon by diluted nitric acid. Mercury combines with oxygen in two proportions, forming the black oxide Hg_2O, which is generally considered a suboxide, and the red oxide, HgO.

Black oxide of mercury is prepared by decomposing calomel[*] (sub-chloride of mercury,) by a cold solution of potash. It has a strong disposition to resolve itself into metallic mercury and a higher oxide; the mixture should, therefore be rubbed briskly in a mortar, in order that the decomposition may be as rapid as possible, and the oxide allowed to dry spontaneously in a dark place.

There are several ways of preparing the red oxide, or red precipitate as it is called in pharmacy. 1st. By the oxidation of the metal at a high temperature. 2nd. By heating crystals of nitrate of mercury till the vapours of nitric oxide cease to be emitted: or 3rd. By precipitating solution of corrosive sublimate[†] by excess of caustic potash. The colour of the oxide varies according to the process by which it is made; by the first, it is obtained in deep red crystals; by the second, in an orange-red crystalline powder; and by the third, as a lemon or canary-yellow hydrate. At a full red heat, red oxide of mercury is totally resolved into mercury and oxygen.—(See page 150.)

Hydrochloric acid and solutions of the chlorides occasion an immediate white precipitate in proto-salts of mercury, which is rendered black by ammonia. When any solid compound of mercury is heated in a hard glass tube with carbonate of potash,

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[*] This invaluable medicine is prepared either by precipitation or by sublimation. For the first, nine parts of mercury are digested in eight parts of nitric acid, sp : gr : 1·25 without heat, and a solution of eight parts of common salt, in 250 parts of boiling water added, calomel in a state of purity immediately precipitates. To obtain calomel by sublimation:—thirty-one parts of dry sulphate of red oxide of mercury are intimately mixed with twenty and one-third parts of metallic mercury, and twenty parts of fused common salt, and the whole rubbed together till the mercurial globules disappear. The sublimation is carried on in an earthen pot, to which a glass head is fitted, and the resulting calomel well washed with boiling water.

[†] Chloride of mercury. It is prepared on the large scale by adding four parts of mercury to five of sulphuric acid, and boiling till it is converted into a dry mass. This dry sulphate is then strongly heated in a retort, on a sand-bath, with an equal weight of common salt;—corrosive sublimate sublimes and condenses in the upper part of the retort, and sulphate of soda remains with the excess of common salt. It is highly poisonous. The best antidote is liquid albumen, with which it forms an inert compound.

a sublimate of metallic mercury is obtained; when the quantity is small, it appears as a ring of grey powder; but if viewed through a magnifying glass, it is seen to consist of minute metallic globules. Sulphuretted hydrogen added in excess, to a solution of peroxide of mercury, occasions a black precipitate; but if the mercurial salt be in excess, the precipitate becomes white on agitation. A drop of a solution of either protoxide or peroxide of mercury, placed on a piece of bright copper and rubbed off with paper, after having been for some time in contact, leaves upon the copper a silvery stain, which disappears when it is heated to redness.

When mercury is to be sought for in a solid organic substance, if it be not soluble in water, it should be dissolved, if possible, in ammonia, and a bright copper plate placed in the solution; but if the subject of the experiment be insoluble in ammonia also, it should be dried, mixed with three or four times its weight of carbonate of soda or potash, and gradually heated to redness, in a retort connected, not quite air-tight, with a receiver; if any mercury be present, it will be found in the interior of the neck of the retort, in minute metallic globules, easily recognised by rubbing the finger on the place where they appear, and examining through a lens.

Mercury is quantitatively estimated by reducing it to the metallic state; the agent usually employed is protochloride of tin, which effects the reduction of the metal, whether it exists in solution, or whether it be in the state of an insoluble chloride or peroxide; all that is necessary in the latter case is, to pour on the compound concentrated hydrochloric acid, and then boil for a few minutes with concentrated protochloride of tin, to which a sufficient quantity of hydrochloric acid, to render it clear, has been added. The reduced mercury has frequently the appearance of a black precipitate, which, however, speedily unites into larger globules, when boiled for a few minutes with hydrochloric acid. It must be dried by the action of the air alone.

Silver: Ag: Eq: 1351·6. This metal, which must have been known at a very early period, is principally derived from South America. Before the discovery of America, the silver mines of Saxony were of considerable importance. A considerable quantity of silver is also obtained from the ores of lead, by the following curious process. The *galena* is melted in a shallow porous dish, made of bone ashes, and when at a full red heat, a current of air is urged across it from a powerful bellows. The lead becomes converted into litharge, part of which is absorbed by the bone earth, and part blown away as it forms, and collected in the front of the furnace. The silver remains unaffected, and the completion of the oxidation of the lead is known by the melted surface suddenly becoming brilliant, or *flashing* as it is technically termed. This process has been much shortened by the discovery that the quantity of silver may be concentrated in a comparatively small quantity of lead by crystallization. The silver forms an alloy with a certain quantity of lead, which alloy is mixed with the excess of lead. Now it is found that this alloy is more fusible than lead itself, so that when a small quantity of silver is present in a large basin of lead, the whole is melted and allowed to cool very slowly, so as to crystallize; the portions which solidify first are pure lead, and these being removed, all the silver remains in the *mother liquor.*

To extract silver from its most frequent ore, the sulphuret. The ore is roasted in a reverberatory furnace, with 10 per cent. of common salt, by which it is converted into a chloride. It is then introduced into barrels with water, iron, and a small quantity of mercury, and agitated for eighteen hours. Chloride of iron is formed, and the silver enters into combination with the mercury, from which it is afterwards separated by distillation.

Silver is obtained pure for chemical purposes, by dissolving it in nitric acid, precipitating by common salt, and after well washing, and drying the chloride, projecting it a little at a time into twice its weight of carbonate of potash, fused in a crucible, chloride of potassium is formed, and carbonic acid and oxygen escape with effervescence; the crucible is then exposed to a sufficient heat to fuse the reduced silver which subsides to the bottom.* Although there are probably three compounds of silver with oxygen, only one of them, the protoxide AgO, is known well: this is formed by adding caustic potash or lime-water, to a solution of nitrate of silver. It is a brown powder, which, when heated strongly, is decomposed into metallic silver and oxygen. Silver is readily recognised in solution by the precipitation which occurs on the addition of common salt, by the action of solution of protosulphate of iron, which precipitates metallic silver, as do also protochloride of tin and formiate of soda.

Silver is quantitatively estimated by precipitating it from its solution (which should be acid,) by hydrochloric acid; the chloride of silver, after being well washed and dried, is fused in a little porcelain crucible. 100 parts contain 75·3 silver, and 24·7 chlorine.—*Turner.*

Gold: Au: Eq: 1243. The principal supply of this valuable metal is from the mines of South America, Hungary, and of the Uralian mountains in Siberia. It is found only in the metallic state, either pure or alloyed with other metals, principally with silver, tellurium, and mercury. From silver it is separated by a process termed *quartation,* which consists in alloying the gold with three times its weight of silver, and then acting on the mass with nitric acid; the larger quantity of gold in the original alloy, protects the smaller quantity of silver, but when the proportion of the latter metal is increased, and its solution by the acid once commenced, it does not cease till the whole is dissolved. Mr. Lewis Thompson gives the following method for assaying gold. Fuse 6 grains of the subject of the experiment in a small crucible, with 15 grains of silver, from 8 to 12 grains of chloride of silver, and 50

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* The standard silver of the Mint is composed of 222 parts of pure silver and 18 of copper.

grains of finely powdered common salt, and subject the metallic button produced to the action of dilute nitric acid. In this operation the baser metals are wholly removed by the chlorine of the chloride of silver, and their place supplied by pure silver.*

There are two oxides of gold, Au_2O, and Au_2O_3. The first is a green powder, obtained by decomposing the corresponding chloride by a cold solution of potash; the latter is a brown powder, prepared by decomposing perchloride of gold by an excess of magnesia; neither of these oxides combine with acids.

Gold coin is an alloy of eleven parts of gold and one of copper: of this alloy, 20 troy pounds are coined into 934 sovereigns, and one half sovereign; one pound formerly was coined into 44½ guineas; it now produces 46$\frac{29}{40}$ sovereigns. All the gold at present coined in our mint is alloyed with copper only: previous to the year 1826, the alloy consisted in part of silver: hence the paler colour of the sovereigns and half sovereigns of former coinages.—*Brande.* When protochloride of tin is added to a dilute solution of gold, a purple coloured powder falls, which has received the name of *purple of cassius.* The same compound is formed by fusing together 2 parts of gold, 3½ parts of tin, and 15 parts of silver under borax, and dissolving out the silver with nitric acid. It is a mixture of peroxide of tin and metallic gold.—*Graham.*

Gold is precipitated from a solution of its chloride in a metallic state by iron, copper, zinc, and tin; also, though less rapidly, by lead, mercury, and antimony. When a solution of gold is boiled with formiate of soda, the metal is also precipitated. This metal is quantitatively estimated by reduction, the agent generally employed is proto-sulphate of iron. It is precipitated in the state of a fine brown powder. The solution should be previously acidulated with hydrochloric acid. Solution of pure oxalic acid may also be employed, but a

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* L. & E. Phil: Mag: vol. 15. p. 310.

longer time is required to effect the complete reduction. By oxalic acid, gold may be separated from platina; the solution of the two metals may be made in aqua-regia, and the gold precipitated by oxalic acid in the metallic state, and the platina by formic acid.*

Platinum: Pl: Eq: 98·84. This is the densest substance at present known. It is found in the metallic state, in small grains, in South America. It exists native, but is associated with a great number of metals, particularly with palladium, iridium, rhodium, and osmium, which are never found except in combination with platinum. For details respecting the processes for extracting platinum from the crude ore, and for Dr. Wollaston's mode of purifying the metal, and rendering it malleable, the student is referred to Brande's Manual of Chemistry.

There are two oxides of platinum, the protoxide, PtO, and the deutoxide, PtO_2. The first is, when pure, a black powder, obtained by digesting the protochloride with as much potash as exactly suffices for its decomposition. The *deutoxide* is obtained by decomposing the nitrate of the metal by soda.

Platinum in solution is easily detected by the precipitates, produced on the addition of potash or ammonia; when the solution is acid, a yellow precipitate is formed; when neutral, it should be acidulated with hydrochloric acid. The metal is also precipitated in the form of a black powder by a slip of zinc, and with protochloride of tin, a chocolate precipitate is formed, or the solution is coloured deep red, according to the quantity of platinum present.

The quantitative estimation of platinum is best effected by adding to a concentrated solution, a *very concentrated solution* of muriate of ammonia, and then a sufficient quantity of alcohol to cause the perfect precipitation of the resulting double salt, composed of muriate of ammonia and chloride of platinum. The precipitate must be washed with spirits of wine,

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* Journal de Pharmacie, January, 1842.

and cautiously and gradually ignited; upon which reguline platinum, in a porous state, remains behind and may be weighed.

Palladium: Pd: Eq: 665·9. In its general character, this metal is very similar to platinum, but it is not nearly so dense, its specific gravity being only 11·5, whereas, that of platinum is 21·5. It appears to form three compounds with oxygen, but the protoxide, PdO, only has been studied with care. This oxide is formed by dissolving palladium in nitric acid. It is a black or brown powder. Palladium is recognised by giving, with ammonia, a flesh-red precipitate, soluble in excess, giving a colourless solution. Cyanuret of mercury is the best quantitative precipitant of palladium. The solution, should it be acid, must be neutralized with soda, previous to the addition of the cyanuret; the precipitate, when dry, is yellowish grey, and is decomposed by ignition, metallic palladium being formed:—the metal becomes blue during the ignition.—*Rose.*

Iridium: Ir: Eq: 1233·5. This metal is extracted from the crude ore of platinum. It resembles platinum, but it is still more infusible, though not so dense, its specific gravity being 18·6. It derives its name from Iris, the rainbow, suggested by the various colours exhibited by the muriatic solution of its oxide. According to Berzelius, there are four oxides of Iridium. IrO, Ir_2O_3, IrO_2, IrO_3.

Rhodium: R: Eq: 661·4. This metal, which is also extracted from the nitro-muriatic solution of the ore of platinum, derives its name from the beautiful rose (ϱοδος) colour of its solutions. It is very difficult of fusion, and when pure, hardly acted upon, even by nitro-hydrochloric acid. The sesquioxide of Rhodium, R_2O_3, is the base of the most important compounds of this metal; there are other oxides, but they have not been studied much.

Osmium: Os: Eq: 1244·5. This metal, which exists alloyed with Iridium, and accompanies the ores of Platinum, derives its name from ὀσμὴ, smell, on account of the penetrating odour of a highly volatile oxide which it forms. It combines with oxygen in three proportions, forming OsO, OsO_2, OsO_4. The formation of this highly volatile oxide, and the odour which it produces, constitutes an excellent test, whereby to ascertain the presence of this metal in iridium.

Analysis of siliceous minerals. The native compounds of silicic acid, may be divided into two general classes. 1st. Those which are decomposable by hydrochloric acid: and, 2nd. Those which withstand the action of acids, but are decomposed by fusion with carbonated alkalies. Of the first class, some undergo decomposition with remarkable ease, while others require prolonged digestion; in which case the *complete* decomposition can only be effected by employing slightly diluted sulphuric acid, which, indeed, by a prolonged digestion, can be made to decompose nearly all the silicates. Of the second class, there are a few minerals which are decomposed with great difficulty, even by fusion with carbonated alkalies, in which cases, the decomposition is effected by mixing them in a very finely levigated state, with three times their weight of pure potash, and exposing the mixture, in a silver crucible, to ignition.

When a silicate is to be decomposed by hydrochloric acid, it must be finely pulverized, slightly warmed, and weighed in a counterpoised platinum crucible, then transferred to a glass that can be closely shut by a glass plate, and therein mixed with the acid. In some cases, the decomposition takes place almost immediately, the silicic acid separating in a gelatinous form: in others, a long digestion with the aid of heat is required, the silicic acid separating in the form of a powder. If the decomposition has been completely effected no creaking sound is produced on rubbing the bottom and sides of the vessel with a glass rod, which *is* the case if any portion of the mineral has escaped the action of the acid, in which case, the undecomposed powder must be removed from the solution by adding water, and pouring it off into another vessel, while the silicic acid is in suspension, and then treating it with a fresh portion of acid. The precipitated silicic acid is collected on a filter, washed, dried, heated to redness in a counterpoised platinum crucible, and weighed while warm;—about one per cent. of silicic acid remains in the solution.

The silicic acid being thus removed, ammonia is added in slight excess, by which alumina and peroxide of iron are completely precipitated, together with small quantities of magnesia and protoxide of manganese: these substances are separated from each other in the manner already described, and from the filtered liquid, lime is separated by oxalic acid; after which, if no magnesia or protoxide of manganese be present, the fixed alkalies, (if the mineral contained any,) can be determined by evaporating the filtered solution to dryness, by which they are left in the state of chlorides. When, however, magnesia is present, the analysis becomes much more difficult, and must be conducted in the manner described in page 372.

When the decomposition of the mineral is to be effected by fusion with carbonate of potash, the greatest pains must be taken to reduce it to the *finest* powder, which is best done by first breaking it into coarse grains, and then grinding with water on an agate slab, after which it is poured into a glass and allowed to repose for a short time, that the coarse powder may fall to the bottom, while the fine suspended powder is poured with the water into another glass and allowed to settle: the water is then poured off and the powder dried, till it ceases to lose weight. It is then transferred into a large platinum crucible, very carefully mingled with four times its weight of pure warm carbonate of potash, and exposed to a full red heat for an hour.* According as the substance under examination contains more or less silicic acid, the mass in the crucible is found either completely fused, or only softened into a con-

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* The platina crucible should be protected from the injurious action of the ashes of the fuel, by enclosing it in a cylindrical Hessian crucible; platina vessels should never, if possible, be exposed naked to the action of the fire.

glomerate. In the latter case, it is not difficult to remove it from the crucible, by bending and pressing the sides of which the mass generally loosens in a single lump; but if the mixture be melted together, as much as possible must be removed by softening it with water, and the remainder by dilute hydrochloric acid.

The mixture is transferred into a glass and cautiously acidified with hydrochloric acid, and after the effervescence has ceased, it must be set by in a warm place to digest till the decomposition is complete. Part of the silicic acid remains undissolved, and part exists in solution, but sometimes, particularly when a large quantity of carbonate of potash has been used, and the quantity of silicic acid small, the whole of it is dissolved. The next operation is to evaporate the solution to dryness, in a platinum or porcelain capsule, being careful not to employ too great a heat, particularly towards the last: when dry and cold, the mass is moistened with concentrated hydrochloric acid, and after an hour's digestion, water is added, upon which the silicic acid remains undissolved, while the other constituents of the mineral remain in solution, and are separated as already described.

The only acid by which the ignited, or the native pulverized silicic acid can be dissolved with facility, is the *hydrofluoric*. Berzelius pointed out a method of decomposing siliceous minerals by means of this acid, which, however, on account of the difficulty of procuring it in a state of purity, is seldom adopted. In order to obviate this difficulty, Mr. C. Brunner has proposed* to place the siliceous substance to be acted upon, in an atmosphere of hydrofluoric acid, which, for this purpose, is prepared in a leaden vessel, of the form shown in *Fig.* 96. The diameter is about six inches, and the other dimensions in proportion. In the middle of this vessel, supported by leaden feet, a very flat platina dish is placed, in which is placed the siliceous substance, reduced to the finest

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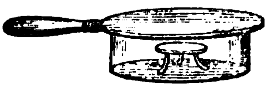
* Poggendorff's Annals, No. 5, 1838, p. 135.

Fig. 96.



powder, and moistened with a little water. The bottom of the leaden vessel is covered to the depth of from ⅛th to ¼th of an inch, with a mixture made to the consistence of a paste of fluate of lime and sulphuric acid. A small flat cover with a wooden handle closes the vessel. So provided it is submitted to the gentle heat either of a sand-bath or small lamp. By means of the hydrofluoric acid gas thus given out, a quantity from 20 to 30 grains of siliceous mineral is completely decomposed in the space of one or two hours. During the process, the powder must be twice moistened with a few drops of water. If the powder is well spread out at first, it is seldom necessary to stir it. When this operation is finished, a quantity of concentrated sulphuric acid is added drop by drop to the powder, as long as any hydrofluosilicic acid is given off; at the same time it is to be warmed by a spirit lamp, and finally, the excess of sulphuric acid is driven off by a continued heat and evaporation to dryness. The dry residue, after being moistened with hydrochloric acid, is boiled in water, and further examined in the usual way. This method is particularly applicable to the examination of such minerals as contain alkalies.

A new method of analysing closely aggregated minerals has been pointed out by Dr. Abich.* It consists in fusing the mineral with carbonate of barytes, which, at a white heat, loses the whole of its carbonic acid, and its caustic power is then so great, that it completely and quickly decomposes the aluminates and corundum, bodies which are with the greatest difficulty acted upon, even by pure potash: cyanite, staurolite, andalusite, cymoptane, zircon, and the felspars, are also acted upon in the most complete manner. To conduct the analysis successfully, the following precautions are necessary. A furnace, by which an extremely high and well-regulated temperature can be obtained in a short time. The mineral reduced

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* Annales de Chimie; December, 1835.

to powder, which need not be very fine, must be mixed with from four to six times its weight of pure carbonate of barytes, and placed in a platinum crucible; this is then enclosed in a Hessian crucible, covered and luted, which placed on any convenient support in the furnace, must be heated to whiteness, and kept at that temperature from 15 to 20 minutes: a perfectly fused mass is obtained, which dissolves with facility in dilute hydrochloric acid.

Separation from phosphoric acid. When the siliceous substance under examination contains phosphoric acid, Rose recommends to ignite with three or four parts of carbonate of potash, in a platinum crucible: water is then to be poured over the ignited mass, and the insoluble portion filtered and washed. In this case the solution contains phosphoric acid combined with potash. It also contains the excess of carbonate of potash. The insoluble matter consists of silicic acid, and the bases which were contained in the substance submitted to analysis. The separation thus effected is not, however, quite complete. The solution contains a small quantity of silicate of potash, to separate which, carbonate of ammonia is added and the solution warmed, upon which flocks of silicic acid are deposited. This silicic acid, after being washed, is added to the undissolved mass.

To the filtered solution, muriatic acid is added in excess, and after standing 34 hours to insure the complete disengagement of the carbonic acid, an excess of ammonia is added, and immediately after a solution of chloride of calcium:—The flask in which the operation is conducted is then corked, to prevent the formation of carbonate of lime from the carbonic acid in the atmosphere, and after the precipitate has completely subsided, it is filtered and washed as quickly as possible; it is phosphate of lime which is to be converted into sulphate by sulphuric acid, and from the weight of the sulphate of lime, the quantity of dry phosphoric acid, with which the lime was previously saturated, can be calculated.

M. Schulze gives the following process for the estimation of phosphoric acid in soils, rocks, wood ashes, &c.:—it is founded on the insolubility of phosphate of the peroxide of iron, and phosphate of alumina in acetic acid. In soils, the phosphoric acid is generally in the form of phosphates of lime and magnesia. If to a solution of the compounds in *acetic acid*, a sufficient quantity of a solution of acetate of peroxide of iron is added, all the phosphoric acid is precipitated as phosphate of the peroxide of iron, which may be collected and weighed. Instead of acetate of iron, acetate of alumina may be employed with a similar result.

As soils usually contain more peroxide of iron and alumina than is sufficient to combine with the whole of the phosphoric acid, all that is required to be done in estimating the phosphoric acid of soils, is to add excess of ammonia to the solution of the earthy matter in hydrochloric acid, and treat the precipitate with acetic acid; nothing but the phosphates of the peroxides of iron and alumina remain undissolved.

Separation of the oxides of iron. The following process proposed by Fuch, is extremely accurate: mixtures of the proto- and per-salts are boiled with carbonate of lime. The peroxide of iron is precipitated in the state of a subsalt, and so completely, that the solution is not turned red by the sulphocyanate of potash. The only inconvenience is, that the filtered solution being perfectly neutral, becomes slightly turbid, owing to the conversion of a small portion of protoxide into peroxide. But this may be avoided by using carbonate of magnesia instead of carbonate of lime; the solution does not become turbid, and probably because magnesia forms a more stable double salt with the protoxide of iron.

Carbonate of lime may be advantageously employed for separating peroxide of iron from the oxides of cobalt and nickel.

LECTURE TWELFTH.

ON THE ANALYSIS OF ORGANIC BODIES: AND THE CHEMISTRY OF AGRICULTURE.

PRELIMINARY REMARKS:—DETAIL OF THE PROCESS FOR DETERMINING THE COMPOSITION OF ORGANIC SUBSTANCES, AS RECOMMENDED BY LIEBIG — NEW METHOD OF DETERMINING THE NITROGEN, BY DRS. WILL AND VARRENTRAP. —THE CHEMISTRY OF AGRICULTURE—FOOD OF PLANTS—SOURCES OF THEIR CARBON, OXYGEN, HYDROGEN, AND NITROGEN—THE LATTER DERIVED PARTLY FROM AMMONIA AND PARTLY FROM NITRIC ACID—SOURCE OF THE AMMONIA AND NITROGEN EVOLVED IN VOLCANIC COUNTRIES FROM THE EARTH—REFERENCE TO VOLCANIC ACTION—DAUBENY'S VIEWS—REMARKS OF BISCHOF THEREON—NITRATE OF AMMONIA PRODUCED IN THE AIR BY THE ACTION OF ELECTRICITY—ITS DETECTION AFTER THUNDER-STORMS IN RAIN WATER—ARTIFICIAL NITRE-BEDS OF FRANCE—IN TEMPERATE CLIMATES ORGANIC MATTER IS NECESSARY FOR THE COMMENCEMENT OF NITRIFICATION—IN HOT CLIMATES IT DOES NOT APPEAR NECESSARY—SUBSTANCES PRODUCED IN PLANTS—1st. FROM CARBON, OXYGEN, AND HYDROGEN. —WOODY FIBRE — ITS NATURE, PROPERTIES AND TRANSFORMATIONS — ITS CONVERSION BY SULPHURIC ACID INTO STARCH, GUM, AND SUGAR.—STARCH—ITS PROPERTIES AND TRANSFORMATIONS —QUANTITY FOUND IN DIFFERENT VEGETABLES — PROCESS FOR OBTAINING STARCH PURE — ITS ULTIMATE COMPOSITION—IT IS RESOLVABLE INTO TWO DISTINCT SUBSTANCES — AMIDIN AND AMYLIN — ITS CONVERSION INTO GUM AND GRAPE SUGAR.—GUM—VARIETIES

OF—ULTIMATE COMPOSITION.—SUGAR—ITS VARIETIES—CANE SUGAR—PROCESS FOR MAKING IT FROM THE SUGAR CANE IN THE WEST INDIES—PROPERTIES AND ULTIMATE COMPOSITION OF CANE SUGAR—GRAPE SUGAR—ITS COMPOSITION—HOW DISTINGUISHED FROM CANE SUGAR—ACIDS FOUND IN VEGETABLES—ACETIC ACID—ITS COMPOSITION—MANUFACTURE OF VINEGAR FROM ALCOHOL, FROM WOOD, AND FROM SUGAR—OXALIC ACID.—TARTARIC ACID—ITS COMPOSITION—HOW FORMED IN FRUITS.—CITRIC ACID—ITS COMPOSITION—MALIC ACID ISOMERIC WITH CITRIC ACID—2nd. VEGETABLE PRODUCTS CONTAINING NITROGEN—GLUTEN—ITS PROPERTIES AND COMPOSITION—IT IS THE NUTRITIVE PRINCIPLE IN WHEAT, IN WHICH IT IS FOUND IN GREATER ABUNDANCE IN WARM CLIMATES, WHICH IS PROBABLY REFERABLE TO THE GREATER SUPPLY OF NITRIC ACID AND AMMONIA.—VALUE OF THE NITRATES OF POTASH AND SODA AS FERTILIZERS—DETAIL OF EXPERIMENTS AND CALCULATIONS THEREFROM.—DIASTASE—ITS GREAT IMPORTANCE AND SINGULAR PROPERTIES—IT CONVERTS STARCH INTO SUGAR—WHENCE DERIVED—METHOD OF OBTAINING IT PURE—PROCESS OF MALTING—DEXTRINE—ITS PREPARATION AND USES—REVIEW OF THE PRODUCTS OF VEGETATION—LIMITATION OF THE POWERS OF THE CHEMIST—HE CAN ONLY TRANSFORM—HE CANNOT CONSTRUCT—OUR KNOWLEDGE RESPECTING THE PHŒNOMENA OF VEGETATION IS VERY LIMITED—GENERAL VIEW OF THE CHEMICAL CHANGES WHICH TAKE PLACE DURING THE PROGRESSIVE GROWTH OF THE PLANT—WONDERFUL RAPIDITY WITH WHICH SOME VEGETABLES ASSIMILATE AND CONVERT THEIR FOOD—INORGANIC CONSTITUENTS OF PLANTS—PROPORTION IN SOME OF THE MORE COMMONLY CULTIVATED PLANTS—NATURE OF THE ASH LEFT BY BURNING, CONSTANT IN QUANTITY AND QUALITY FOR EACH PLANT—INORGANIC MATTER MUST BE CONSIDERED AS FOOD OF PLANTS EQUALLY WITH ORGANIC MATTER—A KNOWLEDGE OF THE CHEMI-

CAL COMPOSITION OF THE ASH OF DIFFERENT PLANTS USEFUL FOR DETERMINING THE NATURE OF THE SOIL BEST ADAPTED FOR EACH.—THE TEMPORARY DIMINUTION OF THE FERTILITY OF SOILS REFERABLE, ACCORDING TO LIEBIG, TO THE EXHAUSTION OF THE ALKALIES—EXCRETORY POWER OF PLANTS—PHYSIOLOGISTS DIVIDED RESPECTING IT.—INTERCHANGE AND ROTATION OF CROPS—USES OF MANURES—THEY ACT EITHER BY SUPPLYING MINERAL INGREDIENTS OR BY PROVIDING ORGANIC MATTER—THE SOLID EXCREMENTS OF ANIMALS SUPPLY SILICATE OF POTASH, AND SALTS OF PHOSPHORIC ACID—THE LIQUID EXCREMENTS FURNISH NITROGEN — CALCULATIONS SHOWING THE EFFICACY OF THE SOLID EXCREMENTS OF ANIMALS—USE OF BONE MANURE—CALCULATION, SHOWING THE GREAT VALUE OF URINE AS MANURE.—FORMATION OF COMPOST HEAPS—FERTILIZING PROPERTIES OF GYPSUM—OF AMMONIACAL SALTS—PREPARATION OF SULPHATE OF AMMONIA FROM THE AMMONIACAL GAS LIQUOR—SUPERIORITY OF HUMAN EXCREMENT AS MANURE OVER THAT OF ANIMALS—ITS OFFENSIVE SMELL DESTROYED BY THE PROPER USE OF THE MINERAL ACIDS—VINOUS FERMENTATION—PREPARATION OF BEER—NATURE AND ACTION OF YEAST—QUANTITY OF ALCOHOL IN ALE AND SMALL BEER—USE OF THE HOPS—PREPARATION OF BEER BY THE BAVARIAN METHOD—ITS SUPERIORITY OVER THE COMMON METHOD—PHŒNOMENA OF THE VINOUS FERMENTATION—NO EVOLUTION OF HYDROGEN—IT DEOXIDIZES SUBSTANCES DISSOLVED IN FERMENTING LIQUORS, AND GIVES TO EACH A PECULIAR CHARACTER—PANARY FERMENTATION—BREAD MAKING — DETAIL OF THE PROCESS — METHOD OF DETECTING POTATOE STARCH IN WHEAT FLOUR—PROCESS FOR RENDERING BREAD VESCICULAR.—PUTREFACTION—FERMENTATION—ITS NATURE—THEORY OF THE MORBIFIC ACTION OF CONTAGIONS — EXEMPLIFIED IN THE POISONOUS PROPERTIES OF BAD SAUSAGES—SUBJUGATION OF CHEMICAL FORCE TO THE VITAL PRINCIPLE.

On entering upon the study of the Chemistry of organic bodies, we are forcibly struck with the immense number and varied nature of the compounds to which different arrangements of *three*, or at most, *four* only of the elementary substances give rise: while in inorganic Chemistry, we have to deal with arrangements of fifty-four distinct bodies. All the numerous products of the animal and vegetable kingdom are formed principally out of carbon, hydrogen, oxygen, and nitrogen: hence the complexity which characterizes organized substances, from which, however, it does not seem philosophical to conclude, as some Chemists have done, that there is an essential difference between the affinities which unite the atoms constituting organic principles, and those which unite the atoms of unorganized bodies; for though the former are much more unstable, much more easily decomposed, much more liable to decomposition, and much more complicated in their structure than the latter, we must consider that they are made by processes connected with vegetable and animal life, and that they constitute results proceeding from the wisdom of *One*, whose skill the utmost ingenuity of man can imitate only at an immeasurable distance.

Proximate vegetable principles are, generally, *ternary* compounds, composed of a great number of atoms, and nothing can be more dissimilar than the products formed by the same elements. How different are starch, sugar, gum arabic, and lignine (the principle of woody fibre) from each other, in their physical and chemical properties! yet how similar is their composition: thus—

Starch.... $C_{12}\ H_{10}\ O_{10}$.
Sugar..... $C_{12}\ H_{11}\ O_{11}$ (or $C_{12}H_{10}\ O_{10}+HO$.)
Arabin.... $C_{12}H_{11}O_{11}$.
Lignine... $C_{10}H_{8}O_{8}$.

Common sugar in crystals and arabin, are thus shown to have precisely the same constitution; starch is seen to differ from both only in containing one equivalent less of oxygen and hydrogen, and lignine in containing three equivalents less of these elements.

Again, the tartaric, acetic, and succinic acids are composed of carbon, hydrogen, and oxygen, yet how totally different are they in properties from the above, and though so similar in composition, how different are they from each other in their chemical characters: thus—

Tartaric acid .... $C_4\ H_2\ O_5$.
Acetic acid............. $C_4\ H_3\ O_3$.
Succinic acid........... $C_4\ H_2\ O_3$.

Although most organized principles are composed of three constituents, Chemists are acquainted with a very important class, consisting of carbon and hydrogen only. These are called *hydro-carbons*, and include the greater part of the essential oils.* Oxalic acid is a compound of carbon and oxygen, (C_2O_3,) and cyanogen is composed of carbon and nitrogen, (C_2N); while that remarkable family of bodies, termed the vegetable alkalies, such as quinine, cinchonine, aricine, morphia, narcotine, strychnine, brucine, &c., compounds existing *naturally* in the plants from which they are derived, and which confer upon them their most active medicinal properties, are composed of carbon, hydrogen, oxygen, and nitrogen; it is the presence of the latter element which distinguishes them from most other substances of a vegetable origin, and which is supposed to be connected with the source of their alkaline power.

The methods adopted by the earlier Chemists, to obtain a knowledge of the chemical constitution of organic bodies, were very different from the organic analysis of the present day. They submitted them to destructive distillation, and from the products obtained, they endeavoured to form an idea of the difference in their composition. The results, however,

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* According to Gerhardt and Cahours, most essential oils containing oxygen, may, by the action of fused hydrate of potash, be separated into an acid and an oil destitute of oxygen.

of destructive distillation are liable to infinite variation, according to the manner in which it is conducted, and consequently it is utterly incapable of conveying the information desired; hence this method is entirely rejected, except where some specific product is to be examined, and others have been substituted, which have for their object the conversion of a known weight of the substance into carbonic acid and water; when the compound contains nitrogen, that element is either collected in a separate state, or estimated in the form of ammonia, and oxygen is always ascertained indirectly.

To effect these objects in an unexceptionable manner, a peculiar apparatus is required, and it is to the introduction of this, in a cheap and compact form, that the extraordinarily rapid progress of organic chemistry within the last few years is in a great measure to be attributed.

It will be unnecessary to describe the various steps of the operation of organic analysis with very great minuteness, as every one who enters on this interesting branch of Chemistry, will not fail to possess himself of Professor Liebig's valuable tract,* in which the most detailed instruction for conducting every part of the operation with exactness is given. I shall give here merely an outline of the general process.

The substance to be analyzed is burnt with oxide of copper, by which the carbon and hydrogen, which it contains, are oxidized, the carbon being converted into carbonic acid, and the hydrogen into water, and by means of an ingenious contrivance the former is completely absorbed by caustic potash, and the latter by fragments of strongly dried but not fused chloride of calcium.

We will suppose the substance to be crystallized loaf sugar.

The combustion is effected in a tube of Bohemian potash glass, which contains no lead, which does not crack, even

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* Instructions for the Chemical Analysis of Organic Bodies, by Justus Liebig, translated by Dr. W. Gregory, and forming Part I. of Griffin's Scientific Miscellany. Tegg: London: price 2s. 6d.

when suddenly surrounded with red-hot charcoal, and which is extremely difficult to melt; it is usually 14 or 15 inches long, and from ⅛ to ½ of an inch in diameter; the closed end is drawn out to a point, which is bent obliquely upwards and sealed, as in *Fig.* 97.

To obtain a measure of the quantity of oxide of copper* required, the tube is filled to three-fourths of its length with the oxide out of the crucible in which it has been just ignited and while it is yet hot. From 5 to 7 grains of the sugar, quite dry, are rubbed in a porcelain mortar with a little oxide, and when the mixture is intimately made, the whole of the oxide which was measured in the tube is gradually added. On the perfect mixing of the substance to be analyzed with the oxide of copper, its complete combustion depends. About half an inch at the closed end of the tube of combustion is first filled with pure oxide, the mixture is then transferred from the mortar; this is followed by a portion of oxide with which the mortar is rubbed out, and then the tube is filled to within one inch of its open extremity with pure oxide. In the figure, the dotted lines show the comparative lengths occupied by the different layers, *a,* pure oxide: *b,* mixture; *c,* rinsing from the mortar; *d,* pure oxide.

Oxide of copper is a very hygrometric substance, and therefore, during its mixture with the organic compound, it invariably absorbs moisture from the air, which coming off afterwards during the ignition, would vitiate the determination of

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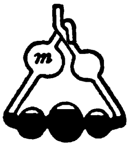
* The oxide of copper is prepared by igniting sheet copper, and throwing it, while red-hot, into cold water; the impurities on the surface peel off with the crust of oxide formed, the clean well-washed metal is now dissolved in pure nitric acid, and the solution evaporated to dryness in a porcelain capsule, it is then ignited in a well-covered Hessian crucible, (taking care not to introduce too much at once, as the salt froths up,) and the calcined mass stirred frequently with a copper wire. The ignited oxide is reduced to a fine powder and preserved in a well-stopped vessel.

the hydrogen. It is necessary therefore, to remove these traces of moisture, which is done by means of a small exhausting syringe, which is attached to the combustion-tube by a cork, a tube containing chloride of calcium being interposed. The combustion-tube is bedded in sand, heated to 250°, and by means of the syringe, the damp air it contains is withdrawn, and replaced by air which is dried in its passage over the chloride of calcium; after a few repetitions of this process, all the moisture may be considered to be removed.

The tube, *Fig.* 98, is filled with chloride of calcium, large fragments being placed in the bulb, and coarse powder in the long tube, and a little cotton-wool is put near to the two open ends, in order to prevent any chloride of calcium from falling out; the tube, thus filled, is carefully weighed and then connected with the combustion-tube by means of an accurately fitting and thoroughly dried cork. To the larger end, *a*, of the chloride of calcium tube, a smaller tube is connected by means of a cork which is cut off close to the tube and covered with sealing wax; this serves to connect it with the potash bulb tube, *Fig.* 99.

This very ingenious little arrangement was devised by Liebig, and has contributed more, perhaps, than any other, to the rapid progress of organic Chemistry. In the pamphlet before alluded to, full directions for making these tubes are given, but they are to be procured at a moderate price at any philosophical instrument maker's. The three central bulbs are nearly filled with a solution of caustic potash, sp: gr: 1·25,[*] and the ap-

Fig. 99.



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[*] Dr. Gregory gives the following method for preparing the potash ley. "Two parts of the subcarbonate of potash of the shops, are dissolved in 20 to 24 of boiling water. One part of quicklime is slaked by being *covered* with *hot* water in any conve-

paratus is attached to the chloride of calcium tube, by a caoutchouc connector, tied very carefully on.

The furnace in which the combustion is carried on, is shown in *Fig.* 100. It is made of sheet iron, 22 to 24 inches long and 3 inches high. The bottom is three inches wide, and furnished with apertures which form a sort of grate: these apertures are narrow slits, running across at half an inch distance

Fig. 100.

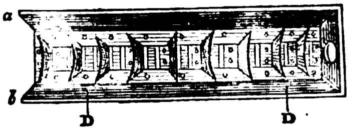


Fig. 101.

Fig. 102.

nient vessel. In this way the whole of the lime is converted into an uniform cream, without the formation of any hard sandy particles, which occur in the ordinary method of slaking, and which are not only useless but hurtful, by preventing, from the space they occupy, and the increased proportion of lime they render necessary the separation, by decanting, of much of the ley. The cream of lime is added in small portions to the boiling solution of carbonate of potash, which is boiled a few minutes after each addition, water being occasionally added to supply the loss by evaporation. When the whole of the lime has been added, the mixture is boiled for a short time longer, and is then allowed to cool, the cover of the vessel being carefully closed. After 12 hours, the whole of the ley may be decanted perfectly clear, and quite caustic, if the vessel has been nearly full. The carbonate of lime is sandy and occupies a very small bulk. The clear liquid is now to be rapidly boiled down in a clean iron vessel, till small crystals begin to separate. It is then allowed to cool in a stopped bottle of green glass, when it deposits the whole of the sulphate of potash originally present in the subcarbonate, that salt being absolutely insoluble in a strong solution of caustic potash. The specific gravity of this ley is 1·25; it is nearly pure, containing no foreign matter, except a little chloride of potassium, and it is perfectly adapted for organic analysis. The necessity for using at least 10 or 12 parts of water to 1 of carbonate of potash, arises from the curious fact noticed by Professor Liebig, that when less water is present, the potash takes back the carbonic acid from the carbonate of lime."

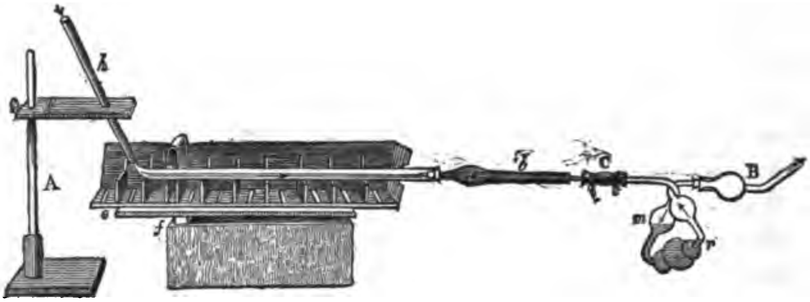
from each other. The sides of the furnace are inclined outwards, so that at the top they are 4½ inches apart. To support the combustion-tube, pieces of strong sheet iron, of the form D, *Fig.* 101, are rivetted to the bottom of the furnace at intervals; they are of exactly equal heights, with their edges ground flat to correspond with the round aperture in the front of the furnace, A. The furnace rests on a large tile, or on two thin bricks, supported upon two blocks of wood. The whole apparatus, arranged for the combustion, is shown in *Fig.* 102; a small wedge of iron being introduced at *a*, between the tile and the supports, for the purpose of giving the furnace a slight inclination towards the potash apparatus, which is best supported on a folded towel.

Before proceeding with the combustion, and indeed before joining the combustion-tube with the other parts of the apparatus, it must be tapped smartly in a horizontal position on a flat table, in order to produce above the mixture, *Fig.* 97, through the whole length of the tube a vacant space, to afford a passage to the gaseous products of the combustion. Without this precaution, it often happens that the oxide of copper is thrown forwards, or that the tube at the further end becomes choked. The same precaution must be taken in the preparatory operation of drying the oxide of copper.

The joinings having been proved to be completely tight, the analysis may be proceeded with. The anterior portion, about three inches, of the tube of combustion, is first surrounded with red-hot charcoal, and when the pure oxide of copper is completely red-hot, the next portion, consisting of the rinsing of the mortar, is to be similarly ignited. The hydrogen of the organic substance reduces the oxide of copper, and forms water, which is collected by the chloride of calcium in the water tube; the carbon of the substance likewise reduces the oxide of copper, and becoming converted into carbonic acid, is dried in passing over the chloride of calcium, and is absorbed by the potash in the bulbs. The fragments of charcoal are kept in their place, and the heat prevented from spreading by a screen of sheet iron, *b*, the same width as the furnace. This screen is slowly moved backwards by half an inch to an inch at a time, and the fire space immediately filled up with red hot charcoal, so as to raise rapidly the portion of tube newly exposed to a red heat. The fore-end of the tube which is empty, and projects one inch out of the furnace, must be kept during the whole operation so hot that not the smallest quantity of water can condense within it: it is useful, however, to place another screen upon the front of the furnace, both to prevent the cork of the combustion-tube from being burnt, and the chloride of calcium-tube from being heated by radiation. The operator cannot be too careful only to heat small portions of the tube at once, and the bubbles of gas should form an uninterrupted and tolerably rapid current. When the whole tube of combustion, at the end of the operation (which generally lasts from twenty minutes to half an hour,) is surrounded with red-hot charcoal, the heat is increased along the whole length of the furnace. This is done below, by admitting air through all the slits, and above, by blowing the fire with a sheet of pasteboard, moved rapidly backwards and forwards. When the evolution of gas stops all at once, the operator may be sure that the combustion has been complete, and a good result may be expected; if it continue on the contrary, at intervals, for a long time, the mixture with oxide of copper has not been well made, and a deficiency in the determination of the carbon is to be looked for. The tube should be heated red-hot, but not to bright redness: when too hot it is apt to stick to the supports.

As soon as no more gas comes over, the ley rises in the large bulb, *m*, of the potash apparatus, the size of which prevents all chance of the liquid's rising into the chloride of calcium tube. The pointed extremity of the combustion-tube should then be broken off by means of a pair of pliers, after removing the charcoal from that end of the furnace, and an open tube, *h*, 15 to 20 inches long placed over it, supported by a stand; a suction-tube is now placed on the end of the potash apparatus, and a certain quantity of air is drawn with the mouth through the apparatus; by this means, all the carbonic acid and watery vapour which have remained in the apparatus are absorbed by the chloride of calcium and ley. *Fig.* 103, shows the disposition of the apparatus at this period.

Fig. 103.



The apparatus is now taken apart, and the potash tube and water tube weighed; the increase of weight gives, of course, the quantities of carbonic acid and of water collected, and hence, by a simple calculation, the proportions of carbon and hydrogen contained in the quantity of substance that had been operated on. The carbonic acid is 27·67 per cent. of the increase of weight in the potash bulbs, and the hydrogen is one-ninth of the increase of weight in the chloride of calcium tube. The oxygen is the quantity obtained by adding the weights of the hydrogen and carbon together, and deducting their sum from the weight of matter originally employed.

In the case of sugar, the following are the details of a particular analysis by Dumas.

Weight of sugar..............	600
Weight of carbonic acid.......	921
Weight of water...............	353

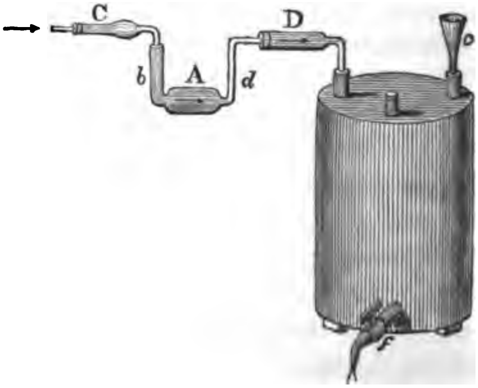
These give by calculation—

Carbon	254·6	42·4
Hydrogen	39·2	6·5
Oxygen	306·2	51·1
	600	100

The atomic constitution of sugar is obtained from these results, by dividing the quantities of carbon, hydrogen and oxygen in the last column, by their equivalents, 76, 12·5 and 100. We thus obtain 0·558 of an equivalent of carbon, 0·528 of an equivalent of hydrogen, and 0·511 of an equivalent of oxygen, which are more nearly proportional to the following than any other whole numbers; 12 carbon, 11 hydrogen, 11 oxygen, and gives $C_{12}H_{11}O_{11}$, the usually received formula for cane sugar.—*Graham.*

As all organic substances greedily absorb moisture from the air, it is absolutely necessary before attempting their analysis to deprive them of all hygrometric moisture. The importance of this is immediately seen when it is considered that an excess of water to the amount of $\frac{7}{100}$ths or $\frac{8}{100}$ths of a grain is equivalent to a loss of twice as much carbonic acid. The apparatus, shown in *Fig.* 104, may be employed for this purpose. The substance is introduced into the glass vessel, A, through the tube *b*, which should be ¼ of an inch in diameter; this is then connected with the chloride of calcium tube, C. The opposite tube *a*, is joined with the tube D, which is, by means of a cork, connected, air tight, with a vessel of tin

Fig. 104.

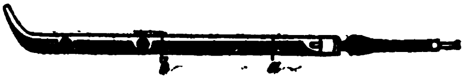


plate, capable of holding about four gallons of water. The funnel, *c*, serves for replenishing the vessel when empty. By means of the stop-cock *f*, we can produce a perfectly uniform discharge of water. The drying apparatus, A, is placed in a sand-bath, a water-bath, a bath of solution of chloride of calcium, &c., according to the temperature to which we wish to expose the substance, and as when the cock is turned, all the air which passes into the tin vessel must pass through A, and previously through the chloride of calcium tube C, it is perfectly dried in its passage, and by degrees, entirely removes all moisture from the substance. If it be wished to ascertain the amount of water given off by the substance under examination, the apparatus A, is weighed first empty, and then with the organic compound. It is then placed in the bath, and a stream of dry air is made to pass through it as long as water condenses in D; by weighing occasionally we ascertain if it loses weight. When the weight becomes constant, a small portion of the substance is shaken out of *b*, into a long and perfectly dry test tube, which is heated by a spirit lamp or sand-bath,—of course, to a degree insufficient to produce decomposition. If no trace of water bedew the side of the test tube, we may be certain that the substance is perfectly dry; if any moisture appear, the water-bath must be replaced by one of a solution of salt, or of chloride of calcium, and the operation repeated at a higher temperature.

When the substance retains water with great obstinacy, it must be enclosed in a strong tube, placed in a concentrated solution of chloride of zinc, and heated nearly to the temperature at which it is decomposed; a tube of chloride of calcium must be connected with it, and the moist air removed from time to time by means of a small hand air-pump. All hygrometric moisture or water of crystallization is thus removed in a few minutes.

When volatile liquids are to be analyzed, (and as the results with them are more exact, and the manipulation more easy, beginners are recommended to occupy themselves with the combustion of such substances first,) they are weighed in small glass bulbs blown from a piece of barometer tube; the bulbs should be about $\frac{2}{10}$ths of an inch in diameter, and provided with narrow necks from 1 to 1¼ inches long; they are easily filled by first warming them and then introducing the open end of the neck into the liquid to be examined. When by cooling a certain quantity has entered, the bulb is again warmed; the vapour which is formed expels almost the whole of the atmospheric air, and when the point is again dipped in the liquid, the bulb fills to three-fourths of its bulk. The point is now sealed up, and the whole weighed, and subtracting the weight of the bulb when empty, we have the weight of the liquid. There are generally two of these bulbs, holding from five to eight grains of liquid, one placed about two and the other about six inches from the sealed end of the tube, as shown in *Fig.* 105. The little stem is broken across in the act of introducing them, so that the liquid may easily flow out, when by the approach of a piece of red-hot charcoal, it is gently heated so as to form vapour.

Fig. 105.



When the liquid boils at a high temperature, and is rich in carbon, (the essential oils for instance,) it should be divided into three portions in separate bulbs, without, however, taking more than from 7 to 9 grains in all the bulbs, being separated by layers of oxide of copper. Fixed oils may be weighed in a small tube, which must be allowed to slide into the tube of combustion with the open end upwards, when two inches of oxide of copper have been introduced.

When the subject of the analysis contains chlorine, or when it is *very* rich in carbon, as indigo, coal, ulmine, &c., chromate of lead* is employed in the place of oxide of copper, in the

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* Prepared by precipitating nitrate or acetate of lead with bichromate of potash; after being well washed and dried, it should be strongly ignited till it begins to melt, and then reduced to a fine powder. Its colour is hereby changed from yellow to brownish red.

proportion of about one half the bulk of the oxide of copper; the process is the same as before, except that at the end of the process a strong heat should be given, by which pure oxygen is disengaged, and the combustion of the carbon rendered thereby complete. This increase of temperature renders it necessary to protect the tube by covering it with a thin sheet of copper, which, from its flexibility may be easily wrapped round the tube, and which may be kept in shape by a few rings of iron wire bent round it. The chromate of lead possesses the advantage of not being in the slightest degree hygroscopic, hence it is likely to be preferred to oxide of copper, where it is desirable to determine the proportion of hydrogen with extreme accuracy.

Determination of Nitrogen. Before the elegant method proposed recently by M. M. Will and Varrentrap, and which will be described presently, the direct valuation of nitrogen in an organic compound was a very delicate and tedious operation. It is always a separate process, in which every thing else is neglected, the carbon and hydrogen having been ascertained by a previous experiment, and the method is more or less simple, according to the amount of nitrogen present in the substance.

In the determination of the carbon it is soon seen whether the object of the experiment contains nitrogen, by the bubbles, which escape through the potash ley during the whole combustion. The presence of this principle is also ascertained by fusing a portion of the compound in a test-tube, with 4 to 10 times its weight of fused caustic potash. Nitrogenized substances are thus decomposed without blackening, and the whole nitrogen is disengaged in the form of ammonia, which is easily recognised by the smell; this is the basis of the method of M. M. Will and Varrentrap.

When the proportion of nitrogen, in the organic substance is large, as in uric acid, it is mixed with forty or fifty times as much oxide of copper as would suffice for its complete oxidation; it is then introduced into a combustion-tube, (the end of which is to be simply sealed, and not drawn out into a point,) so as to occupy half its length of the remaining two quarters of the tube; one is filled with the oxide of copper, and the other, towards the open end, with clean bright copper turnings; these must be kept at a full red heat during the combustion, the object of which is, to decompose the deutoxide of nitrogen, which is frequently formed when nitrogen passes over red-hot oxide of copper, and which, its volume being double that of the nitrogen it contains, would falsify the result. The combustion-tube being placed in the furnace, a small tube is joined by a caoutchouc connector with the open end; by this the gas evolved is conveyed to the mercurial trough, where it is from time to time collected in a graduated tube, and the carbonic acid being absorbed by caustic potash, the proportion which the remaining nitrogen bears to it is observed, care being taken that the level of the mercury is the same inside and outside the tube, and if the result is the same in several successive trials, and if no red nitrous fumes be observed, the calculation for the nitrogen may be made. Now the quantity of carbonic acid yielded by a given weight of the substance, has been ascertained by a previous analysis, and as an equal volume represents an atom for each,* the relative number of atoms of carbon and nitrogen is thus determined. For example: caffein, a crystallized substance, obtained from coffee, contains 49·796 per cent. of carbon. It also yields carbonic acid and nitrogen in the proportion of 4 to 1, consequently it contains carbon and nitrogen in the proportion of 4 atoms of carbon to one of nitrogen :—

Therefore, as 4×76.437, (the atomic weight of carbon,) is to 177·036, (the atomic weight of nitrogen,) so is 49·796 to X. That is, $305.748 : 177{\cdot}036 :: 49{\cdot}796 : X = 28{\cdot}834$ = the quantity of nitrogen in 100 parts.†

As in this method of determining the nitrogen, it is only

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* See Lecture 5th, page 132, et seq.

† See Liebig's Pamphlet.

the analysis of the gas in the tubes that is required for the result; no weights need be attended to, and it is found to give very accurate results where the nitrogen is to the carbon in no smaller proportion than 1 to 8; but where it is less than this, it is necessary to collect and measure the whole nitrogen evolved, which is a matter of no small difficulty. A combustion-tube, 24 inches long is selected, one end of which is sealed but not drawn out; next to the sealed end is placed carbonate of copper for a space of six or eight inches; then follow two inches of pure oxide; next, the mixture of the substance with oxide of copper; then another layer of pure oxide; and lastly, a layer of copper turnings. To the combustion-tube is fitted by a sound cork, a delivery-tube, furnished with a vertical arm, more than 30 inches long, through which the evolved gases are conducted to a large graduated jar over mercury, half filled with a strong solution of caustic potash. There is also a connexion with an exhausting syringe. The air is exhausted, and the tube filled with carbonic acid by heating one-half of the carbonate of copper. The atmospheric air is hereby expelled, and to render this more effectual, the whole apparatus is again exhausted, and again filled with carbonic acid, and this is continued till the bubbles of gas which pass over are perfectly absorbed by solution of potash. The combustion of the mixture is then conducted in the usual manner, and after it is complete, heat is again applied to the end of the tube containing the remaining half of the carbonate of copper, and carbonic acid is evolved, which sweeps out the last portions of nitrogen into the receiver, when the volume of that gas is observed, and after being corrected for temperature and pressure, as directed in pages 50-51, its weight is calculated.

*New method by Drs. Will and Varrentrap.** This is likely to supersede every other method of determining the nitrogen in an organic compound. It is founded, as was above ob-

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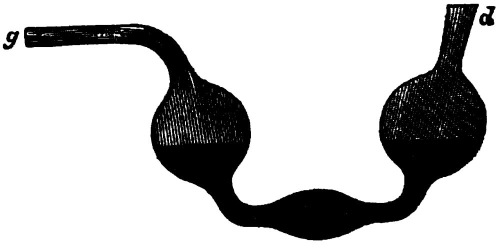
* See London, Edinburgh, and Dublin Phil: Mag: Vol. 20, page 216, et seq.

served, on the action of the hydrates of the alkalies on nitrogenous organic compounds at high temperatures, and consists in determining the weight of the nitrogen in the form of ammonia, *i. e.* as ammonio-chloride of platinum, or as metallic platinum.

The apparatus employed, consists of a common small-sized tube of combustion, and glass bulbs, shaped as in *Fig.* 106, containing muriatic acid for the absorption of the ammonia generated, fixed air-tight to the tube, by means of a bored cork. The bulb apparatus is fitted by inserting the pointed end, *g*, into muriatic acid of the usual strength, (sp: gr: 1·13,) and drawing it in with the mouth at *d*, until the stand of the liquid attains the level indicated by the shading.

Fig. 106.



The alkaline mixture recommended is composed of one part by weight of hydrate of soda, to two parts of caustic lime, and is easily prepared by slaking the caustic lime with a solution of soda of known concentration; it is then heated in a crucible and powdered finely; or the melted and cooled hydrate of soda is pounded quickly in a warm mortar, and well mixed with the finely powdered caustic lime in the above proportions. The mixture is again exposed to a gentle heat to drive off all moisture, and preserved in a well stopped bottle with a wide mouth.

When the substance to be examined has been reduced to a fine powder, dried, and weighed, the previously cleansed and dried tube of combustion is filled, one half with the mixture of alkali and lime, in order to have a fixed measure for the quantity with which the substance to be analyzed is to be mixed. The quantity of the latter which is requisite for a combustion can be taken according to the supposed amount of nitrogen it contains; it is, however, rarely requisite to employ more than 400 milligrames* with substances containing little nitrogen, and not less than 200 milligrames of those which contain much. The weighed quantity of the substance is mixed with the measured quantity of soda-lime, in a mortar previously somewhat *warmed* and *unglazed*, by stirring *gently* with the pestle. If these two measures of precaution are observed, there is no danger of any loss resulting from an adhesion of substance to the sides of the mortar and pestle. When the mixture has been introduced into the tube in the usual manner, the mortar is repeatedly rinsed with some soda-lime, the tube filled within an inch of the aperture, and a close layer of previously ignited *asbestos* introduced to prevent any of the fine powder being carried away by the gases evolved during the burning, which, especially if a mixture of hydrate of *potash* and lime be employed, would give rise to incorrect results, as the potash-chloride of platinum acts in the same way towards solvents as the ammonio-chloride. In this respect, the mixture of soda and lime is preferable, for should any such accident happen, the soluble soda-chloride of platinum is easily removed by washing.

The tube is then connected with the apparatus containing the muriatic acid, by a soft tight-fitting cork, placed in the combustion furnace, and some air expelled by warming the bulb with a glowing charcoal, to see whether the apparatus is air-tight; if so, the front part of the tube, which contains none of the organic substance, is heated to redness by surrounding it with glowing charcoal, that nothing may distil over undecomposed. The cork must be kept as warm as possible, that it may not retain or imbibe any moisture, which, by absorbing ammonia, would occasion an error in the result. As soon as this part of the tube is red-hot, the combustion is

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* A milligramme is equal to ·0154 English grain, consequently 400 milligrames are equivalent to 6.16 grains.

proceeded with; carbonic acid is formed from the oxygen of the hydrate, and the whole or a part of the carbon of the substance; *the hydrogen that is set free combines with the nitrogen in its nascent state, as ammonia, which escapes in a gaseous state.* At the same time, according to the amount of carbon in the substance, pure hydrogen, or carburetted hydrogen is given off, which not being absorbed by the acid, indicates the progress of the combustion. It is to be particularly observed, that the burning must be carried on so quickly, that a constant and uninterrupted evolution of gas takes place; there is no danger of any ammoniacal gas escaping; the absorption is so complete and rapid, that there is rather reason to fear the acid rising into the tube, which would render the analysis useless. Only few substances contain so much nitrogen that the whole carbon requires to be oxidized and converted into carbonic acid, in order that sufficient hydrogen be set free to form ammonia, with the whole of the nitrogen; and every nitrogenous organic substance in which the nitrogen is not present in the form of nitric acid, contains sufficient carbon for the purpose. When the substance to be examined is particularly rich in nitrogen, as mellon, mellamin, sulphuret of cyanogen, &c., the authors recommend adding an equal weight of some substance containing no nitrogen, (sugar for instance,) this affords permanent gases by its decomposition, which dilute the ammonia and render its absorption by the acid less rapid. After the tube has been gradually brought to redness the whole of its length, and the evolution of *gas* has *entirely* ceased, which occurs when all the carbon has become oxidized, and the mixture again appears white, the extreme erect point is broken off, and a current of atmospheric air drawn through the absorbing apparatus, that the ammonia still in the tube may be condensed. In doing this, a tube, containing potash is fixed on to the extremity of the absorbing apparatus by which the air enters. This perfectly secures it against acid vapours which may accompany the current of atmospheric air. The becoming white of the mixture in the tube is of importance, as ammonia in contact with alkali and carbon, at a high temperature, easily forms prussiate of ammonia, which would cause a loss of nitrogen in the analysis. All the carbon, however, is burnt when sufficient heat is employed, and not the least fear of the formation of cyanogen need be entertained.

When the burning is finished, the contents of the absorbing apparatus are poured into a small porcelain evaporating dish, a mixture of alcohol and æther is introduced into the apparatus, to remove any carburetted hydrogen from its sides, and it is then washed with water till the same shows no acid re-action. A pure solution of *chloride of platinum* is then added in excess to the sal-ammoniac, and the whole evaporated to dryness in a drying apparatus guarded against dust. When the combustion has been well conducted, the dry ammonio-chloride of platinum is of a beautiful yellow colour: if the substance contains much carbon, or is difficult to burn, it is darker, the muriatic acid becoming black on evaporation from contact with carburetted hydrogen. This colouring has no influence on the result, if the precipitate be carefully washed.

The dried residue in the porcelain vessel is treated, when cooled, with a mixture of two volumes of strong alcohol with one of æther, in which the ammonio-chloride is insoluble, but the chloride easily soluble. It is soon seen whether an excess of the chloride of platinum has been added, from the yellow colour of the liquid. The precipitate is thrown on a filter, which has been dried at 212° and weighed, and then washed with the same mixture of alcohol and æther, until it runs off perfectly clear, leaves no residue, and does not re-act acid. The precipitate, perfectly washed, is dried at 212°, and the amount of nitrogen calculated from its weight. It is proper to controul this weighing by exposing the ammonio-chloride to ignition, and calculating the nitrogen from the platinum obtained. The ammonio-chloride may be considered as pure when the two calculations do not sensibly differ.

The Authors, however, prefer determining the amount of nitrogen, in the form of ammonio-chloride of platinum, as in this case every 177 parts of nitrogen, require 2788 parts of the salt; whereas, with metallic platinum, only 1233 parts are required, thus doubling the chance of error in weighing.

It is particularly to be observed, that *perfectly pure* chloride of platinum must be employed: it must contain previously no ammonio-chloride of platinum in solution. It is not easy to free the platinum-sponge obtained from the ammonio-chloride entirely from the muriate of ammonia. If the sponge be boiled in distilled water, the filtered liquor frequently gives a considerable precipitate with nitrate of silver. It is, therefore advisable to boil the sponge several times in distilled water, previous to dissolving it in aqua-regia.

In decomposing the ammonio-chloride, Rose recommends to place the salt with the filtering paper in the crucible, and to expose it for some time with the lid closely applied to a moderate heat. If this precaution be not taken, some undecomposed salt and metallic platinum may be mechanically carried away by the vapours of the muriate of ammonia, which would occasion a loss of platinum, and consequently of nitrogen.

Such are the general principles on which organic analyses are now conducted. I should have been more particular in describing each step of the operation, and the precautions to be adopted in order to guard against all sources of error, but the translation of Liebig's pamphlet, and its publication in so cheap a form, renders such detail unnecessary. In this tract the student will find every information on the subject that he can desire, with excellent wood-cuts of all the apparatus required, and I believe, that with a little practice and attention, he will, by its aid, soon find himself enabled to undertake organic analyses and conduct them with tolerable precision.

It will not be expected in an elementary work like the present, that a complete view should be given of the discoveries which have been made during the last few years in organic chemistry, and yet the subject is so intimately connected together, and one discovery has so led on to another, and all are of such scientific interest, that it would be a difficult task to select for our prescribed limits the most important. After much consideration, therefore, I have decided on occupying the remainder of this lecture, with a consideration of that part of organic chemistry only which relates to, and which has a practical bearing *on agriculture.* I have thought that this course will probably give the work a more useful and interesting character, and as a mutilated insertion of our existing knowledge of scientific organic chemistry would certainly be worse than useless, I shall content myself with referring the student to the works of Thomson, Graham, Kane, and Liebig, for a full exposition of the subject.

Food of Plants. In a former part of this work,* it has been shown that the food of plants consists of carbon, oxygen, hydrogen, and nitrogen. It was also shown in a most convincing manner, that the first of these elements was principally furnished by the carbonic acid existing in the atmosphere; it must not, however, be concluded that the organic matter in the soil is passive with regard to this particular. It is true, that *originally,* all the carbon in the vegetable world may be traced to atmospheric carbonic acid, for we learn from sacred history, that there was a time when no vegetable matter existed in the soil which overspread the earth's surface, but we also know that plants do not *luxuriate* or readily ripen their seed in a soil destitute of organic matter, and that by constant cropping a soil is gradually exhausted. Organic matter must, therefore, be removed from the field with every crop. The proportion of carbon which plants derive from the soil on which they grow, varies according to the nature of the plant, to the period of its growth, to the soil, and to the climate, and it may be considered as a general law in nature, that plants, like animals,

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* Lecture 7th.

have the power of adapting themselves, to a certain extent, to the conditions in which they are placed, and of supporting life by the aid of such sustenance as may be within their reach. But whether the carbon of vegetables be derived from the air, or from the soil, it is unquestionably carbonic acid that is decomposed to furnish by far the greater part. It cannot, observes Liebig, be assimilated from humus, or from sugar, starch, or gum, for these are the *products* of plants which live only while they generate them. Humus is woody fibre in a state of decay, the process being the absorption of oxygen and the liberation of an equal volume of carbonic acid, so that in a soil permeable to air, every particle of decaying humus, must be surrounded by an atmosphere of carbonic acid, which is the *first and most important food of young plants.* The observation, however, of Liebig, " that when the plant is matured, the carbonic acid of the soil is no longer required, and that in summer the carbon is exclusively derived from the atmosphere," must be received with certain strictures, as has been shown by Johnstone.* " A little consideration," observes this intelligent Chemist, " will show us that while the proposition contained in the former part of the quotation, may be entertained and advanced as a *matter of opinion*—the latter is obviously incorrect. In the summer, when the sun shines the brightest and for the greatest number of hours, the evaporation from the leaves of all plants is the greatest;—the largest supply of water, therefore, must at this season be absorbed by the roots, and transmitted upwards to the leaves. But this water, before it enters the roots, has derived carbonic acid and other soluble substances, from the air and from the soil, in as large a quantity at this period as at any other during the growth of the plant, and these substances it will carry with it in its progress through the roots and the stem."

We know that soluble organic matter is absorbed by the roots of plants, and carried into their circulation, for the

* See his Lectures on Agricultural Chemistry and Geology, p. 86.

flower of the white hyacinth becomes red after a few hours, when the earth in which it is planted is sprinkled with the juice of *phytolaca decandra*,* and that a chemical change takes place in the organic matter after it is absorbed, may be inferred from the fact, that the colour imparted to the flower of the white hyacinth disappears in the sunshine in the course of a few days; there does not, therefore, seem any philosophical reason for supposing that plants reject the carbon presented to them in the form of soluble organic matter, or for supposing that this element is furnished *exclusively* by the decomposition of carbonic acid.

The source from whence plants derive oxygen may be perceived without difficulty, this element constituting eight-ninths of the weight of water, $\frac{21}{100}$ths of the bulk of the atmosphere, and $\frac{72}{100}$ths of the weight of carbonic acid: each of these compounds, therefore, presents an ample supply; but it is from water probably that the principal part of the oxygen, as well as of the hydrogen of the vegetable world is derived.

The question, whence do plants derive their nitrogen? has been already discussed in Lecture 7th, where it was stated, on the authority of Liebig, that it is furnished by the decomposition of the ammonia, condensed by rain from the atmosphere. A few more remarks on this interesting subject will not be out of place here. In the case of a well cultivated farm, cited by Liebig,† in which, after a given number of years, the quantity of nitrogen is supposed to be increased, notwithstanding the annual exportation of corn and cattle, it is clear, that if the excess of carbon and nitrogen was derived from the decomposition of animals and vegetables extraneous to the farm, uncultivated land ought to differ from that which is cultivated, and in proportion as land is cultivated, that which remains in a state of nature ought to be the less adapted to support vegetable and animal life. But does this accord with observation and experience? We have no reason for supposing that

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* Biot.

† See page 209.

plants in a wild condition are not as well able to supply themselves with those principles which are necessary for their existence as those which are cultivated by man, although it is true that the latter being selected for the nutriment they are capable of affording, require more nitrogen; there must, therefore be some compensatory process by which this element is furnished, *besides* what is due to the products of the decomposition of animals and vegetables, for as animal life is undoubtedly extending over the earth, and as civilization, and consequently cultivation are also increasing, we shall be reasoning "in a vicious circle," as Professor Daubeny observes, if we refer the nitrogen which plants absorb, to the decomposition of animals, while these very animals are supposed to have obtained their nitrogen from the vegetable food on which they had themselves subsisted. Besides, we cannot suppose that the whole of the ammonia, formed by the decomposition of animal and vegetable matter, is ever brought within the reach either of the roots or leaves of living plants. A portion is daily washed from the soil by rain, and carried to the sea, and much more, probably is washed from the air by the water of the sea itself, or by the rains which fall directly into the wide ocean; and we know of no compensating process by which this ammonia can be restored to the air and again made useful to vegetation. Again, of the ammonia which remains in the atmosphere, it can hardly be doubted that part undergoes decomposition by natural processes. Carburetted hydrogen is constantly escaping from stagnant pools, as was shown, page 310, nevertheless, traces of it are only occasionally met with in the atmosphere, there is no doubt therefore, that at the expence of the oxygen of the atmosphere, it becomes resolved into carbonic acid and water, and in a similar manner it is highly probable that ammonia may be decomposed into watery vapour and nitrogen.* In volcanic countries, carbonic acid is

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* Johnston concludes, that of the ammonia which is formed from the nitrogen actually existing in animal and vegetable substances during their decay, only a compara-

known to be evolved in vast quantities from rents and fissures in the earth, and in some of these districts, especially in Italy and Sicily, ammonia, combined with muriatic acid, in the form of sal-ammoniac, is also given off; and in the lagoons of Castel Nuova and Cherchiago, where the boracic acid, which accompanies hot steam, issuing from the interior of the earth is condensed, there is invariably present ammonia, which, coming from out of depths in which human beings and animals never could have lived, could not have been produced by the living organism,* but, according to Liebig, "must have existed before the creation of human beings, and be a primary constituent of the globe itself." This opinion is eagerly seized by Professor Daubeny,† and he brings it forward in support of his conjecture, "that every particle of carbon as well as of nitrogen, which enters into the constitution of the plants and animals, either now existing or which have existed since the beginning of time, may have been originally evolved from the interior of the globe;—that the evolution is proceeding continually and without interruption, and has been so, like the volcanic processes which produce it, from the beginning of time. This suggestion is connected with the view which Daubeny is well known to adopt with regard to the phœnomena of volcanoes, which he explains on the supposition of intense chemical actions, a heat sufficient to melt lavas being produced by the combination of the metals of the earths with oxygen, hence the escape of atmospheric air, deprived of a portion of its oxygen:—the ammonia disengaged is referred by the Professor to the decomposition of water, which, meeting with oxidizable elements in the interior of the globe, gives up its oxygen to them, and its hydrogen to the nitrogen of the previously de-

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tively small portion ever returns again to minister to the wants of new races. *See Lectures on Agricultural Chemistry and Geology. Page* 236.

* In the large works in Liverpool, where natural boracic acid is converted into borax, many hundred pounds of sulphate of ammonia are obtained at the same time.—*Liebig.*

† See his Lectures on Agriculture; page 92.

composed atmospheric air, and thus he attempts to account for the comparatively insignificant quantities of nitrogen evolved in the neighbourhood of such subterraneous actions.* But, according to Berzelius, ammonia is not unfrequently formed when organic substances which contain *no* nitrogen are oxidized

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* The arguments in favour of the chemical theory of volcanoes, have been ably, and to my mind, convincingly combated by Professor Bischof, of Bonn.* Speaking of the quantity of air requisite to produce a certain quantity of lava by oxidation of the earthy and alkaline metals, he makes the following calculations. Supposing that 58 parts of the metallic bases of the lava from *Etna*, require 42 parts of oxygen to give 100 parts of lava, 100 parts of atmospheric air containing 23·32 parts of oxygen by weight, 100 parts of lava will require 180 parts of air by weight to be produced. Lava being 3·2 times heavier than water, and water being 770 times heavier than atmospheric air, lava is consequently 2,464 times heavier than the latter. Therefore, the production of 1 volume of lava will require 4,435 volumes of air. In the year 1783, a mass of lava was brought up during an eruption in the low country of Skaptar Jokul, in Iceland, so considerable as to surpass in magnitude the bulk of Mount Blanc; and if constituted like the lava of Etna, this mass would require for its production a quantity of atmospheric air equal to the bulk of 4,435 times the size of Mount Blanc, had it been generated by oxidation of the metals contained in it. Thus a bulk of nitrogen gas of 3,503 times as great as that of the mountain mentioned must have been evolved during the formation of that mass of lava; with respect to the suggestion of Daubeny, that this nitrogen may reach the air not only in a separate condition, but also united with hydrogen, in the form of ammonia: Bischof adverts to the small quantities of ammonia and sal-ammoniac which occur among the volcanic matters in craters or fumaroles, quantities by no means sufficient to account for the huge quantities of nitrogen which, according to the chemical theory, must be separated; besides, we have no reason to suppose that the same laws of combination which take place in our laboratories do not prevail in volcanoes, and chemists have hitherto been unable to unite directly hydrogen and nitrogen, even by letting down a mechanical mixture of the gases under the sea, to a depth of 540 metres, where the pressure is equal to 50 atmospheres; *pressure* therefore does not seem to favour the combination, and even supposing it did, the ammonia formed could scarcely be supposed to escape decomposition from the high degree of heat to which it would be immediately subjected. But supposing that nitrate of ammonia was formed from the ignition of mechanical mixtures of hydrogen in excess, oxygen, and nitrogen, this salt could not possibly escape decomposition into water and protoxide of nitrogen. It is, nevertheless, an undoubted fact, that both ammonia and sal-ammoniac are among the products of volcanic action, and Bischof refers their production to the action of heat on the organic matters contained in the sedimentary rocks in which many volcanoes like Vesuvius are found. In support of this view, he alludes to the known facts; that among the masses thrown out of Vesuvius, there are not seldom large masses of limestone, which have likely occasioned the formation of sal-ammoniac,

* Jameson's Philosophical Journal, Vol. xxvi. p. 291.

in the air, hence it must be produced in unknown quantities, during the annual decay of *all* vegetable substances, and it is not unlikely that it may be also formed in the soil itself by the absorption of oxygen, for when moist iron filings are exposed to the air, *ammonia* is produced, according to Chevallier,

and that during volcanic eruptions, bituminous odours are frequently perceived in the vicinity of the crater. It is also observed by Johnston, that the passage of moist air over red-hot charcoal, gives rise to the formation of ammonia as well as of carbonic acid as may be proved by drawing a current of atmospheric air and steam through a red-hot gun-barrel filled with well-burned charcoal, and causing the current on leaving the barrel to pass through water acidulated with muriatic acid, after a time, the water on evaporation will be found to contain traces of sal-ammoniac; which thus takes place in a small experiment of this kind, must more readily and more largely take place in the interior of the earth, where combustible substances at a high temperature happen to be exposed to a current of atmospheric air, mixed with watery vapour, and this he thinks quite sufficient to account for the ammonia evolved in volcanic districts, without having recourse to doubtful speculations. Since the existence of combustible matters in such districts and at great depths beneath the surface, can in few cases be doubted, and the passage of a mixed atmosphere of common air and steam over such combustible matter at a high temperature is all that is required.

But according to the chemical theory of volcanoes, water plays a prominent part in the phœnomena; indeed, according to Daubeny, it may be supposed to be the *primum mobile* of the chemical changes which take place; and he accounts for the non-appearance of hydrogen gas in the immense quantities to which such extensive decompositions would give rise, by supposing it to combine with those elementary substances to which it would be presented, and for which it possesses a strong affinity. Bischof meets this by calculating the quantity of water which would have been required to oxidate the metallic principles, which formed the lava ejected from the Skaptar Jokul, this he finds would be equal in bulk to 1·5 that of Mount Blanc, now supposing the hydrogen eliminated from this to combine with sulphur, forming sulphuretted hydrogen, calculation shows that a mass of sulphur 1·4 times the bulk of Mount Blanc would be required; but sulphur and hydrogen combine only at a high temperature, and if sulphur be supposed to be present when the oxidation of the metallic bases takes place, it ought rather to combine with the alkalies and alkaline earths produced, for which it is well known to have a strong affinity. A strong argument against this supposed union of the hydrogen with sulphur, is the fact, that the disengagements of sulphuretted hydrogen do not take place before the issuing of lava, but for the most part after all other volcanic phœnomena have ceased, whereas, the decomposition of water being the *first phasis* of volcanic action, the second should be the combination of the hydrogen separated with sulphur, and this should precede by a long period the eruption of lava. The formation of sulphuretted hydrogen in volcanic districts may, according to Bischof, be occasioned in a measure by the re-action of carbonaceous matter upon sulphates, in the same manner as the waters on the coast of Africa become impregnated,* for organic matters are not wanting

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* See page 278.

and when certain oxidized substances are decomposed in the air, by means of potassium, according to Faraday, the same compound is formed, and we have seen, (Lecture 8th, page 235,) that when tin is rapidly dissolved in nitric acid, ammonia is formed. But is ammonia the *only* substance, by the decomposition of which, plants are supplied with nitrogen? Is there not any other compound of this element to be found in soils, or which may be formed in the atmosphere, through which a supply may be obtained? According to Johnston, *nitric acid* and its compounds appear to *exist* ready formed in nature, in larger quantity than either ammonia or any of its compounds. It is true, that nitric acid does not form a necessary constituent of any of the solid rocks of which the crust of the globe is composed, but it is diffused almost universally through the soil which overspreads the surface, and in India, in Africa, and in South America, it accumulates in vast quantities. There can be little doubt that nitric acid is formed in the atmosphere, and that too, not unfrequently, at the expence of ammonia. It was shown in Lecture 8th, page 230, that by passing a succession of electric sparks through a mixture of oxygen and nitrogen, nitric acid is formed. Is it not, therefore, highly probable that the currents of electricity, which in nature, traverse the atmosphere, may produce the same effect? In the rain which fell during seventeen thunder storms, Liebig found nitric acid always present, generally in combination with lime and ammonia, and if, after a thunder storm in our climate, this acid, (difficult as it is of detection in small quantities,) is to be discovered, what vast quantities must be formed in those regions where such storms are so violent and frequent! When a mixture of oxygen gas and ammonia is exploded, nitric acid is formed. It is scarcely

in sedimentary rocks which have been broken through by volcanic actions, and sulphates exist in many volcanic products. When liver of sulphur abounds, exhalations of sulphuretted hydrogen during the course of many ages may be easily imagined, for this gas would be formed whenever the alkaline sulphurets come into contact with water and carbonic acid.

possible, therefore, that some portion at least of the ammonia given off from decaying animal matters, can escape decomposition in the atmosphere during thunder storms, indeed the existence of *nitrate of ammonia* in rain water makes the fact almost certain, and as Johnston observes, renders improbable the existence of ammonia in the atmosphere in the large quantity supposed by some chemical writers. Now nitric acid and its compounds are exceedingly soluble, and although a large quantity, as with ammonia, must be carried down to the sea by rains, and absorbed by the waters of the ocean, a portion must reach the leaves and roots of vegetables, and enter into their circulating system.

In the artificial nitre-beds of France and the north of Europe, which consist of long ridges, or conical heaps of earth of different kinds, mixed with large quantities of animal and vegetable matter, which are frequently watered with liquid manure, and turned over to expose fresh portions to the air, the quantity of nitric acid which is formed, is much greater than could be produced by the oxidation of the *whole of the nitrogen* contained in the organic matters present in the mixture,* proving *in an instructive manner the formation of nitric acid at the expence of the nitrogen of the atmosphere.*† We may then with reason conclude, that nitric acid has as important an influence over the growth of plants in their natural

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* See page 238.

† It appears that in our climate, organic matters are necessary to cause the formation of nitric acid to *commence*, but that after it has begun it will proceed in the same heap for an indefinite period; and, at the expence apparently, of the *nitrogen of the air only*. (Johnston.) In other climates, however, the presence of organic matter seems unnecessary; thus, the formation of nitrate of lime, in the celebrated mammoth cave in Kentucky, is so rapid and inexhaustible, that during the war with Great Britain, fifty men were constantly employed in lixiviating the earth of this cave; nevertheless, in about three years, the washed earth is said to have become as strongly impregnated as at first. Now this cave is situated in a limestone ridge, and a strong current of air is continually rushing through it, inwards in winter, and outwards during the summer months. According to Davis, in China, the old plaster of the houses is so much esteemed as manure, that parties will often purchase it at the expence of a coating of new plaster.

as well as in their cultivated state as ammonia, though the precise influence of each must be considerably affected by *climate and locality.*

Substances produced in plants. Under this head, I shall only introduce those products of vegetation which constitute the great bulk of vegetables, for though the chemical compounds which may be extracted from the juices of different plants are almost innumerable, new substances being daily discovered, and though some of them are highly important, as well from their use in medicine as in a scientific point of view, they form so minute a part of the weight of the vegetables from which they are derived, that they may be entirely neglected in the view of vegetation, which I am endeavouring briefly to lay before you.

Substances produced from carbon, oxygen, and hydrogen. Woody fibre; its properties and transformations. The chief bulk of all trees and herbs, is *woody fibre,* or *lignine.* It may be procured free from foreign matter, and of a constant composition, ($C_{12}H_8O_8$,) by treating any kind of wood successively, and repeatedly, by dilute acids and alkalies, by water and by alcohol, so that every soluble material is removed from it. It is a white fibrous mass, without taste or smell, and perfectly insoluble in water. It consists, according to Payen, of two organic principles; one is the primitive tissue, composing the vessels of the wood, and the other fills the cells, and is called the incrusting matter. Although it will be observed, that in lignine, the oxygen and hydrogen exist in the proportions to form water, yet, as when heated or distilled, it cannot be resolved into charcoal and water, we cannot suppose it to consist of these alone. Woody fibre forms nearly half the weight of the dried stalks of the grasses and the corn growing plants, but in roots and in some plants which are raised for food, its quantity is comparatively small. By the action of heat, woody fibre may be changed into *starch,* for when fine sawdust is well boiled in water, then dried, and several times heated in a oven, it becomes crisp and hard, and when ground, it has a taste and smell similar to the *flour of wheat.* In this state it may be fermented with yeast, after which bread may be made from it, and it yields, when boiled with water, a stiff tremulous jelly, like that from starch.* By the action of sulphuric acid also, woody fibre may be converted into starch, and even into a substance resembling gum-arabic,† and if this gum be digested with dilute sulphuric acid, it will be gradually converted into *grape sugar,* indeed it is possible to convert linen or fine woody fibre directly into sugar, by the prolonged action of dilute sulphuric acid. Woody fibre is also converted into starch by the action of hydrate of potash, for if saw dust be mixed with eight times its weight of this compound, and boiled till a crust forms on its surface, and if dilute sulphuric acid be then added till the whole is slightly sour, an instantaneous deep blue will be occasioned on the addition of iodine.‡ Unlike as woody fibre, starch, gum, and sugar, are in their properties, the above changes will not be wondered at, when we learn the composition of these vegetable products.

2. *Starch, its properties and transformations.* When wheat flour paste is kneaded under a small stream of water, till that fluid runs off colourless, a tough dirty white substance remains in the hand, and by standing, a white powder is deposited from the water,—this is *starch.* When potatoes are reduced to a pulp and washed on a sieve, grains of exceedingly pure starch pass through and are slowly deposited from the water;—arrow-root, sago, tapioca, salop, &c., are each very pure varieties of the same vegetable product.

Starch may be considered next to woody fibre, as the most abundant product of vegetation, and as it forms a large portion of the weight of the various roots and grains which are

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* Schubler, Johnston.

† Braconnot.

‡ See Lecture 9th, page 302.

the principal objects of the art of culture, and as it is one of the staple ingredients of the food of man and animals, it is a substance of much interest.

The following table, exhibits the quantity of starch in 100lbs. of each of the substances named.*

	STARCH, PER CENT.
Wheat Flour,	39 to 77
Rye, Ditto,	50 — 61
Barley, Ditto,	67 — 70
Oatmeal,	70 — 80
Rice Flour,	84 — 85
Maize Ditto,	77 — 80
Buck Wheat,	52
Pea and Bean Meal,	42 — 43
Potatoes, containing 73 to 78 of water,	13 — 15

To obtain starch free from *gluten*, and of that white and crystallized appearance which distinguishes the starch of commerce, the manufacturers steep good wheat in cold water, till it becomes soft, and yields a milky juice when squeezed. It is then taken out of the water, and put into coarse linen sacks, which are subjected to pressure in a vat filled with water; a milky juice containing abundance of starch exudes and mixes with the water of the vat. This process is repeated as long as the wheat yields any milky juice; the sack and its contents are then removed. The starch soon falls to the bottom of the vat, and the water which covers it gradually ferments, in consequence of the substances which it holds in solution; alcohol and vinegar are formed; and the acid thus evolved, dissolves all the impurities, and leaves behind nothing but starch.† After being well washed, it is dried by a moderate heat, during which, it splits into those regular columner masses in which it is met with in commerce.

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* Johnston.

† For this fermentation, the action of a weak solution of caustic alkali has lately been substituted, by which the gluten of the flour is dissolved and the starch left.

The composition of starch is—

Carbon,	44·91 which corresponds to	C_{12}.
Hydrogen,	6·11	H_{10}.
Oxygen,	48·98	O_{10}.
	100	

When pure, starch has a fine white colour, no smell, and very little taste, when kept dry it continues long unaltered, though exposed to the air. When examined under the microscope, it appears under the form of rounded grains, which vary in their shape, not only when the starch is extracted from different plants, but even from the same plant. Each grain is formed by a number of concentric layers, which increase in density and consistence from the centre. They are lodged in particular cells, in the plant which produces them, and increase in size as the plant advances to maturity.* In cold water, and in alcohol, starch is completely insoluble; but by boiling water it is resolved into a mucilaginous liquid, which forms a jelly on cooling. By exposure to a heat not above 300°, starch is gradually converted into a *gum*;† which is found a good substitute for gum-arabic, and which is largely manufactured in this country; by the action of boiling water, it is

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* According to Raspail, these grains consist of vescicles, inclosing within them a clear, transparent, colourless liquid. In cold water, these vescicles remain entire and insoluble, but when put into boiling water they burst, the central liquid dissolves in the water, and the husk, or outer coat of the vescicle becomes much more bulky and transparent than it was before, and floats undissolved in the liquid. Heat causes these vescicles to burst, and to empty themselves of the liquid which they contain. Thus it appears, that starch consists essentially of two distinct substances. 1. The liquid which fills each little vescicle, consisting of water, holding in solution a peculiar substance, called by its discoverer Guerin-Varry, *amidin*. 2. The vescicular portion of the grain which is insoluble in water, and which is called *amylin*. For a detailed description of these substances, see Thomson's Organic Chemistry, page 652, et seq.

† According to Vogel, during the baking of bread, there is a conversion of starch into gum, for he found that flour which contained no gum, gave when baked, a bread of which, 18 per cent. consisted of gum.

after a time, converted into gum or sugar; and by boiling 100 parts of starch for seven hours, with 600 of water, and 10 of sulphuric acid, it is transformed into *grape sugar;* the same change may be effected in a few minutes at the temperature of 250°. It is said, that this mode of converting potatoe starch into grape sugar, is extensively practised in France, for the purpose of subsequently fermenting the sugar and converting it into *brandy.* (Johnston.)

3. *Gum.* This name was originally applied to a thick transparent tasteless fluid, which exudes from various trees and plants, and which gradually concretes into a solid substance when left exposed to the air. The gum most commonly used in this country is known by the names of *gum arabic* and *gum senegal,* but many seeds of plants, *lintseed* for example, when macerated in water, render the liquid thick and adhesive, converting it into what is called mucilage. Gums are all characterized by being insoluble in alcohol, by dissolving or becoming gelatinous in hot or cold water, and by giving mucilaginous, viscid and glutinous solutions, which may be employed as a paste. There appear to be three distinct species of gum; *viz., Arabin,* which is soluble in cold water: *Cerasin,* existing in the gum of the cherry tree, which is insoluble in cold, but soluble in hot water, and *Bassorin,* forming a large portion of gum tragacanth, which swells and becomes gelatinous in cold water, but does not dissolve in water hot or cold.* All these gums possess the same chemical constitution, *viz.*

Carbon,	45·10 which corresponds to	C_{12}.
Hydrogen,	6·1	H_{10}.
Oxygen	48·8	O_{10}.
	10·0	

This it will be seen is precisely the constitution of starch,

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* For the chemical history of these gums, the student is referred to Thomson's Organic Chemistry.

and both consist of carbon and the elements of water united together in the *same proportions.* Gum exists in the juices of many trees from which it does not exude, and in the sap of most plants it is to be detected. It is a most important compound in the vegetable economy, being one of those forms of combination through which organic matter passes, in the series of changes it undergoes during the development and growth of the plant. By a prolonged digestion with sulphuric acid gum is partly converted into sugar.

4. *Sugar.* There are various substances which from their sweet taste, are known as sugars, though they have no other properties in common; but the most important are those which, when mixed with yeast, undergo a peculiar decomposition, and are converted into carbonic acid and alcohol, these are cane sugar, grape and starch sugar, milk sugar, mushroom sugar, and the insipid sugar of Thenard, of which varieties the two first are the most abundant, and the best understood.

Cane Sugar. This sugar exists in many plants, in the juice of the maple tree, of the turnip, carrot, and beet, in the unripe grains of corn, at the base of the flowers of many grapes and clovers when in blossom, and even in many small roots it may be detected. Almost the whole of our sugar is produced in the East and West Indies; the plant from which it is obtained is the *arundo saccharifera,* or sugar cane,* but during

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* The following is the process for making sugar, adopted in the West India islands. The juiee extracted by passing the cane twice between iron rollers is received in a leaden bed, and thence conducted into a receiver. Here it can not be allowed to stand above twenty minutes without beginning to ferment. Therefore, as soon as collected, it is run into a flat copper caldron, called a clarifier, capable of holding 400 gallons or more. Here it is mixed with a quantity of lime. The maximum used is a pint of lime to every hundred gallons; but in general much less will serve. Fire is immediately applied, and the juice heated to 140°. The fire is then extinguished; a thick viscid scum forms upon the top, which remains unbroken, and the clear liquid is drawn off from under it by a cock or syphon, and introduced into a large copper boiler. Here it is boiled briskly; the scum as it is formed being continually removed by large skimmers. When the bulk of the liquid is sufficiently diminished it is introduced into a second boiler, and the boiling and skimming continued as before; lime-water being sometimes

the war between Bonaparte and Great Britain, the extraction of sugar from beet-root was introduced into France, and the manufacture still continues.

Cane sugar is perfectly colourless. It dissolves in one third of its weight of cold water, and in all proportions in boiling water, when kept for a long time near its boiling point it loses its property of crystallizing; hence arises the most important source of loss in the manufacture and refining of sugar. From its concentrated solution in water, it gradually deposits itself in the form of sugar candy; in which state it is in combination with one equivalent of water. Pure cane sugar is composed of

Carbon,	44·92	which corresponds with	C_{12}
Hydrogen,	6·11	....	H_{10}
Oxygen,	48·97	....	O_{10}
	100		

It is, therefore, identical in composition with starch and gum.

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added, if the liquid does not appear clear. From the second copper it passes to the third, and from that to a fourth, where the very same process is continued. This last copper is called the *teache*. When by continual evaporation it has become sufficiently concentrated, which is judged of by its viscidity, it is withdrawn from the fire and introduced into the *cooler*. This is a wooden vessel about eleven inches deep, seven feet long, and from five to six wide. As it cools it crystallizes or grains, forming an irregular mass separated from the uncrystallized syrup or *molasses*. From the cooler it is taken and put into empty hogsheads, having holes in the bottom; through each hole the stalk of a plaintain leaf is thrust, long enough to rise above the top of the hogshead. Through these holes the molasses drains into a receiver. In about three weeks, the sugar becomes tolerably dry and fair, and the process is finished. The sugar in this state is sent to Britain, under the name of *muscavado*, or raw sugar. A gallon of raw juice yields about a pound of raw sugar. Edward's History of the West Indies, 2, 222. The raw sugar is purified by dissolving in water, clarifying, and boiling down to a proper consistency, it is then poured into unglazed conical earthen vessels, where it is allowed to grain. The point of the cone is undermost, and perforated, to allow the impurities to separate. The base of the cone is covered with moist clay, the water of which gradually filters through the sugar, and displaces a quantity of impure liquid. The sugar thus purified is called *loaf sugar*. When re-dissolved and treated in the same way a second time. it is called *refined sugar*.

Grape sugar is very extensively diffused in nature. It is the sweet principle of raisins, figs, and of most acid fruits, it forms the solid part of honey, and is the sugar of diabetic urine. It is called by Dumas *glucose*. It may be obtained from raisins or honey, by digestion first with cold strong alcohol, to remove the uncrystallizable sugar, and then expressing the residue which is to be dissolved in water and neutralized by chalk. The sugar so obtained may be clarified by white of egg, and evaporated to crystallization. This sugar is the sweet substance of all fermented liquors, and though it has all the sensible characters of cane sugar it differs considerably from it in chemical constitution, being composed of

Carbon,	40·47	which corresponds with	C_{12}.
Hydrogen,	6·59	....	H_{12}.
Oxygen,	52·94	....	O_{12}.[*]
	100		

Thus it contains the elements of two atoms of water more than cane sugar.[†] By the action of dilute sulphuric acid, aided by a gentle heat, cane sugar is converted into grape sugar, the same change is effected by tartaric and other vegetable acids.

The acids which play the most important part in vegetation, being present in large quantity in many plants, and in most unripe fruits, are the acetic, the oxalic, the tartaric, the citric, and the malic, all of which, except oxalic acid, are composed of carbon, oxygen and hydrogen.

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[*] Solutions of these two sugars may be distinguished by the following chemical characters. 1st. If the solution be heated and a few drops of sulphuric acid then added, cane sugar will be decomposed, blackened and made to fall as a black or brown powder, while a solution of grape sugar will at most be only slightly discoloured. 2. If instead of sulphuric, caustic potash be employed, the cane sugar will be unchanged, while the grape sugar will be blackened and thrown down.—*Johnston*.

[†] For a detailed account of the various sugars, and for a list of the plants from which sugar has been extracted, the student is referred to Thomson's Organic Chemistry.

1. *Acetic acid, or vinegar.* This acid is by far the most extensively diffused, and the most largely produced of all the organic acids. It is formed during the fermentation of seeds; it exists in the juices of plants, and it is abundantly evolved during the fermentation of all vegetable substances; its compounds with lime, magnesia, and alumina are very soluble in water. It is composed of

Carbon,	47·5 which corresponds with	C_4.
Hydrogen,	5·8	H_3.
Oxygen,	46·7	O_3.

Like sugar and starch, therefore, it consists of carbon and the elements of water, hence the rationale of its formation, though long wrapped in obscurity, is easily explained. Vinegar is well known to be largely derived by the action of the air upon alcoholic liquors, now no carbonic acid is evolved during this conversion, as was ascertained by Dobereiner, and when platinum black is placed in contact with alcohol, it becomes incandescent, and vinegar is formed. The composition of alcohol is represented by $C_4\,H_6\,O_2$, and if to this we add four equivalents of oxygen, and deduct three equivalents of water, we shall get the expression for acetic acid. Thus

$$\begin{array}{lr}
\text{Alcohol} & C_4\,H_6\,O_2 \\
\text{Four of Oxygen} & O_4 \\
\hline
 & C_4\,H_6\,O_6 \\
\text{Deduct} & H_3\,O_3 \\
\hline
 & C_4\,H_3\,O_3
\end{array} \quad = \quad \text{Acetic acid.}$$

Pure alcohol, diluted with water and exposed to the air, does not acidify. The presence of an oxidable ***azotized*** body is necessary, the action of which I shall endeavour to explain presently.* Vinegar is also obtained by the distillation of dry

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* In Germany, vinegar is made from alcohol, in the following manner. Strong alcohol is diluted with 4 or 6 parts of water, and about 1-1,000th of yeast, must of beer, vinegar or honey added to it. To acidify this liquid it is heated to 75° or 80°, and made

wood; as thus produced it is frequently called pyroligneous acid. Its formation from woody fibre is easily to be understood, the absorption of the elements of one equivalent of water being all that is required; thus

WOODY FIBRE. 3 EQUIV: OF VINEGAR.

$$C_{12} H_8 O_8 \quad \text{plus } H_1 O_1 = C_{12} H_9 O_9$$

Vinegar is also frequently prepared for household purposes by keeping sugar and water with a little vinegar for a length of time at a moderate temperature. The change in this case is easily understood, for if the elements of one equivalent of water be deducted from the formula for cane sugar, the elements of three equivalents of vinegar will remain. Thus

CANE SUGAR. 3 EQUIV. OF VINEGAR.

$$C_{12} H_{10} O_{10} \quad \text{minus } H_1 O_1 = C_{12} H_9 O_9$$

2. *Oxalic acid*, $C_2 O_3$. This acid which has been already described,* occurs in combination with potash in the sorrels, in rhubarb, and in the juices of many lichens. Those lichens which incrust the sides of rocks and trees, not unfrequently contain half their weight of this acid, in combination with lime.

3. *Tartaric Acid.* This acid exists in many fruits, and also as tartrate of lime in several roots. In the juice of the grape it exists in the form of bitartrate of potash, and owing to its

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to trickle through a cask filled with beech wood shavings, and pierced with holes at top and bottom, to allow a circulation of air through it. From the great surface exposed by the liquid, the absorption of oxygen is most rapid, and the temperature rises to 100 or 104°. When the liquid has been passed three or four times through the barrel at the high temperature, all the alcohol it contains is changed into vinegar, an operation which may be completed in 24 or 36 hours. This method has almost entirely superseded the old one, of mere partial exposure to the air in vats. The vinegar of commerce has frequently its pungency and acidity increased by the addition of acrid herbs, as capsicum, and by sulphuric acid. To obtain it free from these impurities it may be re-distilled. A pure and strong acetic acid is best obtained by distilling one part of *dry* acetate of soda with *two* parts of oil of vitriol, by the aid of a moderate heat. The sulphuric acid with which the first distillation is contaminated, may be removed by rectifying over per-oxide of lead.

* Lecture viii. page 260.

insolubility in alcohol it is precipitated during the fermentation of wine as *argol*, in which state it is known and much used in commerce, as also when purified as cream of tartar. Pure tartaric acid is composed of

Carbon,	36·81 which corresponds with	C_4
Hydrogen,	3·	H_2
Oxygen,	60·	O_6
	100	

In this acid, therefore, the oxygen and hydrogen are not in the proportion to form water, and consequently it cannot, like starch, sugar, &c., be represented by carbon, and the elements of water alone.

In the grape and other fruits in which tartaric acid exists, there are two ways in which it may be sùpposed to be formed. First, from the elements of carbonic acid and water with the *evolution* of oxygen, thus—

4 of Carbonic acid, $= C_4\,O_8$
2 of water, ... $H_2\,O_2$
TARTARIC ACID.
$C_4\,H_2\,O_{10}$ or $C_4\,H_2\,O_5 + 5\,O$.

Second, from the gum and sugar already present in the sap, aided by the *absorption* of oxygen from the atmosphere, thus—

Grape sugar, $C_{12}\,H_{12}\,O_{12}$
$\frac{1}{3}$ of grape sugar, $C_4\,H_4\,O_4$
3 of oxygen, O_3
TARTARIC ACID.
$C_4\,H_4\,O_7$ or $C_4\,H_2\,O_5 + 2\,HO$

In the sunshine, the green parts of plants absorb carbonic acid and give off oxygen. If, therefore, any of the green parts of plants which contain tartaric acid in their general sap, give off only $\frac{5}{8}$ of the oxygen contained in the carbonic acid they drink in, tartaric acid may be produced. In the dark, they absorb oxygen, and give off carbonic acid. If the bulk of this latter gas which escapes, be less than that of the oxygen which enters, a portion of the sugar, or gum of the sap, may be converted into tartaric acid.—*Johnston.*

The conversion of tartaric acid into grape sugar, as the fruit advances to maturity, may take place: first; by the direct evolution of excess of oxygen: thus—

$$\begin{array}{lcl}
\text{3 of tartaric acid,} & = & C_{12}\,H_{6}\,O_{15} \\
\text{6 of water,} & = & \quad H_{6}\,O_{6} \\
\hline
 & & C_{12}\,H_{12}\,O_{21} = \overset{\text{GRAPE SUGAR.}}{\underbrace{C_{12}\,H_{12}\,O_{12}}} + 9O
\end{array}$$

Or grape sugar may be formed from 3 of tartaric acid and 6 of the water of the sap, by the evolution, at the same time of 9 of oxygen. Second; by the absorption of oxygen and the evolution of carbonic acid; thus—

$$\begin{array}{lcl}
\text{1 of tartaric acid,} & = & C_{4}\,H_{2}\,O_{5} \\
\text{1 of oxygen,} & = & \qquad O_{1} \\
\hline
 & & C_{4}\,H_{2}\,O_{6} = \overset{\frac{1}{6}\text{th of grape sugar.}}{C_{2}\,H_{2}\,O_{2}} + 2\,C\,O_{2}
\end{array}$$

Citric acid. It is this acid which gives their acidity to the lemon, the lime, the orange, the cranberry, the red whortleberry, the bird-cherry, and the fruits of the dog-rose, and the woody night shade. It is also formed in some roots, as in the dahlia pinnata, and mixed with much malic acid in the currant, cherry, gooseberry, raspberry, strawberry, common whortleberry, and the fruit of the hawthorn. It is usually prepared from lemon juice, which is clarified by rest, then saturated with chalk and the citrate of lime, after being well washed is decomposed by dilute sulphuric acid. Citric acid crystallizes in right rhombic prisms, its taste is very agreeable, it is very soluble in water, but the solution does not keep, soon becoming covered with mouldiness. It is composed of

Carbon,	41·49 which corresponds with	C_4.
Hydrogen,	3·43	H_2.
Oxygen,	55·08	O_4.
	100	

It only differs in composition from tartaric acid, therefore in containing one atom less of oxygen.

Malic Acid. In the living plant this acid is very extensively diffused, but it is found purest and most abundant in the berries of the mountain-ash, and in the house-leek. It is deliquescent, very soluble in water, and strongly acid. It is malic acid, which gives their acidity to the unripe apple, plum, sloe, alderberry and barberry.

It is *isomeric* with, that is, it has precisely the same chemical constitution as citric acid, to which, therefore, it bears the same relation as starch and gum do to cane sugar.

VEGETABLE PRODUCTS CONTAINING NITROGEN.

1. *Gluten.* The soft tenacious and elastic substance which remains in the hand in the process for separating starch from wheat flour paste, is gluten. It was discovered in 1742, by Beccaria, to whom we are indebted for the first analysis of wheat flour. This singular substance bears a good deal of resemblance to animal tendon or membrane. When very thin, it adheres very tenaciously to other bodies, and has been often used to cement together broken pieces of porcelain. Its smell is peculiar, but it has scarcely any taste. Exposed to the air it soon becomes brown, and covered as it were, with a coat of oil, and when dry, it is hard and brittle, and has some resemblance to glue. When kept moist, it soon begins to decompose, emitting a very offensive smell. Gluten is one of the most nutritive of vegetable substances. It forms from 19 to 24 per cent. of good wheaten flour.* In a pure state, how-

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* According to Davy, the wheat grown in the south of Europe, is richer in gluten than that of colder climates, on which account it is peculiarly suitable for the manufacture of macaroni. It is probable that the increase in the proportion of gluten in the wheat of warm climates, is referable to the more abundant supply of nitric acid and ammonia. Wheat is valuable as an article of food, in proportion to the quantity of gluten which it contains, and this substance contains more than 18 per cent. of nitrogen. The great value of the nitrates of potash and soda as fertilizers, is thus rendered apparent in theory. Not only do these salts used on corn lands, at the rate of about 1 cwt. an acre, increase the *quantity* of the grain, but they tend to augment those in-

ever, when separated from starch, it is scarcely digestible. It is not a pure principle; when digested in hot alcohol till every thing soluble is taken up, it leaves a bulky substance of a greyish colour, which has been called *vegetable albumen*, a substance which possesses all the properties of the white of egg; it is soluble in water, but the solution is coagulated, and rendered insoluble by heat and acids. Like sugar and starch, gluten and vegetable albumen are identical in composition, being composed of

Carbon,	54·76
Hydrogen,	7·06
Oxygen,	20·06
Nitrogen,	18·12
	100 †

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gredients which contain the largest amount of nitrogen, and consequently afford the greatest degree of nutriment; namely, the gluten and albumen. As an instance, the following communication of Mr. Hyett, of Painswick, to the journal of the Royal Agricultural Society of England, may be quoted. His experiments were made upon the stone, or corn-brash of Gloucestershire, a coarse and impure oolitic limestone, which had been drilled with white Sicilian wheat in the autumn. Nitrate of Soda at the rate of 1 cwt. to the acre, was on the 21st of April, sown and hoed in over all the field, excepting two square portions, which were staked out and left un-nitrated. On the 16th of May, the effect of the salt was perceived, by the dark green colour of the plants. The results of the harvest were as follows:—

Produce.	Measure Per Acre.						Value Per Acre Excess.		
	Without Nitrate.			With Nitrate					
	Bu.	Pks.	Pts.	Bu.	Pks.	Pts.	Bu.	Pcks.	Pts.
Corn Clean,	30	2	11	37	3	4	7	0	9
— Tail,	2	3	11	5	3	7	2	3	12
— Total,	32	2	6	43	2	11	10	0	5
	Weight.			Per Acre.					
	tons. cwt. qrs. lbs.			tons. cwt. qrs. lbs.			tons. cwt. qrs. lbs.		
Straw,	1 3 1 21			1 11 2 3			0 8 0 10		

† Schreeder.

Diastase. The importance of this singular substance, and the use which the light of science has traced to it in the vegetable economy, cannot fail strongly to impress the most careless observer, to awaken his attention to the wonders of creation, and to impress him with the infinite wisdom and skill displayed by the Great Author of Nature, for the provision of the meanest plant that grows. Diastase is an azotized substance, existing in grains and seeds, *but only after germination.*

ANALYSIS OF THE WHEAT.

	Wheat, on which the nitrate was used, gave	Wheat, on which no nitrate was used, gave
Bran.............	25·000	24·000
Gluten...........	23·250	19·000
Starch	49·500	55·500
Albumen.........	1·375	·625
Extract..........	·375	·250
Loss and Water...	·5	·628
	100 parts	100 parts

This shows an increase per cent. of 4·25 gluten, and 0·75 albumen in the nitrated sample.

Professor Daubeny gives, in his Lectures on Agriculture, p. 76, the results of an experiment made by his brother, in which two equal portions (about ¼ of an acre) of the same field were sown with wheat, one strip being top dressed with nitrate of potash and the other left without any addition :—The amount of produce was

bu. lbs.
From the unnitrated strip.............. 6 · 54 = 6
From the nitrated...................... 7 · 57 = 7

As 6 : 7 : : 100 : 120, or 20 per cent. of increase in the amount of produce.

The weight of the nitrated wheat was 62½lbs. to the bushel. That of the unnitrated 62lbs. 3½lbs. of flour from the nitrated produced 4lb. 14oz. of bread, but 3½lbs. of flour from the un-nitrated produced only 4lbs. 4oz.

As 4lbs. 4oz : 4lbs. 14oz. : : 100 : 114.

Showing an increase per cent. of 14 + 20 = 34 per cent. The superior absorbing power of the nitrated flour over the non-nitrated, was found by Daubeny to depend upon the presence of a larger amount of *gluten*, being 2 per cent. in favour of the nitrated wheat.

A small pamphlet, on the use of saltpetre and nitrate of soda, as fertilizers, has been published by Mr. Cuthbert Johnson, which is well worthy the attentive perusal of the practical Agriculturalist.

To obtain it, ground malt is macerated for some time in water, the whole is then subjected to pressure, and the liquid which flows out filtered, and then heated to the temperature of 158°. This temperature is sufficient to coagulate and cause to separate the greatest part of an azotized matter which exists in the liquid. The liquid being filtered again, is mixed with a sufficient quantity of alcohol to throw down the diastase, while the sugar, colouring matter, and the residue of the azotized substance remain in solution. To obtain the diastase pure, it should be again dissolved in water and thrown down by alcohol, and this should be repeated twice. As thus obtained, when dry, it is a solid white amorphous substance, soluble in water, but insipid. Malted barley contains not more than 1-500th of its weight of diastase. In unmalted barley, it cannot be detected; neither can it be found in the potatoe till the root has thrown out tubers, when it is found at the base of the shoot, but after the first true leaves of the plant have been fully formed and expanded, the diastase disappears.

The remarkable property possessed by diastase is that of decomposing starch into its constituents, entering into combination with the amadin, and causing it to become soluble in water, and separating the vescicular portion or amylin. It is from this property it derives its name.* The soluble portion of the starch is called dextrine;† it has the same composition as starch. The solution of diastase, whether it be pure or contain sugar, separates amadin from all starchy substances containing it, and such is its energy, that one part of it is sufficient to render soluble the interior portion of 2000 parts of starch, and to *convert it into sugar.*

The use of diastase in the germination of seeds is thus rendered apparent. All seeds contain starch, which is the food of the future germ, and all likewise contain nitrogen. Now

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* From the Greek word δυστημι, I separate.

† Because its solution causes the plane of polarization of a ray of polarized light passing through it, to deviate very considerably to the right.

starch is insoluble in water; it could not, therefore, accompany the fluid sap when it begins to circulate. As soon, however, as heat and moisture awaken life in the seed, diastase is formed from the gluten or albumen of the seed; the starch is rendered soluble, it is taken up by the young vessels and conveyed to the point of growth, and there it is converted into sugar, and having performed this important service and exhausted the starch, the functions of the diastase cease, and it is itself transformed and carried into the general circulation.*

Dextrine is prepared on the large scale, from ground malt and flour, and from the syrup obtained, spirits are prepared by fermentation; by checking the action of the diastase, at a proper time, a jelly is formed, which when mixed, while hot, with yeast, and kneaded into a dough, serves well for the preparation of bread. When dried in thin layers by exposure to the air, it may be reduced to powder, and in that state introduced into all kinds of pastries, chocolate, bread, &c.†

On reviewing the series of substances which constitute the

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* In malting, it is well known that the process of germination is artificially produced. It is the diastase in malt which dissolves the starch of the barley and converts it into sugar; but as the diastase contained in malt is sufficient to dissolve so large a quantity of starch, it is obviouzly a waste of labour to malt the whole of the barley employed. One of malt to three of barley, Johnston thinks would probably be sufficient in most cases, to obtain a wort containing the whole of the starch in solution. The art of malting consists in destroying the life of the young plant at the time when the conversion of the starch into sugar is most complete, and yet before much sugar has been assimilated by the germ, and this is practically found to be the case, when the radical has grown as long as the grain, but does not project beyond it. Barley, by being converted into malt generally increases two or three per cent. in bulk; and loses at an average about 1-5th of its weight or 20 per cent., but of these 20 parts, 12 are to be ascribed to kiln-drying, and consist of water which the barley would have lost had it been exposed to the same temperature, so that the real loss does not exceed eight per cent. In the ordinary process of brewing, the mashing or infusing of the malt should be begun at 160° or 170°, the temperature at which the diastase acts more advantageously. The temperature may, afterwards be raised by adding water at 185° or 195° to the mash tun. The saccharization is generally completed in an hour and a half at the utmost, and the sweet worts are then run into a copper to be boiled and hopped. The sugar is afterwards converted into carbonic acid and alcohol by the action of another principle, which will be described presently.

† Thomson.

great bulk of plants, we find that the greater part of them may be formed entirely out of carbon and the elements of water, but taken as a whole, ordinary wood contains a variable excess of hydrogen. It is worthy of remark also, that the power of the Chemist to imitate the living principle, is limited to *one* direction, and even in that he can only *transform*, he cannot *construct*. Thus, he can change lignine into starch, starch into gum, and gum into sugar, but he cannot reverse the process; he cannot change sugar into gum, or gum into lignine, still less can he make lignine, gum, starch, or sugar by the direct union of their elements. By the action of nitric acid upon starch, wood, or sugar, he can form oxalic acid, but he possesses no power by which he can cause the carbon and the oxygen to unite directly, so as to constitute that acid. In producing organic substances, he must employ other organized substances,—substances themselves only formed under the direction of the living principle.

In our attempts to explain the phœnomena of vegetation, and to investigate the mode of formation of the various principles of plants, and the chemical agencies by which one is transformed into another, we are beset with difficulties arising from the complicated nature of the mechanism, and the obscure nature of the decomposing forces which appear to preside in organic changes.

Even at the commencement, when the seed begins to germinate, we are presented with facts which we cannot explain; we know that a seed will not germinate without the presence of atmospheric air; we know that it absorbs oxygen and gives off carbonic and acetic acids; but although it is easy to understand how these two substances are formed from the starch of the seed,* we are as yet ignorant of the immediate purposes

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* Starch may be represented by $12C + 10HO$, it only therefore, requires an additional quantity of oxygen to separate from it carbonic acid and water. Vinegar is represented by $C_4 H_3 O_3$, therefore three atoms of vinegar and one atom of water are equivalent to one atom of starch, $3 (C\ H\ O) + HO = C_{12} H_{10} O_{10}$.

for which they are evolved.* We also know that diastase must be formed out of the gluten or vegetable albumen of the seed, but as we are not acquainted with the chemical constitution of this substance, we cannot explain the nature of the changes by which its production is effected. That there is a conversion of sugar into woody fibre we also know, but it is a transformation we cannot imitate; and we are quite ignorant of the action by which it is effected. When the young plant has thrown out true leaves, it no longer derives nourishment from the seed, but extracts its food from the air and from the soil. It has been shown beyond doubt that the leaf absorbs carbonic acid in the sunshine, and that oxygen is given off; we are warranted therefore in believing that by the action of the sun's rays, carbonic acid is decomposed, but we know nothing of the nature of the action by which this decomposition is effected, or of the processes by which carbon, hydrogen and oxygen are made to assume in one part of the plant gum, sugar, and soluble starch, and in another insoluble starch and woody fibre.

At the period when the most striking step is taken by the plant towards the production of its seed, a new series of chemical changes must commence. If we examine the composition of a young apple, we find it to be nearly tasteless, and to consist of a loose ligneous tissue, in which is imbedded a quantity of starch: as its growth proceeds the starch diminishes in proportional amount, and the fruit becomes intensely sour from the presence of tartaric acid; after some time, the acidity becomes of a much less disagreeable kind, and the tartaric acid is found to be replaced by the malic acid; and in the next and concluding stage of maturity this acid disappears, its place being taken by pectine and by sugar. During the whole of these actions *oxygen* is absorbed from the air, and

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* According to Liebig, the acetic acid formed in the germ and excreted into the soil, is to dissolve and bring into the pores of the root, the lime and other substances which the plant requires for its healthy growth.

water and carbonic acid are given off. The same actions are constantly going on in the *petals* or flower leaves, and the absorption of oxygen and production of carbonic acid is, in some plants, so great as to cause a perceptible increase of temperature.

In the case of plants bearing farinaceous seeds, particularly in annuals, when the flower expands, woody fibre is little required, and the energy of the plant is occupied in transformations exactly the converse of the first; instead of changing starch into gum and sugar, it is occupied in converting the sugar of the sweet and milky sap into starch. Now, as before remarked, although by the agency of diastase and of dilute sulphuric acid, we can transform starch into sugar, we know of no method of *re*-converting sugar into starch, and we cannot, therefore, explain how this change is brought about in the living plant.*

But in trees and perennial plants, a provision is to be made for the young buds which are to shoot out from the stem and branches in the ensuing spring; the labour of the plant is not then finished, as is the case with annuals, when it has deposited in the ripened seed a supply of food for the future germ. In trees and permanent shrubs, the sap continues to flow till the leaf withers and falls, and the food of the plant is converted partly into woody fibre, which is deposited beneath the inner bark to form the new layer of wood by which the tree is annually enlarged, and partly into starch, which is distributed differently in different trees: in some, as in the birch and pine, it is deposited in the same locality as the woody fibre; in others, as in the willow, it is distributed through the substance of the wood itself; and in others, as in palm trees, it is intermingled with the central pith. These deposits con-

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* As nitrogenous substances exist in the sap of plants, and are carried up in considerable quantities to the flowers and seed vessels, it is supposed that they are concerned as immediate agents in effecting these transformations. This element is present in the colouring matter of the petal, and it is said to be given off by the flower leaf.—*Johnston.*

tinue as long as the sap continues to flow, and abundance of nourishment is thus laid up for the young bud.

The rapidity with which some plants convert their food (which we have seen consists principally of carbonic acid and water) into woody fibre, starch, &c., is truly wonderful. A stalk of wheat has been observed to shoot up three inches in as many days; of barley, six inches in the same time. Du Hamel noticed a vine twig which grew nearly two feet in three days; and Johnston mentions a bamboo which he saw at the Botanic Garden, at Brussels, which had increased in height nine feet in 27 days, sometimes making a progress of six to eight inches in a day. Although in our climate instances of such surprising rapidity of growth are uncommon, our garden plants, particularly the French bean or scarlet runner, frequently furnish us with proofs of the amazing rapidity with which vegetable food is absorbed, assimilated, and transformed, and our wonder is not diminished by the consideration of the numerous and complicated chemical changes with which the production of every grain of the substance of these plants is attended, and the length of time during which, year after year, they proceed in the same plant and in the same vessels.

Inorganic constituents of plants. When any vegetable substance is submitted to the action of heat, the carbon, hydrogen, oxygen, and nitrogen, burn away and disappear, but there remains behind, a variable portion of *fixed* matter, which as it bears so small a proportion to the weight of the plant, was long regarded as the result of accidental circumstances, and of no essential consequence to the plant. But when Chemists came to examine this fixed or inorganic residue carefully, when it was found that in each plant, on whatever soil it was grown, the quantity and quality of the ash was the same, when the remarkable discretionary power of absorption which they exercise when in a healthy state was noticed, it became evident that the study of the inorganic constituents of plants is in the art of culture an object of as much importance as that of their organic constituents.

The following table exhibits the weight and composition of the inorganic matter contained in 10,000 parts of the three most commonly cultivated kinds of corn, both seed and straw, and of red clover and sainfoin hay. The Author has been for some time engaged in an investigation into the chemical composition of the ashes of vegetables, and intends hereafter to publish a full account of his results: in the meanwhile, the following selection will serve to show how unlike is the quantity of inorganic matter contained in the same weight of the different crops raised by the farmer.

COMPOSITION OF THE ASH.

NAME.	Weight of ash from 10,000 grs.	Potash.	Soda.	Silica.	Lime.	Magnesia.	Alumina, and Oxide of Iron.	Oxide of Manganese.	Phosphoric acid.	Sulphuric acid.	Chlorine.	Loss.
Wheat......	135	25	26	28·5	8·1	10·3	1·3	—	33·5	1·5	·5	·3
Wheat straw.	355	14·5	15	236·4	20·	20·9	18·5	—	20	4·7	4·2	·8
Barley......	228	24·75	26·25	107·5	2·3	16·12	3·8	—	38·5	5·35	2·16	1·27
Barley straw.	370	43	16·3	240·5	23·	6·3	18·	1·5	12·75	3·2	4·2	1·25
Oats........	270	18·2	17·5	168·	5·75	4·75	2·	—	45·5	5·	2·3	1·
Oat straw....	360	114·	32·3	100·	38·75	10·6	1·4	—	6·	20·	35·4	1·55
Red Clover..	440	98·	32·	68·	126·	40	23	—	24	14	14	1
Sainfoin....	500	138·5	52·3	45·5	84·7	6·2	8·	—	100·3	36·4	23·7	4·4

Now as the quantity and quality of the ash is constant in every soil, it cannot be considered as the result of accident, but must arise from some natural law, and the inference must be drawn, that plants possess the power of drawing from the soil, that proportion of inorganic matter which is adapted to their constitution, and as from the same soil, different plants select different quantities of saline and earthy matter, so from the common sap do the bark, the leaf, the wood, and the seed select and retain that proportion which the healthy growth and nourishment of each requires.

That inorganic matter must, equally with carbon, oxygen, hydrogen, and nitrogen be considered as part of the necessary food of plants, is proved by the fact, that they cannot thrive without it, and that when placed in circumstances where they cannot obtain it, they wither and die. On referring to the composition of wheat ashes, we find abundance of silica, phosphoric acid, magnesia, lime, and potash, consequently, if we sow wheat in a soil which contains neither potash nor phosphoric acid, we cannot expect a productive crop, however rich the soil may be in organic and other matters, but if we previously manure the soil with bone dust, with ashes of weeds, or other substances which may supply the necessary inorganic elements, these will be absorbed, and the plants obtain their full development. From all parts of the structure of plants,—potash, soda, and magnesia, can be extracted in the form of salts of organic acids, though it is not known in what form silica, oxide of iron, and manganese are contained in them; one base may replace another without injury to the plant. Thus, the plants which yield soda when grown upon the sea shore, if transplanted to the interior, gradually lose the soda and acquire potash in its place. The ashes of oaks or pines, grown upon a granitic or basaltic soil, contain abundance of magnesia and of potash, while trees of the same species will flourish on a limestone soil, and in their ashes, lime will be the predominant ingredient.

A knowledge of the chemical composition of the ashes of different vegetables, enables us to understand and explain the circumstances which render a soil barren or productive. There is no plant which does not contain both lime and silica, and few which do not contain potash and magnesia; in most soils these substances are present, but alumina is rarely found in quantity in the ashes of plants, yet this earth is an invariable constituent of all fertile soils, its agency is probably, therefore, of an indirect mechanical kind.*

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* According to Liebig, alumina exercises an indirect influence by its power of attracting and retaining water and ammonia, and it is to this power that he ascribes the benefit derived from using burned clay as a top dressing. Johnston considers the fact of its absorbing ammonia from the atmosphere as hypothetical, and he thinks that the

It would be foreign to the purpose of this work, to enter into an examination of the origin of soils:* I shall merely observe, that when it has originated in the decomposition of granitic or slaty rocks, the silica, alumina and potash are abundantly supplied from feldspar and mica; lime and magnesia also may be derived from associated minerals though it is generally found necessary in such soils to add the former of these earths. When the soil is formed out of pure limestone, clay, and siliceous gravel must be added, and the deficiency of potash must be supplied by the ashes of other plants and cinders of coal. If the soil be purely siliceous, the addition of clay and lime may bring it to a proper composition.

The temporary diminution of the fertility of soils, is attributed by Liebig, to the exhaustion of the alkalies, and not as is generally supposed to the loss of humus. Almost all the cultivated land in Europe, he observes, is in this condition. The first colonists of Virginia found a soil in a state of perfection; and they were able to obtain harvests of wheat and tobacco, on the same spot, without manure for a century. The ground is now exhausted, and will produce neither without artificial manure. Now wheat is well known to be exceedingly exhausting to land, not only on account of the large quantity of phosphoric acid and of potash which it requires, but also on account of those excretory products, which, according to the observations of Macaire and Decandolle, are given off from the rootlets of all plants, and which though without injury, and indeed advantageous for the growth of plants of a different family, are poisonous to those of the same kind.†

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volatile alkali in clays and in oxide of iron, may have been formed in the soil during the oxidation of the iron, or during the decay of animal and vegetable substances.

* The student will find the subject fully discussed in Johnston's "Lectures on Agricultural Chemistry and Geology."

† It is proper to observe, that Physiologists are divided in opinion respecting the excretory power of plants. The experiments of Macaire and Decandolle have been met by counter experiments by Braconnot, and several eminent vegetable Physiologists have, in consequence, rejected the theory.

Here then we see reasons for that interchanging of crops, which is found so necessary in œconomic agriculture. We may easily conceive a portion of undigested matter to pass through one species of animal and to be capable of assimilation by another; and it may be the same with plants; a portion of matter may be taken up by the roots, and not being required, may be returned again to the soil, and yet this excrement may be essential to plants of another species; but where food is once assimilated, it cannot again serve in other plants to form the same constituents. Now this excrementitious matter, by exposure to the air and water, undergoes decay, and is finally converted into a substance which supplies the place of humus. The quickness of this change depends greatly on the nature of the soil; decomposition takes place much sooner on a calcareous than on an argillaceous soil, because the power of absorbing oxygen is increased by contact with alkaline constituents.

By attending to the proper rotation of crops, the soil is preserved fruitful for each. Thus, if wheat be grown upon a soil, the rocky substance of which is rich in potash and phosphoric acid, the crops will, after a few years, be unproductive, and the soil impoverished, because the rock decomposes too slowly to supply materials for the wheat as fast as they are required; but if we take from that soil a crop of wheat but once in three years, and interpose some other plant, as trefoil, turnips, or potatoes, which take up but little potash and no phosphoric acid, the soil has time to recover its constitution.

One of the most important objects then of the alternation of crops, is the artificial production of humus, for the maximum of produce in plants is always in proportion to the quantity of nutriment supplied to them in the first stage of their development; but it is obvious that no alternation, however judicious, can supply the deficiency of those constituents which are removed in the seeds, roots, and leaves of the plants raised upon the soil; hence the use of manures, which may act either by supplying to the soil some mineral ingredient in which it had been deficient, or by providing organic matter, which, by its decomposition may give out carbonic acid and ammonia for the nutrition of the young plants. To the first of these, the solid excrements of animals belong, for they contain so little nitrogen, that they cannot by means of it, be supposed to exercise any important influence on vegetation. The composition of the excrement of animals varies according to the nature of their food: that of animals that feed principally on grass, contains very little azotized matter, but abounds in silicate of potash, and in salts of phosphoric acid. It requires indeed but little consideration to be satisfied, that the excrement of all animals cannot contain as much nitrogen as the food on which they live, for the process of nutrition consists chiefly in the progressive extraction of nitrogen from the food; but yet, the whole of the nitrogen contained in the food is not retained by the animal; suppose a cow, for instance, to consume 25lbs. of hay per day, then ¼ of a lb. of nitrogen must have been assimilated, hay containing, according to Boussingault, one per cent. of nitrogen; this ¼ of a lb. of nitrogen is equivalent to 8·3 lbs. of flesh in its natural condition; but every one knows that a cow does not increase in this proportion, we must look, therefore, for the apparent deficiency to the *milk* and *urine*; now it is found that the urine of a milch cow contains less nitrogen than that of one that does not yield milk, and it is also known that a cow cannot be fattened as long as it yields a plentiful supply of milk. It is in the *liquid* excrements of animals, therefore, that we are to look for nitrogen, and every kind of animal manure usually employed in this country, owes its efficacy, as far as it is dependent on the ammonia present, to the urine rather than to the solid excrement of which it is made up, and hence becomes materially deteriorated in this respect, when the more liquid portions are allowed to drain off.

But the constituents to which the solid excrements of animals in general owe their principal efficacy, are the earthy phosphates. 100 parts of horse dung, dried at 212°, leave from 25 to 30 parts of solid matter, and contain from 69 to 75 parts of water. This solid matter consists of variable quantities of salts and earthy matters, and accordingly with every 3,600 or 4,000lbs. of fresh horse dung that we place on the soil, we add to it from 2,500 to 3,000lbs. of water, from 730 to 900lbs. of gall, and from 100 to 270lbs. of salts, consisting principally of the phosphates of lime and magnesia, carbonate of lime, and silicate of potash: the first three of which preponderate in the corn, and the latter in the hay on which the horse was fed. Thus in 1000lbs. of horse dung we present to a field, the inorganic substances contained in 6,000lbs. of hay, or 8,300lbs. of oats, and a sufficiency of potash and the phosphates to supply 1½ crops of wheat.—*Liebig.*

The great value of animal manures in promoting the growth of corn is thus seen, and we are also enabled to understand why the ashes of some woods, as the beech, are so much more valuable than the ashes of others, as the oak and fir. According to Liebig, every 100lbs. of the lixiviated ashes of the beech spread over the soil, yields as much phosphate as 400lbs of fresh human excrement, and will be sufficient to supply a field with phosphoric acid enough for the production of 3,820lbs. of straw, or for 15 to 18,000lbs. of corn.

The remarkable efficacy of bone manure is also rendered intelligible; according to Berzelius, bones contain 55 per cent. of the phosphates of lime and magnesia, and 8lbs. of bones contain as much phosphate of lime as 1,000lbs. of hay or wheat straw, and 2lbs. as much as 1,000lbs. of the grain of wheat or oats; and 40lbs. of bone dust to the acre are sufficient to supply three crops of wheat, clover, potatoes, and turnips with phosphates.*

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* According to Liebig, the best method of applying bone manure is to digest the bones for some time in half their weight of sulphuric acid, diluted with three or four parts of water; then add one hundred parts of water, and sprinkle the mixture over the field

The great value of urine as an organic manure, has not hitherto been sufficiently appreciated in this country; during its decomposition, it exhales a larger quantity of ammonia than any other species of excrement, and as a considerable part of this ammonia is in combination with muriatic, lactic, and phosphoric acids, it does not evaporate but remains fixed in the soil, and is therefore in a condition to be absorbed by the roots of plants, and even that portion which is evolved in the state of volatile carbonate, may be converted into a fixed salt by the use of gypsum.* The Chinese, who are probably the best agriculturists in the world, use no other manure but urine, and so great is the importance that they attach to it, that the laws of the state forbid that any should be thrown away. "If," says Liebig, "it be admitted that the liquid and solid excrement of man, amount, on an average, to 1½lbs. daily, (5-4ths urine, and 1-4th solid excrement,) and that both together contain 3 per cent of nitrogen, then in one year they will amount to 547lbs., which contain 16·41lbs. of nitrogen; a quantity sufficient to yield the nitrogen of 800lbs. of wheat, rye, and oats, or of 900lbs. of barley; and this is much more than is necessary to add to an acre of land, in order to obtain, with the assistance of the nitrogen absorbed from the atmosphere, the richest possible crop every year."

When organic manures are stored up for use, as in compost heaps, it should be an object with the farmer, to preserve as much as possible the carbonate of ammonia, which has a constant tendency to escape into the atmosphere; for he should consider, that with its loss he loses the material calculated to afford a ready supply of that element, the production of which

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before the plough. No injurious effect will follow this process, for neutral salts will be formed in a few seconds after the acid comes into contact with the soil. The solution of phosphates in muriatic acid resulting from the manufacture of glue, and which has hitherto been thrown away as useless, may be advantageously applied as manure.

* During the decomposition of urine it becomes alkaline, in consequence of the conversion of the urea into carbonate of ammonia.

is the object of cultivation, viz:—nitrogen, and retains a mass which can only influence the growth of plants by virtue of the phosphoric salts and other fixed ingredients still present in it; yet how little is this attended to! Nevertheless, the addition of small quantities of sulphuric or muriatic acid, (both cheap substances,) from time to time to the dung heap, would prevent any loss of ammonia by evaporation, by converting it into sulphate or muriate. A writer in the English Agricultural Journal, recommends a method of constructing compost heaps, which is practically found to succeed in retaining the valuable portion; a substratum is made of peat ¾ths, and sawdust ¼th, over this is spread the dung from the cattle sheds, and the urine preserved for the purpose in tanks contiguous; and then after allowing the mixture to remain exposed for a week, covering it with a fresh layer nine inches or a foot thick of peat and sawdust, or of peat alone. Several such alternations of peat and manure are to be piled one above the other during the winter; great care being always taken that the peat should be as dry as possible, by exposing it previously for several months to the weather. By this method of construction, the ammonia is slowly converted into carbonate, and in that state detained within the pores of a spongy substance till it is spread over the land. It would seem however, more effectual to neutralize the ammonia at once by a mineral acid, than to wait for the slower action of carbonic acid.

One of the fertilizing properties of gypsum, is undoubtedly connected with the power which it possesses of depriving ammonia of its volatility,* as it is well known that great advantage is derived from scattering it in fine powder over the leaves of clover and sainfoin, and also that it is very serviceable to

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* In consequence of the double decomposition which takes place, sulphate of lime and carbonate of ammonia giving rise, when brought together, to carbonate of lime and sulphate of ammonia. Liebig says, that this power of gypsum to fix ammonia in the soil is, its *only* fertilizing property. Johnston, however, has introduced into his Agricultural Chemistry, (see page 72—3,) experiments and calculations, which show that this is far from affording a satisfactory explanation of all the phœnomena.

turnips and cabbages, in the ashes of which it is not to be detected. But the sulphate of ammonia, to which it gives rise, cannot in that state be of any use to the plant, since we have no reason for supposing that it possesses the power of decomposing that salt, and contradictory as it may appear, carbonate of lime is capable of decomposing sulphate of ammonia, even in the cold, as is proved by holding a piece of turmeric or reddened litmus paper over a vessel of powdered chalk, moistened with a solution of sulphate of ammonia.—*Daubeny*. This is probably one of the ways in which ammonia is slowly supplied to the living plant.

It is probably, (observes Daubeny,) in part, by setting at liberty the volatile alkali imprisoned in the soil, that quicklime acts so beneficially in agriculture, and in particular, that it improves soil containing a free acid, such as peat earth, for independently of its use in neutralizing a substance which checks vegetation by its antiseptic properties; quicklime may also disengage a portion of ammonia combined with this acid, and thus afford to the plant a more abundant supply of the nitrogen which it requires.*

The great value of ammoniacal salts in agriculture, is dependent on the nitrogen, which they furnish by their decomposition; the high price of these compounds, have hitherto been a barrier to their general use; but there is one combination which may be obtained sufficiently cheap, and indeed, which for years was thrown away as useless; viz.—the ammoniacal liquor afforded by gas manufactures, through the distillation of coal. This liquor consists principally of carbonate of ammonia with a certain proportion of hydrosulphu-

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* The action of quicklime upon the land, is one of the most important which presents itself to the observation of the practical Agriculturist. Among other effects produced by it, is that of hastening the decomposition of vegetable matter, either in the soil or in compost heaps; but this effect is materially promoted by the presence of air and moisture. By this decomposition, carbonic acid and other compound substances are produced, which the roots are capable of absorbing and converting into the food of plants.—*Johnston*.

ret, and its efficacy as a manure is vouched for by many, who have made trial of it upon their land.*

Dr. Daubeny gives, on the authority of Mr. Richard Phillips, the following method of converting this liquor into sulphate of ammonia, so as to enable the agriculturist to prepare for himself any quantity that he may require on his farm. "One gallon of ammoniacal liquor, added to 1lb. 2½oz. of powdered, but not calcined gypsum will produce one pound of crystallized sulphate of ammonia. To effect the decomposition, the material should be mixed and stirred up together for ten or twelve hours: a heat, below that of ebullition being at the same time employed. The sulphate of ammonia remains in solution and may be obtained in a solid state by evaporating at a low temperature. To obtain them, 60lbs. of crystallized sulphate of ammonia, 70lbs of powdered gypsum, uncalcined, should be introduced into 50 gallons of ammoniacal liquor. With respect to the cost, gypsum is from £2 to £3. per ton, and consequently a gas company could prepare any quantity of impure sulphate of ammonia, at about one penny a pound; reckoning the cost of mixing the materials to be about the same as that of the gypsum. Now nitrate of soda at its present price, (23s. per cwt.) may be reckoned at 2½d. per lb., yet a given weight of sulphate of ammonia contains more ammonia, and consequently ought to yield more nitrogen than nitrate of soda.

Sulphate of ammonia 75 pts. contain 17 ammonia = 14 nitrogen, whilst
Nitrate of soda . . . . . 86 pts. . . . . 17 . . . . = 14 . . . .

So far as *theory* goes, therefore, the balance would seem to be in favour of the efficiency of sulphate of ammonia over nitrate of soda, in the proportion of 75 to 86. This, however, requires the test of experience.

From the foregoing observations, it is easy to understand

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* See a communication by Mr. Paynter, on gas water as manure. *English Agricultural Journal; No.* 1, *p.* 4.

the very great importance which the farmer should attach to human excrement: independently of its being richer in most of those ingredients in which the fertilizing property of manure depends, it possesses this great advantage over every other animal manure, viz:—its perfect freedom from *weeds*, from which it is impossible, even by a long process of fermentation, (during which, be it observed, much valuable matter is lost,) to rid the excrement of animals; hence, the seeds which are always scattered in such abundance over our corn fields, from which, those of the Chinese, who use no manure but human excrement, are remarkably free.

The offensive character of night soil will, no doubt, long stand in the way of its general use, but Chemistry has suggested a method of getting rid of this, viz:—by neutralizing with a cheap mineral acid, the ammonia, which carries with it the offensive odour during its volatilization, and it is to be hoped, that prejudice will not long stand in the way of so vast and undeniable an improvement in our system of agriculture.

Vinous fermentation :—preparation of Beer. In the sketch of the process of malting, given in a note in a preceding page,* it was stated that the conversion of the sugar of the malt into carbonic acid and alcohol, is brought about by the action of another principle. This is called a *ferment.* It is an azotized principle, existing in the wort, and derived from the gluten of the barley, and it is formed at the same time that the transformation of the sugar is effected. At the temperature of 60° or a little higher, the substances held in solution by the wort, begin gradually to act upon and to decompose each other; the temperature rises, an intestine motion takes place, a scum collects on the surface, and carbonic acid is emitted. This intestine motion is called *fermentation.* It is well known, however, that the fermentation of wort does not go on with sufficient rapidity without the addition of some other substance; a quantity of *yeast*, (the scum or frothy matter which collects on the surface of beer while fermenting,) is therefore

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* Page 470.

added, and the saccharine matter of the wort is decomposed before it has had time to run into acidity. The quantity of yeast used by brewers is small, one gallon being found sufficient to ferment three barrels of wort.

The substance in yeast, which possesses this extraordinary power of inducing fermentation is gluten, in a somewhat altered state; it is the same as that which causes the slow fermentation of wort, and, though during the decomposition of the saccharine matter of the wort, it undergoes a partial change itself, it is found to exist after the decomposition is completed, in a quantity thirty times greater than it was originally.

According to Liebig, yeast possesses all the characters of a compound of nitrogen in the state of putrefaction and decay. Water is absolutely necessary for sustaining its fermenting properties, which are arrested by all antiseptic substances. It produces fermentation in consequence of the progressive decomposition which it suffers from the action of air and water, acting as deutoxide of hydrogen does on oxide of silver,* that is, by inducing bodies with which it comes into contact to enter into the same state of decomposition.

The facts connected with the action of yeast, point out the existence of a peculiar power in certain bodies in a state of decomposition, whereby they exert an influence beyond the sphere of their own attraction. Yeast is an azotized substance, and azotized substances are the only causes of putrefaction and fermentation in vegetable substances; no body possesses the property of decomposing spontaneously when pure, while in contact with water, unless it contains nitrogen. Liebig regards fermentation as a process of combustion, taking place in a liquid between the elements of the *same matter*, at a very slightly elevated temperature, and putrefaction is a process of oxidation, in which the oxygen of all the substances present comes into play.*

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* See page 191.

† Liebig applies the term *eremecausis* to the slow combustion, or oxidation of an

By the action of the yeast then, the elements composing the saccharine matter of the wort enter into new arrangements, the temperature rises, carbonic acid is disengaged, and alcohol is formed. The yeast soon collects on the top of the liquid; but the brewer occasionally mixes it again to continue the fermentation. Now as ale is intended as an article of food, it is not the aim of the brewer to convert the whole of the sugar into alcohol, the saccharine matter is only partially decomposed, and a considerable portion remains in the ale, communicating to it that glutinousness and flavour, and those agreeable and wholesome properties for which it is so remarkable, and in the preservation of which the art of the brewer consists. The quantity of alcohol, sp: gr: ·825, even in the strongest Burton ale, does not, according to the experiments of Brande, amount to 9 per cent.; that in London porter to not more than 4·2 per cent., while in small beer it does not amount to 1½ per cent. The use of the hops is partly to communicate a peculiar flavour from the oil which they contain, partly to cover the sweetness of the saccharine matter by the bitter principle which they contain, and partly to counteract the tendency which the wort has to run into acidity.

Now it is the gluten dissolved in the beer which creates this tendency to become sour; it continually acts upon the alcohol, which it gradually converts into acetic acid;—but by causing the fermentation of the wort to proceed very slowly at a low

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organic substance in the air, as in the conversion of wood into humus. The evolution of carbonic acid during the eremacausis of organic substances rich in hydrogen, must, according to this acute Chemist, in a general way, be attributed to a transposition of the elements, similar to that which gives rise to carbonic acid in the processes of putrefaction and fermentation. No change can take place in any organic substance, without a primary external exciting cause; this is generally atmospheric oxygen, which excites a change in the azotized matters dissolved in the juices, acting in a manner not dissimilar to the friction or motion which effects the mutual decomposition of two salts, causing a state of rest to be converted into a state of motion. When this intestine motion is once excited, the presence of oxygen is no longer necessary, the smallest particle of a decomposing azotized matter being sufficient to propagate, by a sort of contagion, fermentation through the whole mass.

temperature, and with a large surface exposed to the air, the entire separation of the gluten in an insoluble state is effected, and though the beer thereby produced possesses more intoxicating properties than beer made from an equal quantity of malt by the ordinary method of fermentation, it has no tendency to become sour. This is the method adopted in Bavaria. The fermentation lasts for five or six weeks, during which time there is scarcely any appearance of scum on the surface of the liquor, and the carbonic acid escapes in minute bubbles. Now the transformation of gluten and other azotized matters during fermentation is a process of several stages. The first is the formation of *yeast*, oxygen being absorbed either from water, the sugar, or from the gluten itself, and the oxygen combining either with the gluten itself, or with its hydrogen only: at any rate, it may be called the stage of oxidation, and is necessarily accompanied by the conversion of sugar into alcohol and carbonic acid. The scum which rises in ordinary cases during the fermentation of wort, is to be considered as oxidized gluten in the state of *putrefaction*, and is capable, as we have seen, of exciting fresh fermentation: but the yeast formed during the Bavarian process, is oxidized gluten in a state of *decay*, and though (during its formation) it is capable of giving rise to a very protracted fermentation in sugar, and also of causing the *eremacausis* of the gluten contained in the wort; it nevertheless causes the whole of the yeast formed in the wort to be deposited in an oxidized state, quite incapable of exciting fresh fermentation, and therefore useless for the purpose of bread making.

The low temperature at which the Bavarian process is conducted, effectually prevents the conversion of the newly formed alcohol into acetic acid; all the oxygen is employed in the complete oxidation of the gluten, and as there is no deoxidation of the sugar required to supply the gluten with oxygen as in the ordinary process, and no insoluble ferment formed, so there is no waste of sugar, which is entirely converted into alcohol.

The difference between the two kinds of fermentation is this—

In the ordinary process of brewing, there is a decomposition of the sugar of the malt; a portion of its oxygen combining with the gluten dissolved in the wort and forming insoluble ferment, or yeast; there is, therefore, a waste of sugar. In the Bavarian process, the *complete decay* of the gluten is insured by the unrestrained access of air and the low temperature, no sugar is consequently deoxidized, there is no waste, and the whole is converted into alcohol.

In beer formed by the ordinary process, there exists in solution a considerable quantity of gluten, which, on account of its strong disposition to attract oxygen and undergo decay, has a constant tendency to convert the alcohol into acetic acid, but in beer made by the Bavarian process, all the substances capable of attracting oxygen are removed, and there consequently exists in it no tendency to become sour.

There is but little alcohol formed during the *spontaneous* fermentation of infusion of malt, most of the gum and sugar passing into the *mucous fermentation;* in order, therefore, to observe the phœnomena of alcoholic fermentation most satisfactorily, a quantity of clear expressed grape juice should be set aside in a lightly covered vessel, at a temperature between 70° and 80°. In a few hours it will become turbid, a slight effervescence will be perceived, and there will be a formation of flocculi moving up and down in the liquid, and conveying the gas bubbles to the surface; this circulation ceases when the fermentation is over, and the flocculi collect as a precipitate at the bottom of the vessel. If the liquor be now tasted, it will be found to have lost its sweetness, and to have acquired intoxicating properties. Now whatever be the kind of sugar employed, it has been found that before it undergoes fermentation it is changed into *grape* sugar, which, when dried at 212° is resolvable into two atoms of alcohol and four of carbonic acid,—

ALCOHOL. CARBONIC ACID. GRAPE SUGAR.

$$2\,(C_4H_6O_2) \;+\; 4\,(C_1O_2) \;=\; C_{12}H_{12}O_{12}$$

and as cane sugar requires the elements of two atoms of water to become converted into grape sugar,—

CANE SUGAR. WATER. GRAPE SUGAR.

$$C_{12}H_{10}O_{10} \;+\; 2\,(H\,O) \;=\; C_{12}H_{12}O_{12}$$

theory requires that in fermenting, it should yield more than its own weight of carbonic acid and alcohol, and it has been proved by experiment that 100 parts actually give 104, whilst by theory 105 should be produced, consisting of 51·3 carbonic acid, and 53·7 of alcohol.—*Kane.*

During the fermentation of beer and wine, no evolution of hydrogen has ever been observed, yet there must be excess of this element present in the liquid, whether it be water or sugar that is decomposed during the formation of yeast from the gluten; now every body knows that wine has a peculiar smell, by which it is easily distinguished from a mixture of alcohol and water of equal strength; this smell is occasioned by the presence of a peculiar substance, analogous in its properties to a volatile oil. It is called *œnanthic ether*. It is rich in hydrogen, and is, undoubtedly a product of the deoxidation of the substances dissolved in the fermenting liquids by the excess of hydrogen.* In the spirits obtained from corn and potatoes there is a peculiar oil,—the *oil of potatoes*. This oil is formed during the fermentation, by the decomposition of the cellular tissue of the grain, or potatoe, for it is worthy of remark, that it is not to be found in the brandy made from potatoe starch, which has been converted into sugar by dilute sulphuric acid.

Panary fermentation.—Bread. The chemical phœnomena attending the making and baking of bread, are of a very in-

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* According to Liebig, the perfume or *bouquet* of wines appears to have some connexion with the acid (tartaric) which they contain. Wines made in warm climates have rarely any odour, while wine made from grapes on the Rhine, which ripen very late, and frequently not at all, have a strong perfume.

teresting nature. The process is well known to consist in a judicious fermentation of wheaten flour, and the subsequent exposure of the loaves to a temperature of about 448°. When flour of wheat is mixed into a dough with water, and allowed to remain undisturbed for some time, the sugar undergoes the vinous fermentation, being decomposed into carbonic acid and alcohol, but the gluten which exists in every part of the dough retains the carbonic acid, in consequence of which it undergoes a considerable increase in bulk. The fermentation gradually changes from the vinous into the acetous, and the alcohol is converted into acetic and lactic acids. It is impossible to prevent this latter action, on account of the slowness with which the vinous fermentation proceeds, and consequently if bread were to be made from flour thus fermented, it would be quite sour, and totally unfit for food. In this state it is called *leaven*, and if a small quantity of it be mixed with new made dough, it is well known that a much more rapid fermentation is excited, which may be checked before any acid begins to be formed, and baked into bread, which is light, spongy, and sweet.

In this country, the fermentation of dough is quickened by an admixture of yeast, and the process followed by our bakers is nearly as follows:—

A certain quantity of salt is dissolved in water, the temperature of which varies according to circumstances, from 70° to 100°; yeast is mixed with this water, and then a portion of flour is added, but always less than is ultimately employed in forming the finished dough. The mixture is covered up and set apart in a warm place; in about an hour fermentation commences, the *sponge* (as the imperfect dough is called) swells, and when the gluten is no longer able to retain the carbonic acid, it bursts forth, the mass sinks, and then gradually rises again: the baker, however, never allows this to be repeated more than twice, or at the most three times, or the bread would prove sour; at the second or third dropping of the sponge, therefore, he adds the remainder of the flour and salt and water, and incorporates the whole together by a laborious *kneading*. The dough is then again left to itself for a few hours, during which time it continues in a state of active fermentation; the baker then kneads it a second time, in order to distribute the imprisoned gas equally through the mass, and weighs it out into different portions to form loaves. The loaves being set aside in a warm place, continue to ferment, and at last are nearly double their original bulk; they are then transferred to the oven, the heat of which puts an immediate stop to the fermentation, and the gas already generated being swelled out, gives to the loaf its peculiar vescicular structure.*

During baking, bread loses in weight, but the loss is variable; the loaf is heaviest when just taken from the oven. It is the practice in some places, for the bakers to mix wheat flour with

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* Some bakers use sesqui-carbonate of ammonia to render their bread porous, in the proportion of about ¼ of an ounce to every pound of flour; in such bread, when hot, the smell of ammonia may be perceived. The following is the process adopted for rendering gingerbread vescicular. The ingredients are flour, treacle, butter, pearlashes, or carbonate of potash, and alum; after the butter is melted, and the potash and alum are dissolved in a little warm water, these three ingredients, along with the treacle, are poured among the flour which is to form the basis of the bread. The whole is then incorporated together into a stiff dough, the alum makes the bread lighter and crisped: but its introduction may be dispensed with. The treacle acts slowly upon the potash, and gradually expels the carbonic acid, which renders the dough vescicular; but the process is very slow. The dough must remain several days before enough gas has been extricated to render it fit for being baked. It was found by Dr. Colquhoun, that if carbonate of magnesia be substituted for pearl ashes in gingerbread, and the requisite quantity of tartaric acid to saturate the magnesia be kneaded into the dough, the gingerbread is as well raised, or as vescicular as when potash is used, and it is fit for being baked within an hour after being formed. The gingerbread made in this way is superior to that made by the bakers' process, because it is free from the large portion of alkali which common gingerbread contains, and which renders it injurious when eaten in any quantity. The proportions which Dr. Colquhoun found best, are the following:—

Flour	1 pound.
Butter	3 ounces.
Sugar or treacle	2 ounces.
Carbonate of magnesia	¼ ounce.
Tartaric acid	⅛ ounce.

Thomson's Organic Chemistry; p. 1032.

potatoe starch. In moderate quantities this is not prejudicial to the bread, but it should not exceed 25 per cent. Its presence may be detected by the following process, suggested by M. Boland, a baker, in Paris. Take about 300 grains of the flour, make it into a paste, and kneading it under a small stream of water, separate the gluten which remains in the hand. The water falls on a cloth stretched on the wide end of a funnel corked at its narrow end. The cloth retains the gluten, and the water, with the starch, falls into the funnel. Let the starch subside from the water in the funnel, then decant off the water by a syphon. Let the starch dry: it will be observed to consist of two layers; the uppermost is grey, and consists of gluten; the undermost of starch. Detach the dry starch from the funnel without breaking the lump. Take the lowest portion; triturate it with water in a mortar; filter, and add a drop of tincture of iodine. If it be potatoe starch, (as it will be if any be present,) the iodine strikes a fine blue. If no potatoe starch be present, the liquid only becomes yellow or violet red, which soon disappears. By repeating this trial on new slices of the starch, the quantity of potatoe starch may be determined.*

Putrefactive fermentation. In vegetable, as well as in animal life, the chemical tendencies of the elements are under the controul of the vital principle; but when this is extinct, the chemical forces prevail, a series of complicated changes commence, organization is destroyed, and the process is called putrefaction. In animal substances, owing to the complexity of their composition, the decomposition is more rapid than in vegetables, and the odour evolved is generally much more offensive, from the formation of ammonia and sulphuretted and phosphuretted hydrogen. When the substance, which is undergoing putrefaction consists of carbon, oxygen, and hydrogen only, the smell which it emits is not offensive. The presence of water and of oxygen is absolutely necessary for pu-

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* Jour. de Pharmacie, xxii, 305.

trefaction, and it cannot go on below 32°, or above 182°. When vegetables are dried, and kept dry, they do not putrefy, neither do they when preserved in vessels from which the air is removed, as is proved by the method employed in this country for preserving green peas. They are put into clean bottles, which are corked completely air-tight, and then plunged into boiling water, and allowed to remain for some time; at this temperature they absorb the oxygen from the small quantity of air contained in the bottles, and may thus be preserved perfectly fresh for a whole year.* It is on the same principle that vegetables are sometimes preserved by being covered over with melted butter or oil. When moist vegetable matter is accumulated in quantities during hot weather, oxygen is absorbed with such rapidity, as to raise the temperature sufficiently high as to cause the mass to ignite. In this way, it is well known, that haystacks frequently catch fire. When linen or hemp is left in contact with drying oils, a similar absorption of oxygen takes place, not unfrequently terminating in combustion. The heat produced by the putrefaction of moist oak bark, taken out of the tan pit, has long been known, and is in familiar use with gardeners and white-lead makers, to raise heat enough to answer the respective purposes which they have in view. The principle on which the action of alcohol and salt depends for preserving animal bodies, is their affinity for water. If a piece of flesh be covered with salt, the water gradually passes from the pores of the flesh, and depositing the salt, forms a brine, which does not wet the flesh, but trickles off its surface, and the water necessary for putrefaction is thus removed.

The morbific action of matters of contagion and miasms, are ascribed by Liebig to their operation as ferments. It is known that during putrefaction, at a stage prior to any fetid gas being evolved, a peculiar organic substance is generated,

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* Animal food, thus prepared, has been kept for fifteen years, at the end of which time, it has been found as fresh and well-flavoured as when first placed in the vessel.

possessed of intensely poisonous properties, and that the blood of persons who have died from its effects, is found to be quite disorganized and irritating when applied to wounds. " In order," says Liebig, " to attain a clear conception of the mode of action of these bodies, it is necessary to call to mind the cause on which the phœnomena of fermentation, decay, and putrefaction depend. This cause may be expressed by the following law, long since proposed by La Place and Berthollet, " *a molecule set in motion by any power, can impart its own motion to another molecule, with which it may be in contact.*" A body in the act of decomposition, added to a mixed fluid in which its constituents are contained, can reproduce itself in that fluid, exactly in the same manner as new yeast is produced when yeast is added to bodies containing gluten. The small quantity of diseased organic matter originally introduced into the system by absorption, *acts as a ferment,* reproduces itself in the mass of blood, until this becomes unfitted for the performance of its functions, and the animal dies. The fatal effects of eating bad sausages, are ascribed by Liebig to this peculiar action. Several hundred cases are known, in which death has occurred from the use of this kind of food. In Würtemburg, the sausages are prepared from very various materials, such as blood, liver, bacon, brains, milk, meal, and bread, mixed together with salt and spices; the mixture is put into bladders or intestines, and after being boiled, is smoked. When well prepared, they may be preserved for months, and furnish a nourishing and savoury food; but when the spices and salt are deficient, and particularly when they are smoked too late, or not sufficiently, they undergo a peculiar kind of putrefaction, which begins at the centre of the sausage. Without any appreciable escape of gas taking place, they become paler in colour, and more soft and greasy in those parts which have undergone putrefaction, and they are found to contain free lactic acid, or lactate of ammonia. The death which is occasioned by eating the sausages in this state, succeeds very lingering and remarkable symptoms. There is a gradual wasting of muscular fibre, and of all the constituents of the body similarly composed, the patient becomes much emaciated, dries to a complete mummy, and finally dies. The carcase is stiff as if frozen, and is *not* subject to putrefaction. The poisonous property of the sausage is destroyed by boiling water and alcohol, but all attempts to discover in them any matter to which their action can be attributed have failed. There can, however, be little doubt that they exercise an action on the organism, in consequence of the stomach and other parts with which they come in contact, not having the power to arrest their decomposition, and entering the blood in some way or other, while still possessing their whole power, they impart their peculiar action to the constituents of that fluid. Now blood is remarkable for the readiness with which it suffers transformations; all the constituents of the animal organism are formed from it, and its nature and constitution is one of the most complex of all existing matter. Its component parts are subordinate to every attraction, and these are in a perpetual state of change or transformation, which is effected in the most various ways, through the influence of the different organs. It is a well known fact, that when blood, cerebral substance, gall, pus, and other substances in a state of putrefaction, are laid upon fresh wounds, vomiting, debility, and at length death are occasioned. It is also well known, that bodies in anatomical rooms, frequently pass into a state of decomposition, which is capable of imparting itself to the living body; the smallest cut with a knife that has been used in their dissection, producing in these cases dangerous consequences.

I cannot conclude these observations better, than by a quotation from the admirable Essay of Liebig, showing in what manner these remarkable actions are to be considered in reference to the vital principle. "In order to explain the effects of contagious matters, a peculiar principle of life has been ascribed to them,—a life similar to that possessed by the germ of a seed, which enables it under favourable conditions, to develop and multiply itself. But our notion of life involves something more than mere reproduction, namely, the idea of an active power, exercised *by virtue of a definite form*, and production and generation in a definite form. By Chemical agency, we can produce the constituents of muscular fibre, skin, and hair, but we can form by their means, no organized tissue, no organic cell. The production of organs, the co-operation of a system of organs, and their power not only to produce their component parts from the food presented to them, but to generate *themselves* in their original form, and with all their properties, are characters belonging exclusively to organic life, and constitute a form of reproduction independent of chemical forces which are subject to it. The vital principle is only known to us through the peculiar form of its instruments, that is, through the organs in which it resides. Hence, whatever kind of energy a substance may possess, if it is amorphous and destitute of organs from which the impulse, motion, or change proceeds, it does not live. Its energy depends, in this case, on chemical action. Light, heat, electricity, and other influences may increase, diminish, or arrest this action, but they are not its efficient cause. In the same way, the vital principle governs the chemical powers in the living body. All substances used for food are chemical compounds, and it is only, therefore, the chemical powers by which their constituents are held together, that the vital principle has to overcome. It opposes to the continual action of the atmosphere, moisture, and temperature, upon the organism, a resistance which is, in a certain degree, invincible. It is by the constant neutralization and renewal of these external influences that life and motion are maintained.

The greatest wonder in the living organism is the fact, that an unfathomable wisdom has made the cause of a continual decomposition or destruction, namely, the support of the process of respiration, to be the means of renewing the organism and of resisting all the other atmospheric influences, such as those of moisture and changes of temperature.

All the supposed proofs of the vitality of contagions, are merely ideas and figurative representations, fitted to render the phœnomena more easy of apprehension by our senses, without explaining them. These figurative expressions with which we are so willingly and easily satisfied in all sciences, are the foes of all inquiries into the mysteries of nature; they are like the *fata morgana*, which show us deceitful views of seas, fertile fields, and luscious fruits, but leave us languishing when we have most need of what they promise."

FINIS.

INDEX.

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ERRATA.

PAGE

55, 17 lines from the top, for " Iron melts," read *cast iron melts.*

48, 10 lines from the bottom, for " reached," read *surrounding.*

102, 6 lines from the bottom, for " acitate," read *acetate.*

105, 6 lines from the bottom, for " flints," read *flint.*

127, 13 lines from the top, for " hydrogen," read *nitrogen.*

127, 12 lines from the bottom, for " multiplies," read *multiples.*

129, 5 lines from the top, for " hydronitrous," read *hyponitrous.*

130, 11 lines from the bottom, for " oxalates," read *oxalate.*

137, 4 lines from the bottom, for " actual," read *relative.*

143, 14 lines from the top, for " 2 Mn O 3," read $Mn_2 O_3$

154, 15 lines from the top, for " protoxide of iron," read *black oxide of iron.*

157, 13 lines from the top, erase comma after " carbonic acid."

231, 8 lines from the bottom, erase " and that an equivalent, or 1267 parts of nitrate of potash."

235, last line, for "pulverized sal ammonia (muriate of ammonia)," read *lime.*

247, 26 lines from the bottom, after " red hot," add *in a closed vessel.*

257, 5 lines from the bottom, dele full stop after " *commerce.*"

260, 12 lines from the top, for " amounts," read *amounting.*

420, 11 lines from the bottom, for " 34," read 24.

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