A
SYSTEM
OF
CHEMISTRY.

IN FOUR VOLUMES.

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VOL. I.

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M.DCCC.II.

PREFACE.

No country, perhaps, in which science has been cultivated with so much ardour and success, has produced so small a number of good elementary works as Britain. Our philosophers have been more anxious to extend the limits of human knowledge, than to facilitate the progress of the young student of nature. The task of composing elementary treatises has been usually entrusted to men of inferior endowments, as a piece of drudgery below the dignity of a philosopher. Hence the first principles of science have been too often rendered disgusting, and calculated rather to deter the student than to allure him to the acquisition of knowledge.

The case is very different in France. Excellent systematic treatises have appeared in that country on almost every part of science; nor have their eminent philosophers disdained to compose them. It is to these excellent works, as much perhaps as to any other cause, that we are to ascribe the currency of the French language in every part of Europe.

This striking difference between the two nations is owing, not so much to the diversity of their genius and disposition, as to the opposite systems of education which have been followed by each—systems attended with peculiar advantages and peculiar defects, and which would perhaps approach much nearer to perfection if they were blended together.

It is not meant to affirm that there are no good elementary works in the English language; fortunately we possess several of the greatest value: even Newton himself has not disdained to leave us a treatise on the first principles of algebra. But we have more frequently satisfied ourselves with translating the systematic works of foreigners, even when the discoveries of our own philosophers had furnished a considerable proportion of the materials of these works. This, in particular, was long the case in Chemistry. The works of Boerhaave, Macquer, Fourcroy, Chaptal, Lavoisier, &c. were successively translated before almost any modern British writer thought of composing a system.

Such translations were certainly proper; and we are highly indebted to those gentlemen who have taken the trouble to present us with these masterly works in an English dress: But why cannot we boast, in our turn, of the treatises of our Blacks, our Cavendishes, our Kirwans, &c.? The consequence of this defect has been what indeed was naturally to be expected—the labours of our philosophers have been frequently overlooked, and their discoveries claimed by others to whom they did not belong; while these claims, constantly inculcated in all the elementary treatises of chemistry, have been received as first principles by the greater number of readers. It is incontrovertible, that, for the rapid progress which chemistry has lately made, the science is deeply indebted to the philosophers of this country. Much indeed has been done by the illustrious body of French chemists; but these gentlemen, not satisfied with a part, have laid claim to the whole.

Several valuable treatises of chemistry have appeared in this country within these twelve or fourteen years, which must have contributed very considerably to produce that taste for the science, now become general. But as these treatises were intended only to give a clear outline of the first principles of chemistry, they by no means supersede the following Work, which has a different object. It was thought that a full detail of the vast number of facts which constitute this important science, blended with the history of their gradual developement and of the theories which have been founded on them, and accompanied with exact references to the original works in which the different discoveries have been registered, was still wanting. The Work now submitted to the public was intended to supply this deficiency: but the Author would by no means insinuate that he has succeeded completely. The task was too difficult to be executed at once, or perhaps by one man. Defects, therefore, and omissions will doubtless be discovered in the ensuing Work. But the Author flatters himself that it contains at least a more complete collection of facts than any publication of the kind which has hitherto appeared, not even excepting the voluminous, and in many respects excellent work, of the celebrated Fourcroy; a work which certainly contains the fullest and best arranged view of that branch of chemistry which the French claim as their own exclusively, and which they have dignified with the title of *French Chemistry* *, that has hitherto appeared. But in other branches of the science the *Systeme des Connaissances Chimiques* is more defective. Its merit, however, is every where great, and the Author of the ensuing Treatise has frequently availed himself of it, as will be seen by the references.

THE arrangement which has been followed in the present Work, though it differs considerably from what is usually adopted by chemical writers, appeared upon mature reflection to be well calculated to give a clear and distinct view of the subject, and to conduct the

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* Forgetting that most of the facts were supplied by Dr Priestley and and Mr Cavendish, and a considerable portion of the theory by Dr Black.

learner without embarrassment from one step to another till the whole of the subject open to his view. The easiest parts of the science have been placed first; no previous knowledge of chemistry has been supposed; and every term is explained as soon as it is introduced. An outline of a considerable part of it has been already published in the Supplement to the Encyclopædia Britannica; but it has now received very considerable alterations and improvements. Of the arrangement the Author speaks with more confidence, because one in many respects similar has been adopted by Fourcroy in his late work. And that celebrated writer informs us that he has followed it in his chemical lectures, and that he has found it a very material improvement. So similar, indeed, is the arrangement of Fourcroy in several parts of his work to that which has been followed in the System now offered to the literary world, that every person must have supposed the latter to have been borrowed from that celebrated writer, had it not been published at least two years before the appearance of Fourcroy's book.

Particular attention has been paid to collect the different synonymes; but the nomenclature which has been used in the Work itself is that which appeared to the Author to have gained the most general approbation of British chemists. In one or two instances indeed, a small deviation has been made from the prevailing fashion, because precision or the genius of our language seemed to require it. The Author is happy to observe, that in most of these cases he has been fortunate enough to agree with Mr Chenevix, who has lately proposed most of the very same alterations in his excellent paper on *the arseniats of copper and iron.* Even the mode of spelling the different new terms has not been adopted without consideration; and it is hoped it will be approved of by our chemical philosophers.

It was originally intended to have given a view of the gradual progress of the science, by inserting in an appendix an analysis of the most celebrated systems of chemistry which have appeared at different periods, from Albertus Magnus downwards. Hence the promise in the note in page 7th of the first volume. But it was soon found that this plan could not be put in execution without adding another volume. It was therefore relinquished, on the supposition that such an enhancement of the expence of the book, without adding any thing whatever to the System, would not have been acceptable to the Public.

CONTENTS

OF

VOLUME FIRST.

A SYSTEM OF CHEMISTRY.

AS soon as man begins to think and to reason, the different objects which surround him on all sides naturally engage his attention. He cannot fail to be struck with their number, diversity, and beauty; and naturally feels a desire to be better acquainted with their properties and uses. If he reflect also, that he himself is altogether dependent upon these objects, not merely for his pleasures and comforts, but for his very existence, this desire must become irresistible. Hence that curiosity, that eager thirst for knowledge, which animates and distinguishes generous minds.

Study of Nature.

Natural objects present themselves to our view in two different ways; for we may consider them either as separate individuals, or as connected together and depending upon each other. In the first case, we contemplate Nature as in a state of rest, and consider objects merely as they resemble one another, or as they differ from one another: in the second, we examine the mutual action of substances on each other, and the changes produced by that action. The first of

Divided into history and science.

these views of objects is distinguished by the name of *Natural History*, the second by that of *Science*.

Science

Natural science, then, is an account of the *events* which take place in the material world. But every event, or, which is the same thing, every change in bodies indicates motion; for we cannot conceive change, unless at the same time we suppose motion. Science, then, is in fact an account of the different *motions* to which bodies are subjected, in consequence of their mutual action on each other.

Of two kinds, *viz.*

Now bodies vary exceedingly in their distances from each other. Some, as the planets, are separated by many millions of miles; while others, as the particles of which water is composed, are so near each other, that we cannot, by our senses at least, perceive any distance between them; and only discover, by means of certain properties which they possess, that they are not in actual contact. But the *quantity* of change or of motion, produced by the mutual action of bodies on each other, must depend, in some measure at least, upon their distance from one another. If that distance be great enough to be perceived by the eye, and consequently to admit of accurate measurement, every change in it will also be perceptible, and consequently will admit of measurement. But when the distance between two bodies is too small to be perceptible by our senses, it is evident that no change in that distance can be perceptible, and that consequently every relative motion in such bodies must be insensible.

Mechanical philosophy and chemistry.

Science therefore naturally divides itself into two great branches: the first, comprehending all those natural events which consist of *sensible* motions; the second, all those which consist of *insensible* motions. The first of these branches has been long distinguished in Britain by the name of *natural philosophy*, and of late by the more proper appellation of *mechanical philosophy;* the second is known by the name of *chemistry*.

Definition of chemistry.

CHEMISTRY, then, is that science which treats of those events or changes in natural bodies which consist of *insensible* motions.

Its importance.

Chemical events are equally numerous, and fully as important, as those which belong to mechanical philosophy: for the science comprehends under it almost all the changes in natural objects with which we are more immediately connected, and in which we have the greatest interest. Chemistry therefore is highly worthy of our attention, not merely for its own sake, because it increases our knowledge, and gives us the noblest display of the wisdom and goodness of the Author of Nature; but because it adds to our resources, by extending our dominion over the material world, and is therefore calculated to promote our enjoyment and augment our power.

As a science, it is intimately connected with all the phenomena of nature; the causes of rain, snow, hail, dew, wind, earthquakes; even the changes of the seasons can never be explored with any chance of success while we are ignorant of chemistry: and the vegetation of plants, and some of the most important functions of animals, have received all their illustration from the same source. No study can give us more exalted ideas of the wisdom and goodness of the Great First Cause than this, which shews us everywhere the most astonishing effects produced by the most simple though adequate means, and displays to our view the great care which has everywhere been taken to secure the comfort and happiness of every living creature. As an art, it is intimately connected with all our manufactures: The glass-blower, the potter, the smith, and every other worker in metals, the tanner, the soap-maker, the dyer, the bleacher, are really practical chemists; and the most essential improvements have been introduced into all these arts by the progress which chemistry has made as a science. Agriculture can only be improved rationally, and certainly, by calling in the assistance of chemistry; and the advantages, which medicine has derived from the same source, are too obvious to be pointed out.

Origin.

The word CHEMISTRY seems to be of Egyptian origin, and to have been originally equivalent to our phrase *natural philosophy* in its most extensive sense, comprehending all the knowledge of natural objects which the ancients possessed. In process of time it seems to have acquired a more limited signification, and to have been confined to the *art of working metals* *. This gradual change was no doubt owing to the immense importance attached by the ancients to the art of working metals. The founders and improvers of it were considered as the greatest benefactors of the human race; statues and temples were consecrated to their honour; they were even raised above the level of humanity, and enrolled among the number of the gods.

How long the word *chemistry* retained this new signification, it is impossible to say; but in the third century we find it used in a still more limited sense, signifying the art of *making gold and silver*. The cause

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* Our English word *phyſician* has undergone a similar change.

of this new limitation, and the origin of the opinion that gold can be made by art, are equally unknown. Chemistry, in this new sense, appears to have been cultivated with considerable eagerness by the Grecian ecclesiastics, to have passed from the Greeks to the Arabians, and by the Arabians to have been brought into the west of Europe. Those, who professed it, gradually assumed the form of a sect, under the name of ALCHYMISTS; a term which is supposed to be merely the word *chemist*, with the Arabian article *al* prefixed.

Of the Alchymists.

The alchymists laid it down as a first principle, that all metals are composed of the same ingredients, or that the principles at least, which compose gold, exist in all metals, contaminated indeed with various impurities, but capable, by a proper purification, of being brought to a perfect state. The great object of their researches was to find out the means of producing this purification, and consequently of converting the baser metals into gold. The substance which possessed this wonderful property they called *lapis philosophorum*, "the philosophers stone;" and many of them boasted that they were in possession of that grand instrument.

Their opinions,

Chemistry, as the term was used by the alchymists, signified the art of making the philosophers stone. They affirmed that this art was above the reach of the human capacity, and that it was made known by God to those happy sages only whom he peculiarly favoured. The fortunate few who were acquainted with the philosophers stone called themselves *adepti*, "adepts;" that is, persons who had got possession of the secret. This secret they pretended they were not at liberty to reveal; affirming, that dire misfortune would fall upon that man's head who ventured to disclose it to any of the sons of men without the clearest tokens of the divine authority.

In consequence of these notions, the alchymists made it a rule to keep themselves as private as possible. They concealed, with the greatest care, their opinions, their knowledge, and their pursuits. In their communications with each other, they adopted a mystical and metaphorical language, and employed peculiar figures and signs, that their writings might be understood by the adepts only, and might be entirely unintelligible to common readers. Notwithstanding all these obstacles, a great number of alchymistical books made their appearance in the dark ages; many of them under the real names of the authors; but a still greater number under feigned titles, or ascribed to the celebrated sages of antiquity.

How far alchymy had extended among the ancients, or whether it had even assumed the form of a sect, cannot be ascertained. Traces of it appear among the Arabians, who turned their attention to literature soon after the conquests of the Caliphs, and who communicated to our barbarous ancestors the first seeds of science. The principal chemical writers among the Arabs were Geber and Avicenna; and in their writings, such of them at least as we have reason to consider as authentic, there appears but little of that mysticism and ænigma which afterwards assumed a systematic form.

The alchymists seem to have been established in the west of Europe at least as early as the 9th century. Between the 11th and 15th centuries, alchymy was in its most flourishing state. The writers who appeared during that period were sufficiently numerous, and very different from each other both in their style and abilities. Some of their books are altogether unintelligible, and bear a stronger resemblance to the reveries of madmen than to the sober investigations of philosophers. Others, if we make allowance for their metaphorical style, are written with comparative plainness, display considerable acuteness, and indicate a pretty extensive acquaintance with natural objects. They often reason with great accuracy, though generally from mistaken principles; and it is frequently easy enough to see the accuracy of their experiments, and even to trace the particular circumstance which led to their wrong conclusions.

The principal alchymists who flourished during the dark ages, and whose names deserve to be recorded, either on account of their discoveries, or of the influence which their writings and example had in determining the public taste, were, Albertus Magnus, Roger Bacon, Arnoldus de Villa Nova, Raymond Lully, and the two Isaacs of Holland *.

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* Albertus Magnus was a German. He was born in the year 1205, and died in 1280. His works are numerous; but the most curious of them is his tract entitled *De Alchymia*. Of this I shall give an abstract in the Appendix to the first part of this Treatise, because it contains a very distinct view of the state of chemistry in the 13th century.

Roger Bacon was born in the county of Somerset in England in 1224. His merit is too well known to require any panegyric. The greater number of his writings are exceedingly obscure, and even mystical; but he generally furnishes us with a key for their explanation. Some of them exhibit a wonderfully enlightened mind for the age in which he wrote. His tract *De mirabili potestate Artis et Naturæ* would have done honour to Lord Bacon himself.

And writings.

The writings of the greater number of alchymists are remarkable for nothing but obscurity and absurdity. They all boast that they are in possession of the philosophers stone; they all profess to communicate the method of making it; but their language is ænigmatical, that it may be understood by those adepts only who are favoured with illumination from heaven. Their writings, in those benighted ages of ignorance, gained implicit credit; and the covetous were filled with the ridiculous desire of enriching themselves by means of their discoveries. This laid the unwary open to the tricks of a set of impostors, who went about the world pretending that they were in possession of the secret of the philosophers stone, and offering to communicate it to others for a suitable reward. Thus they contrived to get possession of a sum of money; and afterwards they either made off with their booty, or tired out the patience of their pupils by intolerably tedious, expensive, and ruinous processes. It was against these men that Erasmus directed his well-known satire, entitled, *The Alchymist*. The tricks of these impostors gradually exasperated mankind against the whole fraternity of alchymists. Books appeared against them in all

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Arnoldus de Villa Nova is believed to have been born in Provence, about the year 1240. His reputation was very high; but all of his writings that I have examined are exceedingly obscure, and often not intelligible.

Raymond Lully was born at Barcelona in 1235. His writings are still more obscure than those of Arnold. The most celebrated of them is his *Last Will and Testament*, which has been translated into English.

It is not known at what period the Isaacs of Holland lived, though it is supposed to have been in the 13th century.

quarters, which the art of printing, just invented, enabled the authors to spread with facility; the wits of the age directed against them the shafts of their ridicule; men of science endeavoured to point out the impracticability, or at least the infinite difficulty, of the art; men of learning rendered it probable that it never had been understood; and men in authority endeavoured by laws and punishments to guard their subjects from the talons of alchymistical impostors.

Chemists had for many ages hinted at the importance of discovering a universal remedy, which should be capable of curing, and even of preventing, all diseases; and several of them had asserted, that this remedy was to be found in the philosophers stone, which not only converted baser metals to gold, but possessed also the most sovereign virtue, was capable of curing all diseases in an instant, and even of prolonging life to an indefinite length, and of conferring on the adepts the gift of immortality on earth. This notion gradually gained ground; and the word *chemistry*, in consequence, at length acquired a more extensive signification, and implied not only the *art of making gold*, but the art also of *preparing the univerſal medicine*[*].

Just about the time that the first of these branches was sinking into discredit, the second, and with it the study of chemistry, acquired an unparallcled degree of celebrity, and attracted the attention of all Europe.

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[*] The first man who formally applied chemistry to medicine was Basil Valentine, who is said to have been born in 1394, and to have been a Benedictine Monk at Erford in Germany. His *Currus triumphalis Antimonii* is the most famous of his treatises. In it he celebrates the virtues of antimonial medicines, of which he was the original discoverer.

This was owing to the appearance of Theophrastus Paracelsus. This extraordinary man, who was born in 1493, near Zurich in Switzerland, was, in the 34th year of his age, after a number of whimsical adventures, which had raised his reputation to a great height, appointed by the magistrates of Basil to deliver lectures in their city; and thus was the first public Professor of chemistry in Europe. In two years he quarrelled with the magistrates, and left the city; and after running through a complete career of absurdity and debauchery, died at Saltzburg in the 47th year of his age.

The character of this extraordinary man is universally known. That he was an impostor, and boasted of secrets which he did not possess, cannot be denied; that he stole many opinions, and even facts, from others, is equally true: his arrogance was unsupportable, his bombast ridiculous, and his whole life a continued tissue of blunders and vice. At the same time, it must be acknowledged that his talents were great, and that his labours were not entirely useless. He contributed not a little to dethrone Galen and Avicenna, who at that time ruled over medicine with absolute power; and to restore Hippocrates and observation to that chair, from which they ought never to have risen. He certainly gave chemistry an eclat which it did not before possess; and this must have induced many of those laborious men, who succeeded him, to turn their attention to the science. Nor ought we to forget that, by carrying his speculations concerning the philosophers stone, and the universal medicine, to the greatest height of absurdity, and by exemplifying their emptiness and uselessness in his own person, he undoubtedly contributed more than any man to their disgrace and subsequent banishment from the science.

Van Helmont, who was born in 1577, may be considered as the last of the alchymists. His death completed the disgrace of the universal medicine. His contemporaries, and those who immediately succeeded him, if we except Crollius and a few other blind admirers of Paracelsus, attended solely to the improvement of chemistry. The chief of them were Agricola, Beguin, Glaser, Erkern, Glauber, Kunckel, Boyle, &c.

Origin of chemistry as a science.

The foundations of the alchymistical system being thus shaken, the facts which had been collected soon became a heap of rubbish, and chemistry was left without any fixed principles, and destitute of an object. It was then that a man arose, thoroughly acquainted with the whole of these facts, capable of arranging them, and of perceiving the important purposes to which they might be applied, and able to point out the proper objects to which the researches of chemists ought to be directed. This man was BECCHER. He accomplished the arduous task in his work entitled *Physica Subterranea*, published at Francfort in 1669. The publication of this book forms a very important æra in the history of chemistry. It then escaped for ever from the trammels of alchymy, and became the rudiments of the science which we find it at present.

Ernest Stahl, the editor of the *Physica Subterranea*, adopted, soon after Beccher's death, the theory of his master; but he simplified and improved it so much, that he made it entirely his own; and accordingly it has been known ever since by the name of the Stahlian Theory.

Ever since the days of Stahl, chemistry has been cul-

Its progress

tivated with ardour in Germany and the North; and the illustrious philosophers of these countries have contributed highly towards its progress and its rapid improvement. The most deservedly celebrated of these are Margraf, Bergman, Scheele, Klaproth, &c.

In France, soon after the establishment of the Academy of Sciences in 1666, Homberg, Geoffroy, and Lemery, acquired celebrity by their chemical experiments and discoveries; and after the new-modelling of the Academy, chemistry became the peculiar object of a part of that illustrious body. Rouelle, who was made professor of chemistry in Paris about the year 1745, contrived to infuse his own enthusiasm into the whole body of the French literary men; and from that moment chemistry became the fashionable study. Men of eminence appeared everywhere, discoveries multiplied, the spirit pervaded the whole nation, extended itself over Italy, and appeared even in Spain.

After the death of Boyle and of some other of the earlier members of the Royal Society, little attention was paid to chemistry in Britain except by a few individuals. The spirit which Newton had infused for the mathematical sciences was so great, that for many years they drew within their vortex almost every man of eminence in Britain. But when Dr Cullen became Professor of Chemistry in Edinburgh in 1756, he kindled a flame of enthusiasm among the students, which was soon spread far and wide by the subsequent discoveries of Black, Cavendish, and Priestley; and meeting with the kindred fires which were already burning in France, Germany, Sweden, and Italy, the science of chemistry burst forth at once with unexampled lustre. Hence the rapid progress which it has made during the last fifty years, the universal attention which it has excited, and the unexpected light which it has thrown on several of the most important arts and manufactures.

And present state.

The object of this Work is to exhibit as complete a view as possible of the present state of chemistry; and to trace, at the same time, its gradual progress from its first rude dawnings as a science, to the improved state which it has now attained. By thus blending the history with the science, the facts will be more easily remembered, as well as better understood; and we shall at the same time pay that tribute of respect, to which the illustrious improvers of it are justly intitled.

A complete account of the present state of chemistry must include not merely a detail of the science of chemistry strictly so called, but likewise the application of that science to substances as they exist in nature, constituting the mineral, vegetable, and animal kingdoms. This Treatise, therefore, shall be divided into two Parts. The first will comprehend THE SCIENCE OF CHEMISTRY, properly so called; the second will consist of A CHEMICAL EXAMINATION OF NATURE.

PART I.

PRINCIPLES

OF

CHEMISTRY.

THE object of chemistry is, to ascertain the ingredients of which bodies are composed; to examine the compounds formed by the combination of these ingredients; and to investigate the nature of the power which occasions these combinations.

Object of chemistry

The science therefore naturally divides itself into three parts: 1. A description of the component parts of bodies, or of *simple substances* as they are called. 2. A description of the compound bodies formed by the union of simple substances. 3. An account of the nature of the power which occasions these combinations. This power is known in chemistry by the name of AFFINITY. These three particulars will form the subject of the three following Books.

BOOK I.

OF

SIMPLE SUBSTANCES.

Book I.

By simple substances is not meant what the ancient philosophers called *elements* of bodies, or particles of matter incapable of farther diminution or division. They signify merely bodies which have not been decompounded, and which no phenomenon hitherto observed indicate to be compounds. Very possibly the bodies which we reckon simple may be real compounds; but till this has actually been proved, we have no right to suppose it. Were we acquainted with all the elements of bodies, and with all the combinations of which these elements are capable, the science of chemistry would be as perfect as possible; but at present this is very far from being the case.

The simple substances at present known amount to about 30. They may be very conveniently arranged under five classes; namely,

1. Oxygen,
2. Simple combustibles,
3. Metals,
4. Light,
5. Caloric.

These shall form the subject of the five following Chapters.

CHAP. I.

OF OXYGEN.

The first of these classes includes under it only one substance, *oxygen;* but a substance of so peculiar a nature, that it must be considered separately, and which acts so important a part in the phenomena of chemistry, that it is proper to become acquainted with it as early as possible.

Method of procuring oxygen.

Take a quantity of nitre, or saltpetre as it is also called, and put it into a gun-barrel A (fig. 1.), the touch-hole of which has been previously closed up with metal. This barrel is to be bent in such a manner, that while the close end, in which the nitre lies, is put into the fire E, the open end may be plunged below the surface of the water, with which the vessel B is filled. At the same time, the glass jar D, previously filled with water, is placed on the support C, lying at the bottom of the vessel of water B, so as to be exactly over the open end of the gun-barrel A. As soon as the nitre becomes red hot, it emits a quantity of air, which, issuing from the end of the gun-barrel, ascends to the top of the glass jar D, and gradually displaces all the water. The glass jar D then appears to be empty, but is in fact filled with air. It may be removed in the following manner: Slide it away a little from the gun-barrel and the support, and then dipping any flat dish into the water below it, raise it on the dish, and bear it away. The dish must be allowed to retain a quantity of water in it, to prevent the air from escaping (see fig. 2.) Another jar may then be filled with air in the same manner; and this process may be continued either till the nitre ceases to give out air, or till as many jarfuls have been obtained as are required. This method of obtaining and confining air was first invented by Dr Mayow, and afterwards much improved by Dr Hales. The stoneware retort (fig. 3.) may be used instead of the gun-barrel. All the airs obtained by this or any other process, or, to speak more properly, all the airs differing from the air of the atmosphere, have, in order to distinguish them from it, been called *gases*, and this name we shall afterwards employ *.

Discovered by Priestley and Scheele.

The gas which we have obtained by the above process was discovered by Dr Priestley on the 1st of August 1774, and called by him *dephlogisticated air*. Mr Scheele of Sweden discovered it in 1775, without any previous knowledge of what Dr Priestley had done: he gave it the name of *empyreal air*. Condorcet gave it first the name of *vital air*; and Mr Lavoisier afterwards called it *oxygen gas*; a name which is now generally received, and which we shall adopt.

Oxygen gas may be obtained likewise by the following process:

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* The word *gas* was first introduced into chemistry by Van Helmont. He seems to have intended to denote by it every thing which is driven off from bodies in the state of vapour by heat. He divides *gases* into five classes "Nescivit inquam schola Galenica hactenus differentiam inter gas ventosum (quod mere aer est, id est, ventus, per syderum blas commotus), gas pingue, gas siccum, quod sublimatum dicitur, gas fuliginosum, sive endimicum, et gas sylvestre, sive incoercibile, quod in corpus cogi non potest visibile." *Van Helmont De Flatibus*, § 4.

Another method.

D (in fig. 4.) represents a wooden trough, the inside of which is lined with lead or tinned copper. C is the cavity of the trough, which ought to be a foot deep. It is to be filled with water at least an inch above the shelf AB, which runs along the inside of it, about three inches from the top. In the body of the trough, which may be called the cistern, the jars destined to hold gas are to be filled with water, and then to be lifted, and placed inverted upon the shelf at B. This trough, which was invented by Dr Priestley, has been called by the French chemists the *pneumato-chemical*, or simply *pneumatic* apparatus, and is extremely useful in all experiments in which gases are concerned. Into the glass-vessel E put a quantity of the black oxide * of manganese in powder, and pour over it as much of that liquid which in commerce is called *oil of vitriol*, and in chemistry *sulphuric acid*, as is sufficient to form the whole into a thin paste. Then insert into the mouth of the vessel the glass tube F, so closely that no air can escape except through the tube. This may be done by covering the joining with a little glazier's putty, and then laying over it slips of bladder or linen dipped in glue or in a mixture of the white of eggs and quicklime. The whole must be made fast with cord†. The end of the tube

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* This substance shall be afterwards described. It is now very well known in Britain, as it is in common use with bleachers and several other manufacturers.

† This process, by which the joinings of vessels are made air-tight, is called *luting*, and the subsances used for that purpose are called *lutes*. The lute most commonly used by chemists, when the vessels are exposed to heat, is fat lute, made by beating together in a mortar fine clay and boiled lintseed oil. Bees wax, melted with about one-eighth part of turpen-

F is then to be plunged into the pneumatic apparatus D and the jar G, previously filled with water, to be placed over it on the shelf. The whole apparatus being fixed in that situation, the glass vessel E is to be heated by means of a lamp or a candle. A quantity of oxygen gas rushes along the tube F, and fills the jar G. As soon as the jar is filled, it may be slid to another part of the shelf, and other jars substituted in its place, till as much gas has been obtained as is wanted. Both these methods of obtaining oxygen gas were discovered by Scheele *.

Properties of oxygen.

1. Oxygen gas is colourless, and invisible like common air. Like it too, it is elastic, and capable of indefinite expansion and compression.

Supports flame,

2. If a lighted taper be let down into a jar of oxygen gas, it burns with such splendor that the eye can scarcely bear the glare of light, and at the same time produces a much greater heat than when burning in common air. It is well known that a candle put into a well closed jar filled with common air is extinguished in a few seconds. This is the case also with a candle inclosed in oxygen gas; but it burns much longer in an equal quantity of that gas than of common air.

And life.

3. It was proved long ago by Boyle, that animals

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tine, answers very well, when the vessels are not exposed to heat. The accuracy of chemical experiments depends almost entirely in many cases upon securing the joinings properly with luting. The operation is always tedious; and some practice is necessary before one can succeed in luting accurately. Some very good directions are given by Lavoisier. See his *Elements*, Part iii. chap. 7. In many cases luting may be avoided altogether, by using glass-vessels properly fitted to each other by grinding them with emery.

[*] On Fire.

cannot live without air, and by Mayow that they cannot breath the same air for any length of time without suffocation. Dr Priestley and several other philosophers have shewn us, that animals live much longer in the same quantity of oxygen gas than of common air. Count Morozzo placed a number of sparrows, one after another, in a glass bell filled with common air, and inverted over water.

	H.	M.
The first sparrow lived	3	0
The second	0	3
The third	0	1

He filled the ſame glaſs with oxygen gas, and repeated the experiment.

	H.	M.
The first sparrow lived	5	23
The second	2	10
The third	1	30
The fourth	1	10
The fifth	0	30
The sixth	0	47
The seventh	0	27
The eighth	0	30
The ninth	0	22
The tenth	0	21

He then put in two together; the one died in 20 minutes, but the other lived an hour longer.

Exists in the atmosphere.

4. It has been ascertained by experiments, which shall be afterwards related, that atmospherical air contains between 20 and 30 parts in the hundred of oxygen gas; and that no substance will burn in common air previously deprived of all the oxygen gas which it contains. But combustibles burn with great splendor

in oxygen gas, or in other gases to which oxygen gas has been added. Oxygen gas, then, is absolutely necessary for combustion.

5. It has been proved also, by many experiments, that no breathing animal can live for a moment in any air or gas which does not contain oxygen mixed with it. Oxygen gas, then, is absolutely necessary for respiration.

6. When substances are burnt in oxygen gas, or in any other gas containing oxygen, if the air be examined after the combustion, we shall find that a great part of the oxygen has disappeared. If charcoal, for instance, be burnt in oxygen gas, there will be found, instead of part of the oxygen, another very different gas, known by the name of carbonic acid gas. Exactly the same thing takes place when air is respired by animals; part of the oxygen gas disappears, and its place is occupied by substances possessed of very different properties. Oxygen gas then undergoes some change during combustion, as well as the bodies which have been burnt; and the same observation applies also to respiration.

Its specific gravity.

7. The specific gravity of oxygen gas, as determined by Mr Kirwan *, is 0.00135, that of water being 1.0000, as is always the case when specific gravity is mentioned absolutely. It is therefore 740 times lighter than the same bulk of water. Its weight to atmospherical air is as 1103 to 1000: 116 cubic inches of oxygen gas weigh 39.03 grains troy, 116 cubic inches of common air, 35.38 grains.

Affinity explained.

8. Oxygen is capable of combining with a great number of bodies, and of forming compounds. As the com-

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* On Phlogiston, Sect. i,

Chap. I.

bination of bodies is of the utmost importance in chemistry, before proceeding farther it will be proper to explain it. When common salt is thrown into a vessel of pure water, it melts, and very soon spreads itself through the whole of the liquid, as any one may convince himself by the taste. In this case the salt is combined with the water, and cannot afterwards be separated by filtration or any other method merely mechanical. It may, however, by a very simple process: Pour into the solution a quantity of spirit of wine, and the salt falls slowly to the bottom in the state of a very fine powder.

Why does the salt dissolve in water, and why does it fall to the bottom on pouring in spirit of wine? These questions were first answered by Sir Isaac Newton. There is a certain attraction between the particles of common salt and those of water, which causes them to unite together whenever they are presented to one another. There is an attraction also between the particles of water and of spirit of wine, which equally disposes them to unite, and this attraction is greater than that between the water and salt; the water therefore leaves the salt to unite with the spirit of wine, and the salt being now unsupported, falls to the ground by its gravity. This power, which disposes the particles of different bodies to unite, was called by Newton *attraction*, by Bergman *elective attraction*, and by many of the German and French chemists *affinity*[*]; and this last term is now employed in preference, because the other two are rather general. All substances which

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[*] The word *affinity* seems first to have been introduced into science by Dr Hooke. See his *Micrographia*.

Book I.

are capable of combining together are said to have an *affinity for* each other: those substances, on the contrary, which do not unite, are said to have *no affinity* for each other. Thus there is no affinity between water and oil. It appears from the instance of the common salt and spirit of wine, that substances differ in the degree of their affinity for other substances, since the spirit of wine displaced the salt and united with the water. Spirit of wine therefore has a stronger affinity for water than common salt has.

In 1719, Geoffroi invented a method of representing the different degrees of affinities in tables, which he called *tables of affinity*. His method consisted in placing the substance whose affinities were to be ascertained at the top of a column, and the substances with which it united below it, each in the order of its affinity; the substance which had the strongest affinity next it, and that which had the weakest farthest distant, and so of the rest. According to this method, the affinity of water for spirit of wine and common salt would be marked as follows:

WATER,

Spirit of wine,
Common salt.

This method has been universally adopted, and has contributed very much to the rapid progress of chemistry.

I shall proceed therefore to give a table of the affinities of oxygen.

Affinities of oxygen.

Oxygen,

Charcoal,
Manganese,
Zinc,
Iron,
Tin*,
Antimony,
Hydrogen,
Phosphorus,
Sulphur,
Arsenic,
Azot,
Nickel,
Cobalt,
Copper,
Bismuth,
Mercury,
Silver,
Oxide of arsenic,
Nitrous gas,
Gold,
Platinum,
Muriatic acid,
White oxide of manganese,
White oxide of lead†.

The reason of this order will appear when the substances themselves come to be treated of.

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[*] Bouillon La Grange, Ann. de Chim. xxxv. 28.

[†] The affinities of molybdenum, tungsten, chromum, ~~uranium~~, titanium, uranium, tellurium, and of most of the metallic oxides, have not been ascertained

CHAP. II.

OF SIMPLE COMBUSTIBLES.

Five simple combustibles.

By *combustibles* I mean substances capable of combustion, and by *simple combustibles* bodies of that nature which have not hitherto been decompounded. These bodies are only five in number; namely, SULPHUR, PHOSPHORUS, CARBON, HYDROGEN, and AZOT. The metals might indeed be classed among combustible bodies; but the greater number of their properties are so different from those of the five bodies just mentioned, that it is proper to consider them by themselves as a distinct class of bodies. All our classifications are in fact artificial; Nature does not know them, and will not submit to them. They are useful, however, as they enable us to learn a science sooner, and to remember it better; but if we mean to derive these advantages from them, we must renounce a rigid adherence to arbitrary definitions, which Nature disclaims.

SECT. I.

OF SULPHUR.

Sulphur, distinguished also in English by the name of *brimstone*, was known in the earliest ages. As it is found native in many parts of the world, it could not fail very soon to attract the attention of mankind. It was used by the ancients in medicine, and its fumes were employed in bleaching wool *.

Sulphur is a hard brittle substance, commonly of a yellow colour, without any smell, and of a weak though perceptible taste.

Properties of sulphur.

It is a non-conductor of electricity, and of course becomes electric by friction.

If a considerable piece of sulphur be exposed to a sudden though gentle heat, by holding it in the hand, for instance, it breaks to pieces with a crackling noise.

Its specific gravity is 1,990.

Oxide of sulphur.

When heated to the temperature of 185° of Fahrenheit, it melts and becomes very fluid. If the heat be continued for some time longer, the sulphur becomes gradually thick and viscid. When in this state, if it be poured into a bason of water, it will be found to be of a red colour, and as soft as wax. In this state it is employed to take off impressions from seals and medals. These casts are known in this country by the name of *sulphurs*. When exposed to the air for a few days, the

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* Pliny, lib. xxxv. c. 15.

sulphur soon recovers its original brittleness, but it retains its red colour. It has been ascertained, that sulphur, rendered viscid and red by a long fusion, has combined with a little oxygen. It is therefore no longer pure sulphur, but a compound of sulphur and oxygen. Mr Fourcroy, a celebrated French chemist, who has contributed with much zeal and success to the rapid improvement of chemistry, has given it, when in this state, the name of *oxide of sulphur*.

Flowers of sulphur.

When sulphur is heated to the temperature of 170°, it rises up in the form of a fine powder, which may be easily collected in a proper vessel. This powder is called *flowers of sulphur* *. When substances fly off in this manner on the application of a moderate heat, they are called *volatile;* and the process itself, by which they are raised, is called *volatilization*.

Sulphur undergoes no change by being allowed to remain exposed to the open air. When thrown into water, it does not melt as common salt does, but falls to the bottom, and remains there unchanged: It is therefore insoluble in water.

Sulphur capable of crystallizing.

There are a great many bodies which, after being dissolved in water or melted by heat, are capable of assuming certain regular figures. If a quantity of common salt, for instance, be dissolved in water, and that fluid, by the application of a moderate heat, be made to fly off in the form of steam; or, in other words, if the water be slowly *evaporated*, the salt will fall to the bottom of the vessel in cubes. These regular figures are called

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* It is only in this state that sulphur is to be found in commerce tolerably pure; *roll sulphur* usually contains a considerable portion of foreign bodies.

crystals. Now sulphur is capable of crystallizing. If it be melted, and as soon as its surface begins to congeal, the liquid sulphur beneath be poured out, the internal cavity will exhibit long needle-shaped crystals of an octahedral figure. This method of crystallizing sulphur was contrived by Rouelle.

Converted by combustion into an acid.

When sulphur is heated to the temperature of 302° in the open air, it takes fire spontaneously, and burns with a pale blue flame, and at the same time emits a great quantity of fumes of a very strong suffocating odour. When heated to the temperature of 570°, or when set on fire and then plunged into a jar full of oxygen gas, it burns with a bright white flame, and at the same time emits a vast quantity of fumes. If the heat be continued long enough, the sulphur burns all away without leaving any ashes or *residuum*. If the fumes be collected, they are found to consist entirely of *sulphuric acid.* By combustion, then, sulphur is converted into an acid *. This fact was known several centuries ago, but no intelligible explanation was given of it till the time of Stahl. That chemist undertook the task, and founded on his experiments a theory so exceedingly ingenious, and supported by such a vast number of facts, that it was in a very short time adopted with admiration by all the philosophic world, and contributed not a little to raise chemistry to that rank among the sciences from which the ridiculous pretensions of the early chemists had excluded it.

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* Acids are a class of compound bodies to be afterwards described. They are distinguished by a sour taste, and by the property which they possess of changing the blue colour of many vegetable infusions (of the flowers of mallows for instance, or red cabbage) to red.

Stahl's explanation of this

According to Stahl, there is only one substance in nature capable of combustion, which therefore he called PHLOGISTON; and all those bodies which can be set on fire contain less or more of it. Combustion is merely the separation of this substance. Those bodies which contain none of it are of course incombustible. All combustibles, except those which consist of pure phlogiston (if there be any such), are composed of an incombustible body and phlogiston united together. During combustion the phlogiston flies off, and the incombustible body remains behind. Now when sulphur is burnt, the substance which remains is sulphuric acid, an incombustible body. Sulphur therefore is composed of sulphuric acid and phlogiston.

To establish this theory completely, it was necessary to shew that sulphur could be actually made by combining sulphuric acid and phlogiston; and this also Stahl undertook to perform. *Sulphat of potass* is a substance composed of sulphuric acid and potass*, and *charcoal* is a combustible body, and therefore, according to the theory of Stahl, contains phlogiston: when burnt, it leaves a very inconsiderable residuum, and consequently contains hardly any thing else than phlogiston. He melted together in a crucible a mixture of *potass* and *sulphat of potass*, stirred into it one-fourth part by weight of pounded charcoal, covered the crucible with another inverted over it, and applied a strong heat to it. He then allowed it to cool, and examined its contents. The charcoal had disappeared, and there only remained in the crucible a mixture of potass and sulphur combi-

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* The nature of *potass* shall afterwards be explained. It is the *potash* well known in commerce in a state of purity.

ned together, and of a darker colour than usual, from the residuum of the charcoal. Now there were only three substances in the crucible at first, potass, sulphuric acid, and charcoal: two of these have disappeared, and *sulphur* has been found in their place. Sulphur then must have been formed by the combination of these two. But charcoal consists of phlogiston and a very small residuum, which is still found in the crucible. The sulphur then must have been formed by the combination of sulphuric acid and phlogiston. This simple and luminous explanation appeared so satisfactory, that the composition of sulphur was long considered as one of the best demonstrated truths in chemistry.

Unsatisfactory.

There are two facts, however, which Stahl either did not know, or did not sufficiently attend to, neither of which were accounted for by his theory. The first is, that sulphur will not burn if air be completely excluded; the second, that sulphuric acid is heavier than the sulphur from which it was produced.

To account for these, or facts similar to these, succeeding chemists refined upon the theory of Stahl, deprived his phlogiston of *gravity*, and even assigned it a principle of *levity*. Still, however, the necessity of the contact of air remained unexplained. At last Mr Lavoisier, who had already distinguished himself by the extensiveness of his views, the accuracy of his experiments, and the precision of his reasoning, undertook the examination of this subject, and his experiments were published in the Memoirs of the Academy of Sciences for 1777. He put a quantity of sulphur into a large glass vessel filled with air, which he inverted into another vessel containing mercury, and then set fire to the sulphur by means of a burning glass. It

Real explanation by Lavoisier.

emitted a blue flame, accompanied with thick vapours, but was very soon extinguished, and could not be again kindled. There was, however, a little sulphuric acid formed, which was a good deal heavier than the sulphur which had disappeared; there was also a diminution in the air of the vessel proportional to this increase of weight. The sulphur, therefore, during its conversion into an acid, must have absorbed part of the air. He then put a quantity of sulphuret of iron, which consists of sulphur and iron combined together, into a glass vessel full of air, which he inverted over water*. The quantity of air in the vessel continued diminishing for eighteen days, as was evident from the ascent of the water to occupy the space which it had left; but after that period no farther diminution took place. On examining the sulphuret, it was found somewhat heavier than when first introduced into the vessel, and the air of the vessel wanted precisely the same weight. Now this air had lost all its oxygen; consequently the whole of that oxygen must have entered into the sulphuret. Part of the sulphur was converted into sulphuric acid; and as all the rest of the sulphuret was unchanged, the whole of the increase of weight must have been owing to something which had entered into that part of the sulphur which was converted into acid. This something we know was oxygen. Sulphuric acid therefore must be composed of sulphur and oxygen; for as the original weight of the whole contents of the vessel remained exactly the same, there was not the smallest reason to suppose that any substance had left the sulphur.

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* This experiment was first made by Scheele, but with a different view.

It is impossible, then, that sulphur can be composed of sulphuric acid and phlogiston, as Stahl supposed; since sulphur itself enters as a part into the composition of that acid. There must therefore have been some want of accuracy in the experiment by which Stahl proved the composition of sulphur, or at least some fallacy in his reasonings; for it is impossible that there can be two contradictory facts. Upon examining the potass and sulphur produced by Stahl's experiment, we find them to be considerably lighter than the charcoal, sulphuric acid, and potass originally employed. Something therefore has made its escape during the application of the heat. And if the experiment be conducted in a close vessel, with a pneumatic apparatus attached to it, a quantity of gas will be obtained exactly equal to the weight which the substances operated on have lost; and this weight considerably exceeds that of all the charcoal employed. This gas is *carbonic acid gas,* which is composed of charcoal and oxygen, as will afterwards appear. We now perceive what passes in this experiment: Charcoal has a stronger affinity for oxygen at a high temperature than sulphur has. When charcoal therefore is presented to sulphuric acid in that temperature, the oxygen of the acid combines with it, they fly off in the form of carbonic acid gas, and the sulphur is left behind.

The combustion of sulphur, then, is nothing else than the act of its combination with oxygen; and for any thing which we know to the contrary, it is a simple substance.

The affinities of sulphur, according to Bergman, are as follows:

Affinities of sulphur.

Fixed alkalies,
Iron,
Copper,
Tin,
Lead,
Silver,
Biſmuth,
Antimony,
Mercury,
Arſenic,
Molybdenum.

SECT. II.

OF PHOSPHORUS.

Method of preparing phosphorus.

Let a quantity of bones be burnt, or, as it is termed in chemistry, *calcined*, till they ceaſe to smoke, or to give out any odour, and let them afterwards be reduced to a fine powder. Put this powder into a baſon of porcelain or stoneware, dilute it with four times its weight of water, and then add gradually (stirring the mixture after every addition) two-fifths of the weight of the powder of sulphuric acid. The mixture becomes hot, and a vast number of air-bubbles are extricated *. Leave the mixture in this state for 24 hours; taking care to stir it well every now and then with a glass or porcelain rod to enable the acid to act upon the powder.

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* The copious emission of air-bubbles is called in chemistry *effervescence*.

The whole is now to be poured on a filter of cloth; the liquid which runs through the filter is to be received in a porcelain bason; and the white powder which remains on the filter, after pure water has been poured on it repeatedly, and allowed to strain into the porcelain bason below, being of no use, may be thrown away.

Into the liquid contained in the porcelain bason, which has a very acid taste, sugar of lead is to be poured slowly; a white powder immediately falls to the bottom: the sugar of lead must be added as long as any of this powder continues to be formed. Throw the whole upon a filter. The white powder which remains upon the filter is to be well washed, allowed to dry, and then mixed with about one-sixth of its weight of charcoal powder. This mixture is to be put into the earthen ware retort (fig. 3.) The retort is to be put into a sand bath*, and the beak of it plunged into a vessel of water, so as to be just under the surface. The whole of the apparatus is represented in fig. 5. Heat is now to be applied gradually till the retort be made red hot. A vast number of air-bubbles issue from the beak of the retort, some of which take fire when they come to the surface of the water. At last there drops out a substance which has the appearance of melted wax, and which congeals under the water †. This substance is *phosphorus*.

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* By a *sand bath* is meant, in chemistry, an iron pot (or any similar vessel) filled with sand. Glass or porcelain vessels are plunged into the sand, and then heat is applied to the pot. The use of the sand is to apply the heat more equally; in consequence of which, the vessels are not so apt to crack and break.

† The theory of this process will be explained afterwards.

History of its discovery.

It was accidentally discovered by Brandt, a chemist of Hamburgh, in the year 1669 *, as he was attempting to extract from human urine a liquid capable of converting silver into gold. He showed a specimen of it to Kunkel, a German chemist of considerable eminence, who mentioned the fact as a piece of news to one Kraft, a friend of his at Dresden. Kraft immediately repaired to Hamburgh, and purchased the secret from Brandt for 200 dollars, exacting from him at the same time a promise not to reveal it to any other person. Soon after, he exhibited his phosphorus publicly in Britain and France, expecting doubtless that it would make his fortune. Kunkel, who had mentioned to Kraft his intention of getting possession of the process, being vexed at the treacherous conduct of his friend, attempted to discover it himself; and about the year 1674 he succeeded, though he only knew from Brandt that urine was the substance from which phosphorus was procured †. Accordingly he is always reckoned, and deservedly too, as one of the discoverers of phosphorus.

Boyle likewise discovered phosphorus. Leibnitz indeed affirms, that Kraft taught Boyle the whole process, and Kraft declared the same thing to Stahl. But surely the assertion of a dealer in secrets, and one who had deceived his own friend, on which the whole of this story is founded, cannot be put in competition with the affirmation of a man like Boyle, who was not on-

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* Homberg, *Mem. Par.* 1692.

† This is Kunkel's own account. See his *Laboratorium Chymicum*, p. 660. See also Wiegleb's *Geschichte des Wachsthums und der Erfindungen in der Chemie*, vol. i. p. 41.

ly one of the greatest philosophers, but likewise one of the most virtuous men of his age; and he positively assures us, that he made the discovery without being previously acquainted with the process [*].

Mr Boyle revealed the process to Godfrey Hankwitz, a London apothecary, who continued for many years to supply all Europe with phosphorus. Hence it was known to chemists by the name of *English phosphorus.* Other chemists, indeed, had attempted to produce it, but seemingly without success [†], till in 1737 a stranger appeared in Paris, and offered to make phosphorus. The French government granted him a reward for communicating his process. Hellot, Dufay, Geoffroy, and Duhamel, saw him execute it with success; and Hellot published a very complete account of it in the Memoirs of the French Academy for 1737. This process was much improved in 1740 by Margraf [‡], but it still continued very tedious, expensive, and disgusting.

In the year 1769, Gahn, a Swedish chemist, discovered, that phosphorus is contained in bones [§]; and Scheele [‖], very soon after, invented a process for obtaining it from them. Phosphorus is now generally procured in that manner. The process described in the beginning of this Section is that of Fourcroy

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[*] Boyle's *Works* abridged by Shaw, iii. 174.

[†] Stahl's *Fundament. Chym.* ii. 58.

[‡] *Miscelan. Berolin*, 1740, iii. 294. and *Mem. Acad. Berlin*, 1746, 289.

[§] Bergman's *Notes on Scheffer.*

[‖] Crell, in his life of Scheele, informs us, that Scheele himself was the discoverer of the fact. This, he says, appears clearly from a printed letter of Scheele to Gahn, who was before looked upon as the discoverer. See *Crell's Annals*, English Trans. i. 17.

and Vauquelin[*]: it differs from that of Scheele, as will appear afterwards in several particulars.

Its properties.

Phosphorus, when pure, is of a clear, transparent, yellowish colour; but when kept some time in water, it becomes opaque internally, and then has a great resemblance to white wax. Its consistence is nearly that of wax: it may be cut with a knife, or twisted to pieces with the fingers. It is insoluble in water. Its specific gravity is 1,714.

It melts at the temperature of 99°[†]. Care must be taken to keep phosphorus when melted under water; for it is so combustible, that it cannot be melted in the open air without taking fire. When phosphorus is newly prepared, it is always dirty, being mixed with a quantity of charcoal dust and other impurities. These impurities may be separated by melting it under water, and squeezing it while melted through a piece of clean shamoy leather. It may be formed into sticks, by putting it into a glass funnel with a long tube, stopped at the bottom with a cork, and plunging the whole under warm water. The phosphorus melts, and assumes the shape of the tube. When cold, it may be easily pushed out with a bit of wood.

If air be excluded, phosphorus evaporates at 219°, and boils at 554°[‡].

Burns when exposed to the air.

When phosphorus is exposed to the atmosphere, provided the temperature be not lower than 43°, it emits a white smoke, which has the smell of garlic, and is luminous in the dark. This smoke is more abundant the higher the temperature is, and is occasioned by the

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[*] Fourcroy's *Systeme de Connaissances Chimique*, ix. 285.

[†] Pelletier, *Journal de Physique*, xxxv. 380.

[‡] Ibid. p. 381.

gradual combustion of the phosphorus, which at last disappears altogether.

When a bit of phosphorus is put into a glass jar filled with oxygen gas, part of the phosphorus is dissolved by the gas at the temperature of 60°; but the phosphorus does not become luminous unless its temperature be raised to 80°*. Hence we learn, that phosphorus burns at a lower temperature in common air than in oxygen gas. This slow combustion of phosphorus, at the common temperature of the atmosphere, renders it necessary to keep phosphorus in phials filled with water. The water should be previously boiled to expel a little air, which that liquid usually contains. The phials should be kept in a dark place; for when phosphorus is exposed to the light, it soon becomes of a dark brown colour. When thus altered, the French chemists give it the name of *oxide of phosphorus;* because it is now no longer pure phosphorus, but phosphorus combined with a little oxygen. Phosphorus, when newly prepared, always contains some of this oxide of phosphorus mixed with it; but it may be easily separated by plunging the mass into water heated to about 100°. The phosphorus melts, while the oxide remains unchanged, and swims upon the surface of the melted phosphorus.

Oxide of phosphorus.

When heated to 122°†, phosphorus burns with a very bright flame, and gives out a great quantity of white smoke, which is luminous in the dark; at the same time it emits an odour which has some resemblance to

Converted by combustion

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* Fourcroy and Vauquelin, *Annales de Chimie*, xxi. 196.

† Morveau, *Encyc. Method. Chimie*, art. *Affinité.*—According to Nicholson, at 160°. See his *Translation of Chaptal.*

that of garlic. It leaves no residuum; but the white smoke, when collected, is found to be an *acid.* Stahl considered this acid as the muriatic [*]. According to him, phosphorus is composed of muriatic acid and phlogiston, and the combustion of it is merely the separation of phlogiston. He even declared, that to make phosphorus, nothing more is necessary than to combine muriatic acid and phlogiston; and that this composition is as easily accomplished as that of sulphur itself [†].

These assertions having gained implicit credit, the composition and nature of phosphorus were considered as completely understood, till Margraf of Berlin published his experiments in the year 1740. That great man, one of those illustrious philosophers who have contributed so much to the rapid increase of the science, distinguished equally by the ingenuity of his experiments and the clearness of his reasoning, attempted to produce phosphorus by combining together phlogiston and muriatic acid; but though he varied his process a thousand ways, presented the acid in many different states, and employed a variety of substances to furnish phlogiston, all his attempts failed, and he was obliged to give up the combination as impracticable. On examining the acid produced during the combustion of phosphorus, he found that its properties were very different from those of muriatic acid. It was therefore a distinct substance. The name of *phosphoric acid* was given to it; and it was concluded that phosphorus is composed of this acid united to phlogiston.

Into phosphoric acid,

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[*] This acid shall be afterwards described.

[†] Stahl's *Three Hundred Experiments*,

But it was observed in 1772 by Morveau*, that phosphoric acid is heavier than the phosphorus from which it was produced†; and Boyle had long before shewn that phosphorus would not burn except when in contact with air. These facts were sufficient to prove the inaccuracy of the theory concerning the composition of phosphorus; but they remained themselves unaccounted for, till Lavoisier published those celebrated experiments, which threw so much light on the nature and composition of acids‡.

Which is phosphorus combined with oxygen.

He exhausted a glass globe of air by means of an air-pump; and after weighing it accurately, he filled it with oxygen gas, and introduced into it 100 grains of phosphorus. The globe was furnished with a stop-cock, by which oxygen gas could be admitted at pleasure. He set fire to the phosphorus by means of a burning glass. The combustion was extremely rapid, accompanied by a bright flame and much heat. Large quantities of white flakes attached themselves to the inner surface of the globe, and rendered it opaque; and these at last became so abundant, that notwithstanding the constant supply of oxygen gas, the phosphorus was extinguished. The globe, after being allowed to cool, was again weighed before it was opened. The quantity of oxygen employed during the experiment was ascertained, and the phosphorus, which still remained unchanged, accurately weighed. The white flakes, which were nothing else than pure phosphoric acid, were found

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* *Digress. Academ.* p. 253.

† The same observation had been made by Margraf, but no attention was paid to it.

‡ *Mem. Par.* 1778 and 1780.

exactly equal to the weights of the phosphorus and oxygen, which had disappeared during the process. Phosphoric acid therefore must have been formed by the combination of these two bodies; for the absolute weight of all the substances together was the same after the process as before it*. It is impossible then that phosphorus can be composed of phosphoric acid and phlogiston, as phosphorus itself enters into the composition of that acid.

Thus the combustion of phosphorus, like that of sulphur, is nothing else than its combination with oxygen: for during the process no new substance appears, except the acid, accompanied indeed with much heat and light.

Phosphuret of sulphur.

Phosphorus combines readily with sulphur, as Margraf discovered during his experiments on phosphorus. This combination was afterwards examined by Mr Pelletier. The two substances are capable of being mixed in different proportions. Seventy-two grains of phosphorus and nine of sulphur, when heated in about four ounces of water, melt with a gentle heat. The compound remains fluid till it be cooled down to 77°, and then becomes solid. These substances were combined in the same manner in the following proportions:

72 Phosphor. 18 Sulphur	congeals at	59°
72 Phosphor. 36 Sulphur	...... at	50°
72 Phosphor. 72 Sulphur	...... at	41°
72 Phosphor. 216 Sulphur	...... at	99°

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* Lavoisier's *Chemistry*, Part I. chap. v.

Phosphorus and sulphur may be combined also by melting them together without any water; but the combination takes place so rapidly, that they are apt to rush out of the vessel if the heat be not exceedingly moderate[*].

Phosphorus is capable of combining also with many other bodies: the compounds produced are called *phosphurets*.

A poison.

Phosphorus, when used internally, is poisonous[†]. In very small quantities (as one-fourth of a grain), when very minutely divided, it is said by Leroi to be very efficacious in restoring and establishing the force of young persons exhausted by sensual indulgence[‡]; that is, I suppose, in exciting the venereal appetite.

The affinities of phosphorus have not yet been ascertained.

SECT. III.

OF CARBON OR DIAMOND.

Method of preparing charcoal.

If a piece of wood be put into a crucible, well covered with sand, and kept red hot for some time, it is converted into a black shining brittle substance, without either taste or smell, well known under the name of *charcoal*. Its properties are the same from whatever wood it has been obtained.

Charcoal is insoluble in water. It is not affected

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[*] Pelletier, *Journ. de Phys.* xxxv. 382.

[†] *Ann. de Chim.* xxvii. 87.

[‡] *Nicholson's Journal*, iii. 85.

(provided that all air be excluded) by the most violent heat which can be applied, excepting only that it is rendered much harder.

Its properties.

It is an excellent conductor of electricity, and possesses besides a number of singular properties which render it of considerable importance. It is incapable of putrifying or rotting like wood, and is not therefore liable to decay by age. This property has been long known. It was customary among the ancients to *char* the outside of those stakes which were to be driven into the ground or placed in water, in order to preserve the wood from spoiling. New-made charcoal, by being rolled up in cloths which have contracted a disagreeable odour, effectually destroys it. When boiled with meat beginning to putrify, it takes away its bad taint. It is perhaps the best teeth powder known. Mr Lowitz of Petersburgh has shown, that it may be used with advantage to purify a great variety of substances.

Absorbs water, air, and oxygen.

New-made charcoal absorbs moisture with avidity. When heated to a certain temperature, it absorbs air copiously. La Metherie plunged a piece of burning charcoal into mercury, in order to extinguish it, and introduced it immediately after into a glass vessel filled with common air. The charcoal absorbed four times its bulk of air. On plunging the charcoal into water, one-fifth of this air was disengaged. This air, on being examined, was found to contain a much smaller quantity of oxygen than atmospherical air does. He extinguished another piece of charcoal in the same manner, and then introduced it into a vessel filled with oxygen gas. The quantity of oxygen gas absorbed amounted to eight times the bulk of the charcoal; a fourth part of it was disengaged on plunging the charcoal into water [*].

This property of absorbing air, which new made charcoal possesses, was observed by Fontana, Priestley, Scheele, and Morveau; but Morozzo was the first philosopher who published an accurate set of experiments on the subject. He plunged a piece of red hot charcoal, 12 lines long and 8 in diameter, into a bason of mercury, and then made it ascend into a glass tube standing over the mercury. The tube was 144 lines long and 12 in diameter, and was filled with common air. The mercury rose in the tube 42 lines, consequently $\frac{1}{3.4}$ of the air was absorbed. When oxygen gas was substituted for common air, only $\frac{1}{6.4}$ of its bulk was absorbed [†].

These experiments have been lately repeated upon a larger scale by Mr Rouppe professor of chemistry at Rotterdam, and Dr Van Noorden of the same city. They filled a copper box, which was made air-tight, with red hot charcoal, allowed it to cool under water, then introduced it into a glass jar full of air. Seventeen cubic inches of charcoal absorbed, in five hours, 48 cubic inches of air: the same quantity, in 12 hours, absorbed 46 inches of oxygen gas [‡]. This absorption is much more considerable than could have been expected from former experiments.

From the experiments of Sennebier it was concluded, that charcoal, when exposed to the atmosphere, absorbs oxygen gas in preference to *azot*, as the other portion of common air is called [§]. But Rouppe and Van Noor-

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[*] *Journ. de Phys.* xxx. 309.

[†] *Journ. de Phys.* 1783.

[‡] *Ann. de Chim.* xxxii. 3.

[§] *Journ. de Phys.* xxx. 309.

den have shown, that this happens only when the charcoal is hot: cold charcoal, they found, absorbed atmospheric air unaltered.

How purified.

Common charcoal obtained by burning wood is not quite pure; but the impurities may be carried off by reducing it to powder, washing it repeatedly with pure water, and then drying it by means of a strong heat in close vessels.

Converted by combustion into carbonic acid gas.

When charcoal is heated to the temperature of 370°[*], it takes fire, and, provided it has been previously freed from the earths and salts which it generally contains, it burns without leaving any residuum. If this combustion be performed in close vessels filled with oxygen gas instead of common air, part of the charcoal and oxygen disappears, and in its room is found a particular gas exactly equal to it in weight. This gas has the properties of an acid, and has been called *carbonic acid gas*. Mr Lavoisier, to whom we are indebted for this discovery, ascertained, by a number of very accurate experiments, that this gas is composed of about 28 parts of charcoal and 72 of oxygen[†].

Composition of charcoal.

Lavoisier supposed pure charcoal to be a simple substance, and for that reason invented the term *carbon* to distinguish it. But other philosophers were of opinion, that charcoal is a compound body, and that it is composed of carbon and oxygen. The truth of this opinion, which, as far as I know, was first maintained by Dr Bancroft[‡], has been lately established by the experiments of Mr Guyton-Morveau.

The *diamond* is a precious stone, which has been

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[*] Morveau, *Encyc. Method.* art. *Affinité.*

[†] *Mem. Par.* 1781, p. 448.

[‡] *Philosophy of Permanent Colours*, i. 48.

Properties of the diamond.

known from the remotest ages. When pure, it is perfectly transparent like crystal, but much more brilliant. Its figure varies considerably; but most commonly it is crystallized in the form of a six-sided prism, terminated by a six-sided pyramid. It is the hardest of all bodies; the best tempered steel makes no impression on it; diamond powder can only be obtained by grinding one diamond against another. Its specific gravity is about 3.5. It is a non-conductor of electricity.

Burns,

As the diamond is not affected by a considerable heat, it was for many ages considered as incombustible. Sir Isaac Newton, observing that combustibles refract light more powerfully than other bodies, and that the diamond possesses this property in great perfection, suspected it, from that circumstance, to be capable of combustion. This singular conjecture was verified in 1694 by the Florentine academicians, in the presence of Cosmo III. Grand Duke of Tuscany. By means of a burning-glass, they consumed several diamonds. Francis I. Emperor of Germany, afterwards witnessed the destruction of several more in the heat of a furnace. These experiments were repeated by Rouelle, Macquer, and Darcet; who proved that the diamond was not merely evaporated, but actually burnt, and that if air was excluded it underwent no change *.

And forms carbonic acid gas.

No attempt, however, was made to ascertain the product till 1772. Lavoisier, in a Memoir published that year, shewed that when the diamond is burnt, carbonic acid gas is obtained, and that there is a striking analogy between it and charcoal †. In 1785, Guyton-Morveau

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* *Mem. Par.* 1766, 1770, 1771, 1772.

† *Lavoisier*, iii. 160.

found that the diamond is combustible when dropped into melted nitre; that it burns without leaving any residuum, and in a manner analogous to charcoal *. This experiment was repeated with more precision by Mr Tennant in 1797 †. The conclusion which he drew from it was, that when a diamond is burnt, the whole of the product is carbonic acid gas; that a given weight of diamond yields just as much carbonic acid gas as the same weight of charcoal; and that diamond and charcoal are both composed of the very same substance.

Differs from charcoal.

This conclusion, that diamond is nothing else but charcoal, was directly contrary to what one would have expected from comparing the two substances together. Their colour, hardness, specific gravity, and electrical properties, are exceedingly different; nor do they resemble each other more nearly in their combustibility. Charcoal takes fire at 370°, gives out a great deal of heat, and when once kindled in oxygen gas continues to burn till it be wholly consumed. The diamond, before it can be burnt, must be exposed to the sun's rays in the focus of a large burning glass, or to a heat not under 5000° ‡: even then it consumes but slowly, and ceases to burn the instant the action of the burning glass is withdrawn. Its surface assumes a black colour

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* *Encyc. Method. Chim.* i. 742. † *Phil. Trans.* 1797, p. 123.

‡ Sir George M'Kenzie, however, found, that diamonds will burn in a muffle when heated no higher than 14° or 15° Wedgwood, which must be considerably lower than 5000° Fahrenheit. *Nicholson's Journal*, iv. 104. As his experiment was made on purpose to ascertain the precise temperature at which the diamond burns, it is more to be depended on than the calculations of Morveau, who does not inform us on what data he goes.

like charcoal; this crust is soon wasted, and another is formed in its place. It was in this manner that a diamond weighing 3.089 gr. troy gradually wasted away completely when exposed by Morveau for 1 hour and 40 minutes in the focus of the celebrated burning glass of Tschirnhausen, while a thermometer exposed to the sun stood at 104°*.

Morveau found, that one part of diamond during its combustion combines with 4.592 parts of oxygen, and the carbonic acid gas formed amounts to 5.592 parts. Consequently carbonic acid gas is composed of one part of diamond and 4.592 of oxygen; or, which is the same thing, 100 parts of carbonic acid gas are composed of

17.88 Diamond,
82.12 Oxygen.

100.00 †

But Lavoisier ascertained, that one part of charcoal, when burnt, combines with 2.5714 parts of oxygen, and forms 3.5714 parts of carbonic acid gas. Consequently 100 parts of carbonic acid gas are composed of

28 Charcoal,
72 Oxygen.

100

But 100 parts of carbonic acid gas are also composed of 17.88 diamond and 82.12 oxygen. We have therefore this equation:

$$\overset{\text{Diamond.}}{17.88} + \overset{\text{Oxygen.}}{82.12} = \overset{\text{Charcoal.}}{28} + \overset{\text{Oxygen.}}{72}.$$

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* *Ann. de Chim.* xxxi. 90.

† Ibid. 99.

Consequently, subtracting 72 parts of oxygen from both sides of the equation, we have

$$\overset{\text{Diamond.}}{17.88} + \overset{\text{Oxygen.}}{10.12} = 28 \text{ charcoal.}$$

That is to say, 28 parts of charcoal are composed of 17.88 diamond and 10.12 oxygen. Of course, 100 parts of charcoal are composed of

63.85 Diamond,
36.15 Oxygen.

100.00

Diamond pure carbon.

Thus we see why diamond and charcoal possess different properties: the one is a simple substance; the other is a compound of the diamond and oxygen, or it is what the French chemists call an *oxide of diamond*. The diamond, then, is that substance in a state of purity to which Lavoisier and his associates gave the name of *carbon*; charcoal is not *carbon*, as they supposed, but the *oxide of carbon**.

Carburets.

Carbon unites with a number of bodies, and forms with them compounds, which have received the name of *carburets;* but the order of its affinities for these bodies has not been ascertained.

Neither carbon nor charcoal seem capable of combining with sulphur, at least no such combination is at present known, nor has any attempt made to form it succeeded.

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* We see here the danger of introducing new terms before we are acquainted with the substances which they are intended to represent. *Carbon* is now merely a useless synonyme for *diamond*. I shall use it, however, in preference; because it prevents the necessity of altering the numerous terms derived from carbon, such as *carbonic*, *carburet*, *carbonat*, *carbonated*.

Phosphuret of carbon.

Phosphorus is capable of combining with carbon, or rather with charcoal. This compound, which has received the name of *phosphuret of carbon*, was first examined by Mr Proust, the celebrated Professor of chemistry at Segovia in Spain. It is the red substance which remains behind when new-made phosphorus is strained through shamoy leather. In order to separate from it a small quantity of phosphorus which it contains in excess, it should be put into a retort and exposed for some time to a moderate heat. What remains behind in the retort is the pure phosphuret of carbon. It is a light, flocky powder, of a lively orange red, without taste or smell. When heated in the open air it burns rapidly, and a quantity of charcoal remains behind. When the retort in which it is formed is heated red hot, the phosphorus comes over, and the charcoal remains behind[*].

SECT IV.

OF HYDROGEN.

Method of procuring hydrogen gas.

PUT into the glass vessel A (fig. 6.), furnished with two mouths, a quantity of fresh iron filings, quite free from rust. Lute into one of these mouths the end of a crooked glass tube. Insert the other end of this tube below a glass jar filled with water, and inverted into a pneumatic tub. Then pour upon the iron filings a

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[*] *Ann. de Chim.* xxxiv. 44.

quantity of sulphuric acid, diluted with four times its own weight of water, and close up the mouth of the vessel. Immediately the iron filings and acid effervesce with violence, a vast quantity of gas is produced, which rushes through the tube and fills the jar. This gas is called *hydrogen gas*. It was formerly called *inflammable air*, and by some chemists *phlogiston*.

It was obtained by Dr Mayow and by Dr Hales from various substances, and had been known long before in mines under the name of the *fire damp*. But Mr Cavendish ought to be considered as its real discoverer; since it was he who first examined it, who pointed out the difference between it and atmospheric air, and who ascertained the greatest number of its properties*. They were afterwards more fully investigated by Priestley, Scheele, Sennebier, and Volta.

Its properties.

Hydrogen, like *air*, is invisible and elastic, and capable of indefinite compression and dilatation.

Its specific gravity differs according to its purity. Kirwan found it 0.00010†; Lavoisier 0.000094‡, or about 12 times lighter than common air.

All burning substances are immediately extinguished by being plunged into this gas. It is incapable therefore of supporting combustion.

Destroys life.

Animals, when they are obliged to breathe it, die almost instantaneously. Scheele indeed found that he could breath it for some time without much inconvenience §; but Fontana, who repeated the experiment, discovered that this was owing to the quantity of common air contained in the lungs when he began to breathe; for on

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[*] Phil. Trans. lvi. 141.

[†] On Phlogiston, Sect. i.

[‡] Lavoisier's Chemistry, Appendix.

[§] Scheele on Fire, p. 160.

expiring as strongly as possible before drawing in the hydrogen gas, he could only make three respirations, and even these three produced extreme feebleness and oppression about the breast*.

The ingenious Mr Davy of Bristol, to whom we are indebted for many curious and important, but rather hazardous experiments on respiration, made chiefly upon himself, after a complete voluntary exhaustion of his lungs, found great difficulty in breathing this gas for so long as half a minute. It produced uneasy feelings in the chest, momentary loss of muscular power, and sometimes a transient giddiness †. But when he did not previously empty his lungs, he was able to breathe it for about a minute without much inconvenience ‡. When much diluted with common air, it may be breathed without injury.

Combustible.

If a phial be filled with hydrogen gas, and a lighted candle be brought to its mouth, the gas will take fire, and burn gradually till it is all consumed. If the hydrogen gas be pure, the flame is of a white colour; but if the gas holds any substance in solution, which is often the case, the flame is tinged of different colours, according to the substance. It is most usually reddish, because the gas holds in solution a little charcoal.

If pure oxygen and hydrogen gas be mixed together, they remain unaltered; but if a lighted taper be brought into contact with them, or an electric spark made to pass through them, they burn with astonishing rapidity, and produce a violent explosion. If these two gases be mixed in the proportion of one part in bulk of oxygen gas and two parts of hydrogen gas, or, more accu-

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* *Journ. de Phys.* xv. 99.

† Davy's Researches. p. 400.

‡ Ibid. p. 465.

Explodes with oxygen gas and forms water.

rately, 85 parts by weight of oxygen gas and 15 of hydrogen gas, they explode over water without leaving any visible residuum; the vessel in which they were contained (provided the gases were pure) being completely filled with water. But if the explosion be made in a close vessel, there is always found instead of them a quantity of water exactly equal to them in weight. This water must be composed of these two gases; for it did not previously exist in the vessel, and no other substance besides the gases was introduced. Water then is composed of oxygen and hydrogen; and the combustion of hydrogen is nothing else but the act of its combination with oxygen *.

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When two parts (in bulk) of hydrogen gas are mixed with five parts of common air, the mixture explodes with equal violence; and after the explosion, the bulk of the mixture is reduced to five parts. The whole of the hydrogen gas is consumed, and likewise all that part of the common air which consists of oxygen gas, and there is formed a quantity of water equal in weight to these two bodies. This experiment is often employed to ascertain the purity of hydrogen gas. Common air and the hyrogen gas to be examined are mixed in

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* The history of this great discovery, and the objections which have been made to it, will be given in the Chapter which treats of WATER, where they will be better understood than they can be at present. This substance was called *hydrogen* by the French chemists, because it enters into the composition of water, from *'υδωρ water*, and *γινομαι I am born*. Objections have been made to the propriety of the name, into which I shall not enter. It ought never to be forgotten, that Newton had long before, with a sagacity almost greater than human, conjectured, from its great refracting power, that water *contains a combustible substance*.

certain proportions in a glass tube, graduated and close at one end; they are then fired by an electric spark. The purity of the gas is proportional to the diminution of bulk. Thus, when the bulk of a mixture of two parts hydrogen gas and six parts air is diminished after the explosion to five parts, the hydrogen gas may be considered as pure; if only to six, it contains some foreign ingredients, and so on. This method of detecting the purity of hydrogen gas was first employed by Berthollet. Volta, indeed, had employed it before him; but for a different purpose [*].

It had been supposed, in consequence of the experiments of Dr Priestley and several other philosophers, that when hydrogen gas is allowed to remain in contact with water, it is gradually decomposed, and converted into another gas; but Mr de Morveau [†], Mr Hassenfratz [‡], and Mr Libes [§], have shewn, that it undergoes no change, provided sufficient care be taken to exclude every other gas.

Hydrogen gas dissolves sulphur, phosphorus, and carbon. The compounds are called *sulphurated*, *phosphorated*, and *carbonated hydrogen gas*.

Sulphurated hydrogen gas,

1. Sulphurated hydrogen gas may be obtained by melting with a burning glass sulphur inclosed in a jarful of hydrogen gas, or by making hydrogen gas pass through melted sulphur. The hydrogen gas dissolves part of the sulphur, and is converted into sulphurated hydrogen gas. But this gas is more usually obtained by the following process.

How obtained.

Melt together, in a crucible, equal parts of iron

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[*] Crell's *Annals*, 1785, ii. 287.

[†] *Encyc. Method. Chim.* i. 754.

[‡] *Ann. de Chim.* i. 192.

[§] *Jour. de Phys.* xxxvi. 412.

filings and sulphur; the product is a black brittle mass. Reduce this to powder, and put it, with a little water, into a glass vessel with two mouths. Lute a crooked glass tube to one of these mouths, and let the other extremity of it pass under a glass jar full of water. Pour muriatic acid through the other mouth, and then immediately close it up. Sulphurated hydrogen gas is disengaged abundantly, and fills the glass jar.

This gas was first examined by Rouelle junior in 1773 [*]. But Scheele and Bergman were the chemists who first published an account of its properties. Scheele, in his Treatise *on Fire*, in 1777 [†], and Bergman, in his Dissertation *on Artificial Hot Mineral Waters*, in 1778 [‡]. Mr Kirwan published a very copious and ingenious set of experiments on it in 1785; and in 1794, Berthollet, with his usual skill, still farther developed its properties. It was long known by the name of *hepatic gas*, because the substances from which it was first obtained were at that time called *hepars*, or *livers of sulphur*.

Its properties.

The specific gravity of sulphurated hydrogen gas is 0.00135 [§]; it is to common air as 1106 to 1000.

It has a very fetid odour, precisely similar to that emitted by rotten eggs, which indeed is owing to the emission of the very same gas.

It is not more respirable than hydrogen gas. When set on fire, in contact with oxygen gas, it burns with a light blue flame, without exploding, and at the same time a quantity of sulphur is deposited. The combustion of this gas, then, is merely the union of its

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[*] Fourcroy, *Connaiss. Chim.* i. 32.

[†] P. 186. English trans.

[‡] Bergman, *Opuscula*, i. 233.

[§] Kirwan on *Phlogiston*, Sect. i.

hydrogen, and perhaps part of its sulphur, with oxygen.

This gas is absorbed readily by water; but as it possesses the properties of an acid, a detailed account of its properties belongs to a different part of this Work*. We learn, from the experiments of Thenart, that it is composed of

70.857	Sulphur,
29 143	Hydrogen†.
100.000	

This gas has the property of dissolving a small quantity of phosphorus. Nothing more is necessary than to allow bits of phosphorus to remain for some hours in glass jars filled with the gas. When common air is admitted to this compound, a very voluminous bluish flame is produced, owing evidently to the combustion of the dissolved phosphorus. When the hands or a sponge are plunged into it, they continue luminous in the air for some time after‡.

Phosphorous hydrogen gas.

2. When bits of phosphorus are kept for some hours in hydrogen gas, part of the phosphorus is dissolved. This compound gas, to which Fourcroy and Vauquelin, the discoverers of it, have given the name of *phosphorous hydrogen gas*, has a slight smell of garlic. When bubbles of it are made to pass into oxygen gas, a very brilliant bluish flame is produced, which pervades the whole vessel of oxygen gas. It is obvious that this flame is the consequence of the combustion of the dissolved phosphorus§.

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[*] Trommsdorf has given it the name of *hydrothionic acid*.

[†] *Ann. de Chim.* xxxii. 267.

[‡] Fourcroy and Vauquelin, *Ibid.* xxi. 206.

[§] *Ibid* xxi. 202.

Phosphorated hydrogen gas.

When phosphorus is introduced into a glass jar of hydrogen gas standing over mercury, and then melted by means of a burning glass, the hydrogen gas dissolves a much greater proportion of it. The new compound, thus formed, has received the name of *phosphorated hydrogen gas*. It was discovered in 1783 by Mr Gengembre [*]; and in 1784 by Mr Kirwan, before he became acquainted with the experiments of Gengembre. But for the fullest investigation of its properties, we are indebted to Mr Raymond, who published a dissertation on it in 1791 [†], and another in 1800 [‡]. These philosophers obtained the gas by a different process, which shall be afterwards described: but in whatever manner it is prepared, its properties are always the same.

Its properties.

It has a very fetid odour, exactly ſimilar to the smell of putrid fish. When it comes into contact with common air, it burns with great rapidity; and if mixed with that air, it detonates violently. Oxygen gas produces a still more rapid and brilliant combustion than common air. When bubbles of it are made to pass up through water, they explode in succession as they reach the surface of the liquid; a beautiful coronet of white smoke is formed, which rises slowly to the ceiling. This gas is the most combustible substance known. It is obvious, that its combustion is merely the combination of its phosphorus and its hydrogen with the oxygen of the atmosphere; the products, of course, are phosphoric acid and water. These two substances mixed, or rather combined, constitute the coronet of white smoke.

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[*] *Mem. Sçav. Etrang.* x.

[†] *Ann. de Chim.* x. 19.

[‡] *Ibid.* xxxv. 225.

Pure water, when agitated in contact with this gas, dissolves at the temperature of between 50° and 60° about the fourth part of its bulk of it. The solution is of a colour not unlike that of roll sulphur; it has a very bitter and disagreeable taste, and a strong unpleasant odour. When heated nearly to boiling, the whole of the phosphorated hydrogen gas is driven off unchanged, and the water remains behind in a state of purity. When exposed to the air, the phosphorus is gradually deposited in the state of red oxide; the hydrogen gas makes its escape; and at last nothing remains but pure water *.

Carbonated hydrogen gas,

3. Carbonated hydrogen gas rises spontaneously from the bottom of stagnant waters in hot weather, and may be easily collected in considerable quantity. It may be formed, too, by exposing charcoal in hydrogen gas to the rays of the sun †, or by distilling wet charcoal in a retort. It is formed also in abundance, when spirit of wine or ether is made to pass through red hot porcelain tubes ‡; and in many other processes to be afterwards described. This gas was formerly called *heavy inflammable air*.

It was first examined with attention by Volta. Dr Priestley soon after made experiments on different kinds of it; but its composition was first pointed out by Lavoisier; and for the most accurate analysis of it which has hitherto appeared, we are indebted to Mr Cruickshank of Woolwich §.

It differs considerably in its component parts, and of

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* Raymond, *Ann. de Chim.* xxxv. 233.

† Fourcroy, *Connaiss.* i. 181.

‡ Dutch chemists, *Ann de Chim.* xxi. 48.

§ Nicholson's *Journal*, v. 1.

course in its properties, according to the process by which it is obtained. Like common air it is invisible and elastic; like hydrogen gas, it is inflammable, and explodes when fired along with oxygen gas or common air; but the product is a mixture of water and carbonic acid. When exploded in a tube with these gases, the residuum occupies more room than the original mixture.

Different species of.

Carbonated hydrogen gas, obtained from stagnant water, from ether, from camphor, or from vegetable substances, contains most carbon. Its specific gravity is 0.000804. It is to common air as 155 to 235, or nearly as 2 to 3. It contains one part by weight of hydrogen gas, holding 5.5 parts of carbon in solution. One hundred parts of it in its usual state contain, according to Mr Cruickshank,

52.35	Carbon,
9.60	Hydrogen,
38.05	Water in the state of vapour.
100.00*[*]	

That obtained by distilling wet charcoal contains the least carbon, and of course is the lightest. Its specific gravity is 0.000554. It is to common air as 14.5 to 31, or nearly as 1 : 2. It contains one part (by weight) of hydrogen gas, holding in solution three parts of carbon. One hundred parts of it are composed of

28	Carbon,
9	Hydrogen,
63	Water.
100	

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[*] Nicholson's *Journal*, v. 8.

The specific gravity of the carbonated hydrogen gas obtained from ether is 0.000787. It is composed of

45 Carbon,
15 Hydrogen,
40 Water.

100

The specific gravity of the gas obtained from spirit of wine is 0.00063. It is composed of

44.1 Carbon,
11.8 Hydrogen,
44.1 Water.

100.0

These are the only species of carbonated hydrogen gas at present known, one only excepted, which is obtained from alcohol, by a peculiar process to be hereafter described.

The affinity of hyrogen gas for these three combustibles is as follows:

Sulphur,
Carbon,
Phosphorus *.

Austin's theory of the composition of carbon

Dr Austin found, that by repeatedly passing electric explosions through a small quantity of carbonated hydrogen gas, it was permanently dilated to more than twice its original bulk. He rightly concluded, that this remarkable expansion could only be owing to the

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* Sulphur decomposes carbonated hydrogen gas; therefore its affinity is greater than that of carbon. The Dutch chemists melted phosphorus in carbonated hydrogen gas, but no change was produced; therefore the affinity of phosphorus is inferior to that of carbon.

evolution of hydrogen gas. On burning air thus expanded, he found that it required a greater quantity of oxygen than the same quantity of gas not dilated by electricity: An addition therefore had been made to the combustible matter; for the quantity of oxygen necessary to complete the combustion of any body, is always proportional to the quantity of that body. He concluded from these experiments, that he had decomposed the carbon which had been dissolved in the hydrogen gas; and that carbon was composed of hydrogen and azot*; some of which was always found in the vessel after the dilated gas had been burnt by means of oxygen†. If this conclusion be fairly drawn, we must expunge *carbon* from the list of simple substances, and henceforth consider it as a compound.

Refuted.

There was one circumstance which ought to have prevented Dr Austin from drawing this conclusion, at least till warranted by more decisive experiments. The quantity of combustible matter had been increased. Now, if the expansion of the carbonated hydrogen gas was owing merely to the decomposition of carbon, no such increase ought to have taken place, but rather the contrary; for the carbon, which was itself a combus-

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* See next Section.—His theory was, that carbonated hydrogen gas was composed of hydrogen, and azot, and carbon of azot, and carbonated hydrogen gas, which comes nearly to the same thing with regard to the elements of carbon. It is singular enough, that though Dr Austin would not allow the presence of carbon in carbonated hydrogen gas, he actually decomposed it by melting sulphur in it: the sulphur combined with the hydrogen gas, and a quantity of carbon was precipitated. This experiment he relates without making any remarks upon it, and seems indeed not to have paid any attention to it.

† *Phil. Trans.* lxxx. 51.

tible substance, was resolved into two ingredients, hydrogen and azot, only the first of which burnt on the addition of oxygen and the application of heat. Dr Austin's experiments have been lately repeated by Mr William Henry with a great deal of accuracy *. He found, that the dilatation which Dr Austin describes actually took place, but that it could not be carried beyond a certain degree, a little more than twice the original bulk of the gas. Upon burning separately by means of oxygen, two equal portions of carbonated hydrogen gas, one of which had been expanded by electricity to double its original bulk, the other not, he found that each of them produced precisely the same quantity of *carbonic acid gas*. Both therefore contained the same quantity of carbon; consequently no carbon had been decompounded by the electric shocks.

Mr Henry then suspected that the dilatation was owing to the water which every gas contains in a larger or smaller quantity. To ascertain this, he endeavoured to deprive the carbonated hydrogen gas of as much water as possible, by making it pass over very dry potass, which attracts water with avidity. Gas treated in this manner could only be expanded one-sixth of its bulk; but on admitting a drop or two of water, the expansion went on as usual. The substance decompounded by the electricity, then, was not the carbon, but the water in the carbonated hydrogen gas. Nor is it difficult to see in what manner this decomposition is effected. Carbon at a high temperature has a greater affinity for oxygen than hydrogen has; for if the steam of water be made to pass over red hot charcoal, it is decomposed, and car-

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* *Phil. Trans.* 1797, Part ii.

bonic acid and hydrogen gas are formed. The electric explosion supplies the proper temperature; the carbon unites with the oxygen of the water, and forms carbonic acid; and the hydrogen, thus set at liberty, occasions the dilatation. Carbonic acid gas is absorbed with avidity by water: and when water was admitted into 709 measures of gas thus dilated, 100 measures were absorbed; a proof that carbonic acid gas was actually present. As to the azot which Dr Austin found in his dilated gas, it evidently proceeded from the admission of some atmospheric air, about 73 parts of which in the 100 consist of this gas: for Dr Austin's gas had stood long over water: and Drs Priestley and Higgins have shewn that air in such a situation always becomes impregnated with azot.

The affinities of hydrogen have not yet been ascertained; but perhaps they are as follows:

Oxygen,
Carbon,
Azot.

Hydrogen gas absorbed by charcoal.

Charcoal has the property of absorbing hydrogen gas, but it absorbs a smaller proportion of it than of any other gas hitherto tried. Morozzo found, that a bit of charcoal, 12 lines long and 8 in diameter, extinguished in mercury, and then plunged into a tube 144 lines long and 12 in diameter, and filled with hydrogen gas, absorbed $\frac{1}{5.5}$ of the whole. Rouppe and Van Noorden found, that new-made charcoal, allowed to cool without being exposed to the air, when plunged into hydrogen gas, absorbed about half its bulk of it. When charcoal, thus impregnated with hydrogen gas, is exposed to common air, the oxygen of the air is absorbed, combines with the hydrogen, and forms water.

The same phenomena present themselves when oxygen gas is employed instead of common air [*].

SECT. V.

OF AZOT.

Method of procuring azotic gas.

If a quantity of iron filings and sulphur, mixed together, and moistened with water, be put into a glass vessel full of air, it will absorb all the oxygen in the course of a few days; but a considerable residuum of air will still remain incapable of any farther diminution. This residuum has obtained the appellation of *azotic gas*. There are other methods of obtaining it more speedily. The most convenient is that discovered by Berthollet. Very much diluted *aquafortis*, or *nitrous acid* as it is called in chemistry, is poured upon a piece of muscular flesh, and a heat of about 100° applied. A great quantity of azotic gas is emitted, which may be received in proper vessels.

This gas was discovered in 1772 by Dr Rutherford now professor of botany in the university of Edinburgh [†].

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[*] *Ann. de Chim.* xxxii. 19.

[†] See his thesis *De Aere Mephitico*, published in 1772.—" Sed aer salubris et purus respiratione animali non modo ex parte fit mephiticus sed et *aliam indolis suæ mutationem inde patitur*. Postquam enim omnis aer mephiticus (*carbonic acid gas*) ex eo, ope lixivii caustici secretus et abductus fuerit, *qui tamen restat* nullo modo salubrior inde evadit; nam quamvis nullam ex aqua calcis præcipitationem faciat haud minus quam antea *et flammam et vitam extinguit*. Page 17.

Scheele procured it by the first mentioned process as early as 1776, and proved that it was a distinct fluid.

Exists in the atmosphere.

The air of the atmosphere contains about 0.73 parts of azotic gas; almost all the rest of it is oxygen gas. Mr Lavoisier was the first philosopher who published this analysis of air, and who made azotic gas known as a component part of air. His experiments were published in 1774, or rather 1775. Scheele undoubtedly was acquainted as early with the composition of air; but his Treatise on Fire, in which that analysis is contained, was not published till 1777.

Its properties.

Mr Kirwan examined the specific gravity of azotic gas obtained by Scheele's process; it was 0.00120: it is therefore somewhat lighter than the atmospheric air; it is to atmospheric air as 985 to 1000*. According to the experiments of Lavoisier, its specific gravity is only 0.00115, or it is to common air as 942.6 : 1000†.

This gas is invisible and elastic like common air; and like it too, capable of indefinite condensation and dilatation. It is exceedingly noxious to animals; if they are obliged to respire it, they drop down dead al-

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" Aer qui per carbones ignitos folle adactus fuit, atque deinde ab omni aere mephitico *(carbonic acid gas)* expurgatus, malignus tamen adhuc reperitur et omnino similis est ei qui respiratione inquinatur. Immo ab experimentis patet, hanc solam esse aeris mutationem quæ inflammationi adscribi potest. Si enim accenditur materies quælibet quæ ex phlogisto et basi ſixa atque simplici constat, *aer inde natus ne minimam aeris mephitici quantitatem in se continere videtur.* Sic aer in quo sulphur aut phosphorus urinæ combustus fuit, licet maxime malignus, calcem tamen ex aqua minime præcipitat. Interdum quidem si ex phosphoro natus fuerit, nubeculam aquæ calcis inducit sed tenuissimam, nec aeri mephitico attribuendam, sed potius acido illi quod in phosphoro inest, et quod, ut experimenta docuerunt, hoc singulari dote pollet." Page 19.

[*] *On Phlogiston*, § 1.

[†] *Ibid* p. 37.

most instantly *. No combustible will burn in it. Hence the reason why a candle is extinguished in atmospherical air as soon as the oxygen near it is consumed. Mr Goettling, indeed, published, in 1794, that phosphorus shone, and was converted into phosphoric acid, in pure azotic gas. Were this the case, it would not be true that no combustible will burn in this gas; for the conversion of phosphorus into an acid, and even its shining, is an actual though slow combustion. Mr Goettling's experiments were soon after repeated by Drs Scherer and Jaeger, who found, that phosphorus does not shine in azotic gas when it is perfectly pure; and that therefore the gas on which Mr Goettling's experiments were made had contained a mixture of oxygen gas, owing principally to its having been confined only by water. These results were afterwards confirmed by Professor Lampadius and Professor Hildebrandt. It is therefore proved beyond a doubt, that phosphorus does not burn in azotic gas, and that whenever it appears to do so, there is always some oxygen gas present †.

Sulphurated azotic gas.

When sulphur is melted in azotic gas, part of it is dissolved by the gas, and *sulphurated azotic gas* formed. This gas has a fetid odour. Its properties are still unknown ‡.

Phosphurated azotic gas.

Azotic gas very readily dissolves phosphorus plunged in it. Its bulk is increased about $\frac{1}{40}$ §, and *phosphorated azotic gas* is the result. When this gas is

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* Hence the name *azot*, given it by the French chemists, which signifies " destructive to life," from α and ζωη.

† Nicholson's *Journal*, ii. 8.

‡ Fourcroy, i. 200.

§ Berthollet.

mixed with oxygen gas, it becomes luminous, in consequence of the combustion of the dissolved phosphorus. The combustion is most rapid when bubbles of phosphorated azotic gas are let up into a jar full of oxygen gas. When phosphorated oxygen gas, and phosphorated azotic gas, are mixed together, no light is produced, even at the temperature of 82° *.

It dissolves also a little carbon: for azotic gas obtained from animal substances, by Berthollet's process, when confined long in jars, deposits on the sides of them a black matter, which has the properties of charcoal †.

Azot a component part of *ammonia.*

When mixed with hydrogen gas, it undergoes no change. It may, however, be combined with hydrogen, by processes which will be described hereafter. The compound formed is known by the name of *ammonia* or *volatile alkali.*

Combustible.

Azotic gas is capable of combustion. Take a glass tube, the diameter of which is about the sixth part of an inch; shut one of its ends with a cork, through the middle of which passes a small wire with a ball of metal at each end. Fill the tube with mercury, and then plunge its open end into a bason of that fluid. Throw up into the tube as much of a mixture, composed of 13 parts of azotic and 87 parts of oxygen gas, as will fill 3 inches. Through this gas make, by means of the wire in the cork, a number of electric explosions pass.

Product nitric acid.

The volume of gas gradually diminishes, and in its place there is found a quantity of *nitric acid.* This acid, therefore, is composed of azot and oxygen: and these

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* Fourcroy and Vauquelin, *Ann. de Chim.* xxi. 199.

† Fourcroy, *Ann. de Chim.* i. 45.

two substances are capable of combining, or, which is the same thing; azotic gas is capable of combustion in the temperature produced by electricity, which we know to be pretty high. The combustibility of azotic gas, and the nature of the product, was first discovered by Mr Cavendish, and communicated to the Royal Society on the 2d of June 1785.

Attempts to decompose azot.

The affinities of azot are still unknown. It has never yet been decompounded, and must therefore, in the present state of our knowledge, be considered as a simple substance. Dr Priestley, who obtained azotic gas at a very early period of his experiments, considered it as a compound of oxygen gas and phlogiston, and for that reason gave it the name of *phlogisticated air*. According to the theory of Stahl, which was then universally prevalent, he considered combustion as merely the separation of phlogiston from the burning body. To this theory he made the following addition: Phlogiston is separated during combustion by means of chemical affinity: *Air* (that is, *oxygen gas*) has a strong affinity for phlogiston: Its presence is necessary during combustion, because it combines with the phlogiston as it separates from the combustible; and it even contributes by its affinity to produce that separation: The moment the air has combined with as much phlogiston as it can receive, or, to use a chemical term, the moment it is *saturated* with phlogiston, combustion necessarily stops, because no more phlogiston can leave the combustible*: Air saturated with phlogiston is

Supposed, 1. A compound of oxygen and phlogiston,

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* This ingenious theory was first conceived by Dr Rutherford, as appears from the following passage of his thesis. " Ex iisdem etiam deducere licet quod aer ille malignus (azotic gas) componitur ex *aere atmo-*

azotic gas. This was a very ingenious theory, and, when Dr Priestley published it, exceedingly plausible. A great number of the most eminent chemists accordingly embraced it: But it was soon after discovered, that during combustion the quantity of air, instead of increasing, as it ought to do if phlogiston be added to it, actually diminishes both in volume and weight. There is no proof, therefore, that during combustion any substance whatever combines with air, but rather the contrary. It was discovered also, that a quantity of air combines with the burning substance during combustion, as we have seen to be the case with sulphur, phosphorus, carbon, and hydrogen; and that this air has the properties of oxygen gas. These discoveries entirely overthrew the evidence on which Dr Priestley's theory was founded: accordingly, as no attempt to decompound azot has succeeded, it has been given up by almost every chemist except Dr Priestley himself.

But erroneously.

More lately, indeed, a new theory concerning the composition of azot has been proposed, and variously modified by different chemists. As this theory has occasioned a controversy which has been maintained in Germany with a good deal of keenness, and which has contributed towards explaining several very curious chemical phenomena, I shall give a short account of the whole in this place.

In the year 1783 Dr Priestley discovered, that when earthen ware retorts, moistened with water in the in-

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ſpherico cum phlogisto unito et quasi saturato. Atque idem confirmatur eo, quod aer qui metallorum calcinationi jam inserviit, et phlogiston ab iis abripuit, ejusdem plane sit indolis." *De aere Mephitico*, p. 20.

side, or containing a quantity of moist clay, are heated above the boiling temperature, very little water issues from their beak in the form of vapour; but instead of it a quantity of air nearly equal to the weight of the water employed. As this air scarcely differed in its properties from common air, he concluded at first that the water by this process was converted into air. But he afterwards ascertained, by the most ingenious and decisive experiments, that the water which had disappeared had made its way through the pores of the vessel, while at the same time a quantity of external air was forced by the pressure of the atmosphere into the interior of the vessel, and that this was the air which issued out of the beak of the retort*.

2. Of water and fire.

This conclusion was objected to by Achard of Berlin in 1784, who endeavoured to prove, by experiment, that whenever steam is made to pass through red hot earthen tubes, or even metallic tubes, it is converted into azotic gas†. Mr Westrum drew the same conclusion from an experiment of his own; and drew as an inference, that azotic gas is composed of *water* and *heat* combined together‡. In 1796, Wiegleb published a long paper on the same subject; in which he endeavours, both by reasoning and experiments, to prove the truth of Westrum's theory§. This paper drew the attention of the associated Dutch chemists Deimann, Troostwich, and Lauwerenburg; and induced them to make a very complete set of experiments, an account of which they published in 1798‖. Their experiments coincided exactly with those of Dr Priestley.

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* Priestley *on Air*, ii. 407.

† Crell's *Annals*, 1785, i. 304.

‡ *Ibid.* p. 499.

§ *Ibid* 1796, ii. 467.

‖ *Ann. de Chim.* xxvi. 310.

No gas made its appearance except when the instruments employed were of earthen ware, and of course capable of being penetrated by air. Wiegleb's method of making the experiment was to lute the tube of a tobacco pipe to a retort containing some pure water. The tobacco pipe was heated red hot by means of a charcoal fire; and then the water in the retort being made to boil, the steam passed through the red hot pipe. The Dutch chemists found, that no gas appeared when instead of the tobacco pipe a glass or metallic tube was used, or when the tobacco pipe was covered with a glass tube; unless the tube was cracked: and that when gas was obtained, it was always the same with the air on the outside of the tube; that is to say, a mixture of carbonic acid and azotic gas when the tube was heated in a charcoal fire, and common air when the tube was withdrawn from the fire. Thus their experiments coincided precisely with Dr Priestley, and led them to the very same conclusion. Mr Wiegleb attempted to answer the objections of the Dutch chemists, and to establish his own theory by new experiments; but he has by no means succeeded: he has not been able to satisfy even himself*.

3. Of oxygen and hydrogen,

Soon after Dr Girtanner published a dissertation on the same subject, in the 34th volume of the *Annales de Chimie*. His experiments coincide pretty nearly with those of Wiegleb and his associates; but he drew from them very different consequences, and founded on them a theory almost diametrically opposite. According to him, azotic gas is obtained whenever water in the state of vapour comes into contact with clay. Thus, it is obtain-

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* Crell's *Annals*, 1799, i. 45, &c.

ed when water is boiled in an earthen retort, or in a glass retort containing a little clay, or ending in an earthen tube. Hence he concludes, that azotic gas is composed of hydrogen and oxygen gas combined together, and differs from water or vapour merely in containing a smaller proportion of oxygen *. These very singular assertions were put to the test of experiment by Berthollet and Bouillon Lagrange. But though they adhered implicitly to the directions of Girtanner, and even varied the process every conceivable way, they did not obtain a particle of azotic gas †. Girtanner therefore either never performed these experiments at all, or he must have been some how or other misled. His theory of course falls to the ground.

But without proof.

Its component parts unknown.

Thus as all the attempts to decompose azot have hitherto failed, we must of necessity consider it as a simple substance. It must be acknowledged, however, that there are several chemical phenomena altogether inexplicable at present; but which might be accounted for if it were possible to prove that azot is a compound, and that one of the component parts of water enters into its composition. One of these phenomena is the formation of RAIN, which will come under our consideration in the Second Part of this Work: Another is, the constant disengagement of azotic gas when ice is melted. Dr Priestley found, that when water, previously freed from air as completely as possible, is frozen, it emits, when melted again, a quantity of azotic gas. He froze the same water nine times without exposing it to the contact of air, and every time obtained nearly the same proportion of azotic gas ‡.

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* *Ann. de Chim.* xxxiv. 3.

† *Ibid.* xxxv. 23.

‡ Nicholson's *Journal*, iv. 193.

Book I.

SUCH are the properties of all the combustibles at present reckoned simple except the metals. We have seen that, during combustion, all of them combine with oxygen; that no sensible part of them is disengaged and lost; and we have concluded, in consequence, that the combustion of these substances is nothing else than the act of their uniting with oxygen. The resulting compound is an acid in all of them except hydrogen, which produces water. It is remarkable, that every one of these bodies has a peculiar temperature at which it combines with oxygen, and that it will not burn at a lower temperature. Phosphorus alone consumes slowly at the common temperature of the atmosphere, sulphur burns at 302°, charcoal at 370°, hydrogen gas at 800°, azotic gas requires not less than 1300°, and the diamond a still higher temperature. During these combustions a quantity of heat and light is emitted, or the burning body exhibits what in common language is called *fire*. Now why is heat necessary for these combinations? and whence come the heat and the light which we perceive during the combustion of these bodies? These questions are of the highest importance, and can only be answered by a particular investigation of the nature and properties of heat and light. But it would be improper to enter upon any inquiry of this kind, till we have made ourselves acquainted with the properties of the metals, which are also combustible bodies; because they will furnish us with a number of additional facts, which will considerably facilitate any subsequent investigation of these important questions.

CHAP. III.

OF METALS.

Properties of metals.

METALS may be considered as the great instruments of all our improvements: Without them, many of the arts and sciences could hardly have existed. So sensible were the ancients of their great importance, that they raised those persons who first discovered the art of working them to the rank of deities. In chemistry, they have always filled a conspicuous station: at one period the whole science was confined to them; and it may be said to have owed its very existence to a rage for making and transmuting metals.

Lustre.

1. One of the most conspicuous properties of the metals is a particular brilliancy which they possess, and which has been called the *metallic lustre.* There are other bodies indeed (*mica* for instance) which apparently possess this peculiar lustre, but in them it is confined to the surface, and accordingly disappears when they are scratched, whereas it pervades every part of the metals. This lustre is occasioned by their reflecting much more light than other bodies; a property which seems to depend partly on the closeness of their texture. This renders them peculiarly proper for mirrors, of which they always form the basis.

Opacity

2. They are perfectly opaque, or impervious to light, even after they have been reduced to very thin plates. Silver leaf, for instance, $\frac{1}{100000}$ of an inch

thick, does not permit the smallest ray of light to pass through it. Gold, however, when very thin, is not absolutely opaque; for gold leaf $\frac{1}{280000}$ of an inch thick, when held between the eye and the light, appears of a lively green; and must therefore, as Newton first remarked, transmit the green coloured rays. It is not improbable that all other metals, as the same philosopher supposed, would also transmit light if they could be reduced to a sufficient degree of thinness. It is to this opacity that a part of the excellence of the metals, as mirrors, is owing; their brilliancy alone would not qualify them for that purpose.

Fusibility.

3. They may be melted by the application of heat, and even then still retain their opacity. This property enables us to cast them in molds, and then to give them any shape we please. In this manner many elegant iron utensils are formed. Different metals differ exceedingly from each other in their fusibility. Mercury is so very fusible, that it is always fluid at the ordinary temperature of the atmosphere; while other metals, as platinum, cannot be melted except by the most violent heat which it is possible to produce.

Weight.

4. Their specific gravity is much greater than that of any other body at present known. Arsenic, the lightest of them, is more than 5½ times heavier than water; and the specific gravity of platinum, the heaviest of all the metals, is 23. This great density, no doubt, contributes considerably to the reflection of that great quantity of light which constitutes the metallic lustre.

Conducting power.

5. They are the best conductors of electricity of all the bodies hitherto tried.

Hardness.

6. None of the metals are very hard; but some of them may be hardened by art to such a degree as to exceed the hardness of almost all other bodies. Hence the numerous cutting instruments which the moderns make of steel, and which the ancients made of a combination of copper and tin.

Elasticity.

7. The elasticity of the metals depends upon their hardness; and it may be increased by the same process by which their hardness is increased. Thus the steel of which the balance-springs of watches is made is almost perfectly elastic, though iron in its natural state possesses but little elasticity.

Malleability.

8. But one of their most important properties is *malleability*, by which is meant the capacity of being extended and flattened when struck with a hammer. This property, which is peculiar to metals, enables us to give the metallic body any form we think proper, and thus renders it easy for us to convert them into the various instruments for which we have occasion. All metals do not possess this property; but it is remarkable that almost all those which were known to the ancients have it. Heat increases this property considerably. Metals become harder and denser by being hammered.

Ductility.

9. Another property, which is also wanting in many of the metals, is *ductility*; by which we mean the capacity of being drawn out into wire by being forced through holes of various diameters.

Tenacity.

10. Ductility depends, in some measure, on another property which metals possess, namely *tenacity*; by which is meant the power which a metallic wire of a given diameter has of resisting, without breaking, the action of a weight suspended from its extremity. Metals differ exceedingly from each other in their tenacity. An iron

wire, for instance, $\frac{1}{10}$th of an inch in diameter, will support, without breaking, about 500 lb. weight; whereas a lead wire, of the same diameter, will not support above 29 lb.

Combustible.

11. When exposed to the action of heat and air, most of the metals lose their lustre, and are converted into earthy-like powders of different colours and properties, according to the metal and the degree of heat employed. Several of the metals even take fire when exposed to a strong heat; and after combustion the residuum is found to be the very same earthy-like substance. If any of these *calces*, as they are called, be mixed with charcoal-powder, and exposed to a strong heat in a proper vessel, it is changed again to the metal from which it was produced. From these phenomena Stahl concluded, that metals are composed of *earth* and *phlogiston*. He was of opinion, that there is only one primitive earth, which not only forms the basis of all those substances known by the name of earths, but the basis also of all the metals. He found, however, that it was impossible to combine any mere earth with phlogiston; and concluded, therefore, with Beecher, that there is another principle besides earth and phlogiston which enters into the composition of the metals. To this principle Beecher gave the name of *mercurial earth*, because, according to him, it exists most abundantly in *mercury*. This principle was supposed to be very volatile, and therefore to fly off during calcination: and some chemists even affirmed that it might be obtained in the soot of those chimneys under which metals have been calcined.

Stahl's theory of their component parts

A striking defect was soon perceived in this theory. The original metal may be again produced by heating its calx along with some other substance which contains phlogiston. Now, if the mercurial earth flies off during combustion, it cannot be necessary for the formation of complete metals, for they may be produced without it: if, on the contrary, it adheres always to the calx, there is no proof of its existence at all. Chemists, in consequence of these observations, found themselves obliged to discard the mercurial principle altogether, and to conclude, that metals are composed of earth only, united to phlogiston. But if this be really the case, how comes it that these two substances cannot be united by art? Henkel was the first who attempted to solve this difficulty. According to him, earth and phlogiston are substances of so opposite a nature, that it is exceedingly difficult, or rather it has been hitherto impossible, for us to commence their union; but after it has been once begun by Nature, it is an easy matter to complete it. No calcination has hitherto deprived the metals of all their phlogiston; some still adheres to the calces. It is this remainder of phlogiston which renders it so easy to restore them to their metallic state. Were the calcination to be continued long enough to deprive them altogether of phlogiston, they would be reduced to the state of other earths; and then it would be equally difficult to convert them into metals, or, to use a chemical term, to *reduce* them. Accordingly we find, that the more completely a calx has been calcined, the more difficult is its reduction. This explanation was favourably received. But after the characteristic properties of the various *earths* had been ascertained, and the calces of metals were accurately examined, it was perceived that the calces differ in many particulars from all the *earths*, and from one another. To call

Improved by Henkel,

And Bergman.

them all the same substance, then, was to go much farther than either experiment or observation would warrant, or, rather, it was to declare open war against both experiment and observation. It was concluded, therefore, that each of the metals is composed of a peculiar *earthy substance* combined with phlogiston. For this great improvement in accuracy, chemistry is chiefly indebted to Bergman.

Refuted by Lavoisier.

But there were several phenomena of calcination which had all this time been unaccountably overlooked. The calces are all considerably heavier than the metals from which they are obtained. Boyle had observed this circumstance, and had ascribed it to a quantity of *fire* which, according to him, became fixed in the metal during the process *. But succeeding chemists paid little attention to it, or to the action of air, till Mr Lavoisier published his celebrated experiments on calcination, in the Memoirs of the Paris Academy for 1774. He put eight ounces of *tin* into a large glass retort, the point of which was drawn out into a very slender tube to admit of easy fusion. The retort was heated slowly till the tin began to melt, and then sealed hermetically. This heat was applied to expel some of the air from the retort: without which precaution it would have expanded and burst the vessel. The retort, which was capable of containing 250 cubic inches, was then weighed accurately, and placed again upon the fire. The tin soon melted, and a pellicle formed on its top, which was gradually converted into a grey powder, that sunk by a little agitation to the bottom of the liquid metal: in short, the tin was partly converted into a *calx*. This

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* *Fire and flame weighed, Shaw's Boyle*, ii. 388.

process went on for three hours; after which the calcination stopped, and no farther change could be produced on the metal. The retort was then taken from the fire, and found to be precisely of the same weight as before the operation. It is evident, then, that no new substance had been introduced; and that therefore the increased weight of calces cannot, as Boyle supposed, be owing to the fixation of fire *.

When the point of the retort was broken, the air rushed in with a hissing noise, and the weight of the retort was increased by ten grains. Ten grains of air, therefore, must have entered, and, consequently, precisely that quantity must have disappeared during the calcination. The metal and its calx being weighed, were found just ten grains heavier than before: therefore the air which disappeared was absorbed by the metal: and as that part of the tin which remained in a metallic state was unchanged, it is evident that this air must have united with the calx. The increase of weight, then, which metals experience during calcination, is owing to their uniting with air †. But all the air in

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* This experiment had been performed by Boyle with the same success. He had drawn a wrong conclusion from not attending to the state of the air of the vessel. *Shaw's Boyle*, ii. 394.

† It is remarkable that John Rey, a physician of Perigord, had ascribed it to this very cause as far back as the year 1630: But his writings had excited little attention, and had sunk into oblivion, till his opinion had been incontestibly proved by Lavoisier. Mayow also, in the year 1674, ascribed the increase of weight to the combination of metals with oxygen. "Quippe vix concipi potest (says he), unde augmentum illud antimonii (calcinati) nisi a particulis nitro aereis igneisque inter calcinandum FIXIS procedat." *Tract.* p. 28.—"Plane ut antimonii fixatio non tam a sulphuris ejus externi assumptione, quam particulis nitro-aereis, quibus flamma nitri abundat, EI INFIXIS provenire videatur." *Ibid.* p. 29.

the vessel was not absorbed, and yet the calcination would not go on. It is not the whole, then, but some particular part of the air which unites with the calces of metals. By the subsequent discoveries of Priestley, Scheele, and Lavoisier himself, it has been ascertained, that the residuum of the air, after calcination has been performed in it, is always pure azotic gas: It follows, therefore, that it is only the *oxygen* which combines with calces; and that a metallic calx is not a simple substance, but a compound.

Mr Lavoisier observed, that the weight of the calx was always equal to that of the metal employed, together with that of the oxygen absorbed. It became a question, then, Whether metals, during calcination, lose any substance, and, consequently, whether they contain any phlogiston? Mr Lavoisier accordingly proposed this question; and he answered it himself by a number of accurate experiments and ingenious observations. Metals cannot be calcined, excepting in contact with oxygen, and in proportion as they combine with it. Consequently they not only absorb oxygen during their calcination, but that absorption is absolutely necessary to their assuming the form of a calx. If the calx of mercury be heated in a retort, to which a pneumatic apparatus is attached, to the temperature of 1000°, it is converted into pure mercury; and, at the same time, a quantity of oxygen separates from it in a gaseous form. As this process was performed in a close vessel, no new substance could enter: The calx of mercury, then, was reduced to a metallic state without phlogiston. The weights of the metal, and the oxygen gas, are together just equal to that of the calx; the calx of mercury, therefore, must be composed of mercury and oxygen;

consequently, there is no reason whatever to suppose that mercury contains phlogiston. Its calcination is merely the act of its uniting with oxygen[*]. The calces of lead, silver, and gold, may be decomposed exactly in the same manner; and Mr Van Marum, by means of his great electrical machine, decomposed also those of tin, zinc, and antimony, and resolved them into their respective metals and oxygen[†]. The same conclusions, therefore, must be drawn with respect to these metals. All the metallic calces may be decomposed by presenting to them substances which have a greater affinity for oxygen than they have. This is the reason that charcoal-powder is so efficacious in reducing them: and if they are mixed with it, and heated in a proper vessel, furnished with a pneumatic apparatus, it will be easy to discover what passes. During the reduction, a great deal of carbonic acid gas comes over, which, together with the metal, is equal to the weight of the calx and the charcoal: it must therefore contain all the ingre-

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[*] This experiment was performed by Mr Bayen in 1774. This philosopher perceived, earlier than Lavoisier, that all metals did not contain phlogiston. " Ces experiences (says he) vont nous detromper. Je ne tiendrai plus le langage des disciples de Stahl, qui seront forcés de restreindre la doctrine sur le phlogistique, ou d'avouer que les precipités mercurials, dont je parle, ne sont pas des chaux metalliques, ou enfin qu'il y a des chaux qui peuvent se reduire sans le concours du phlogistique. Les experiences que j'ai faites me force de conclure que dans la chaux mercuriale dont je parle, le mercure doit son *etat calcaire, non à la perte du phlogistique* qu'il n'a pas essuyée, *mais à sa combinaison intime avec le fluide elastique*, dont le poids ajouté a celui du mercure est la seconde cause de l'augmentation de pesanteur qu'on observe dans les precipités que j'ai soumis a l'examen." *Jour. de Phys.* 1774, pages 288, 295.—It was in consequence of hearing Bayen's paper read that Lavoisier was induced to turn his attention to the subject.

[†] *Jour. de Phys.* 1785.

dients; and we know that carbonic acid gas is composed of carbon and oxygen. During the process, then, the oxygen of the calx combines with the charcoal and the metal remains behind. It cannot be doubted, therefore, that all the metallic calces are composed of the entire metals combined with oxygen; and that calcination, like combustion, is merely the act of this combination. All metals, then, in the present state of chemistry, must be considered as simple substances; for they have never yet been decompounded.

Oxide and oxidation explained.

The words *calx* and *calcination* are evidently improper, as they convey false ideas; we shall therefore afterwards employ, instead of them, the words *oxide* and *oxidation*, which were invented by the French chemists. A metallic *oxide* signifies a metal united with oxygen; and *oxidation* implies the act of that union.

Metals are capable of uniting with oxygen in different proportions, and, consequently, of forming each of them different oxides. These are distinguished from one another by their colour. One of the oxides of iron, for instance, is of a black colour; it is therefore called the *black oxide;* the other, which is brown, is called the *brown oxide.*

Metals divisible into three classes.

The metals at present amount to 21; only 11 of which were known before the year 1730. They may be very conveniently arranged under three classes; namely, 1. Malleable Metals; 2. Brittle and easily fusible Metals; 3. Brittle and difficultly fusible Metals. The metals belonging to each of these classes will be seen from the following table:

I. MALLEABLE.

1. Gold.
2. Platinum.
3. Silver.
4. Mercury.
5. Copper.
6. Iron.
7. Tin.
8. Lead.
9. Nickel.
10. Zinc.

II. BRITTLE AND EASILY FUSED.

1. Bismuth.
2. Antimony.
3. Tellurium.
4. Arsenic.

III. BRITTLE AND DIFFICULTLY FUSED.

1. Cobalt.
2. Manganese.
3. Tungsten.
4. Molybdenum.
5. Uranium.
6. Titanium.
7. Chromum.

The metals of the first class were formerly called *metals* by way of eminence, because they are possessed either of malleability or ductility, or of both properties together: the rest were called *semimetals*, because they are brittle. But this distinction is now pretty generally laid aside; and, as Bergman observes, it ought to be so altogether, as it is founded on a false hypothesis, and conveys very erroneous ideas to the mind. The first four metals were formerly called *noble* or *perfect metals*, because their oxides are reducible by the mere application of heat; the next four were *imperfect metals*, because their oxides were thought not reducible without the addition of some combustible substance; but this distinction also is now very properly exploded.

SECT. I.

OF GOLD.

GOLD seems to have been known from the very beginning of the world. Its properties and its scarcity have rendered it more valuable than any other metal.

Properties of gold.

It is of an orange red, or reddish yellow colour, and has no perceptible taste or smell. Its lustre is considerable, yielding only to that of platinum, steel, silver, and mercury.

Its hardness is $6\frac{1}{2}$[*]; its specific gravity 19.3.

Malleability.

No other substance is equal to it in ductility and malleability. It may be beaten out into leaves so thin, that one grain of gold will cover $56\frac{3}{4}$ square inches. These leaves are only $\frac{1}{282000}$ of an inch thick. But the gold leaf with which silver wire is covered has

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[*] Mr Kirwan's method of denoting the different degrees of hardness by figures is used throughout this Treatise. These figures will be understood by Mr Kirwan's own explanation, which is here subjoined.

3, Denotes the hardness of chalk.

4, A superior hardness, but yet what yields to the nail.

5, What will not yield to the nail, but easily, and without grittiness, to the knife.

6, That which yields more difficultly to the knife.

7, That which scarcely yields to the knife.

8, That which cannot be scraped by a knife, but does not give fire with steel.

9, That which gives a few feeble sparks with steel.

10, That which gives plentiful lively sparks. *Kirwan's Mineralogy*, i. 38.

only $\frac{1}{11}$ of that thickness. An ounce of gold, upon silver wire, is capable of being extended more than 1300 miles in length.

Tenacity.

Its tenacity is considerable, though in this respect it yields to iron, copper, platinum, and silver. From the experiments of Sickingen it appears that a gold wire $\frac{1}{12.0}$ inch in diameter is capable of supporting a weight of 272 lbs. without breaking.

Fusibility.

It melts at 32° of Wedgewood's pyrometer*. When melted, it assumes a bright bluish green colour. It expands in the act of fusion, and consequently contracts while becoming solid more than most metals; a circumstance which renders it less proper for casting into moulds.

It requires a very violent heat to volatilize it; it is therefore, to use a chemical term, exceedingly *fixed.* Boyle and Kunkel kept it for some months in a glass-house furnace, and yet it underwent no change; nor did it lose any perceptible weight, after being exposed for some hours to the utmost heat of Mr Parker's lens†. Homberg, however, observed, that when a very small portion of gold is kept in fusion, part of it is volatilized. This observation was confirmed by Macquer, who observed the metal rising in fumes to the height of five or six inches, and attaching itself to a plate of silver, which it gilded very accurately; and Mr Lavoisier observed the very same thing when a piece of silver was held over gold melted by a fire blown by oxygen gas, which produces a much greater heat than common air.

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* According to the calculation of the Dijon academicians, it melts at 1298° Fahrenheit; according to Mortimer, at 1301°.

† Kirwan's *Mineralogy*, i. 92.

After fusion, it is capable of assuming a crystalline form. Tillet and Mongez obtained it in short quadrangular pyramidal crystals.

Gold is not in the least altered by being kept exposed to the air; it does not even lose its lustre. Neither has water the smallest action upon it.

Oxides two.

It is capable, however, of combining with oxygen, and of undergoing a kind of combustion. The resulting compound is an *oxide of gold.* There are two oxides of gold; one of them of a purple or violet, the other of a yellow colour. The purple oxide contains the least, the yellow the most oxygen. According to Fourcroy, the yellow oxide is composed of about 90 parts gold and 10 oxygen*. Gold must be raised to a very high temperature before it is capable of abstracting oxygen from common air. It may be kept red hot almost any length of time without any such change. Homberg, however, observed, that when placed in the focus of Tschirnhausen's burning glass, its surface became covered with a purple oxide; and the truth of his observations were put beyond doubt by the subsequent experiments of Macquer with a still more powerful burning glass. It was remarked also in 1773 by Camus, that when the electric explosion is transmitted through gold leaf placed between two plates of glass, or when a strong charge is made to fall on a gilded surface—in both cases the metal is oxidated, and assumes a purple colour. The reality of the oxidation of gold by electricity was disputed by some philosophers, but it has been put beyond the reach of doubt by the experiments of Van Marum. When that celebrated philo-

1. Purple.

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* Fourcroy, vi. 385.

sopher made electric sparks from the powerful Teylerian machine pass through a gold wire suspended in the air, it took fire, burnt with a green coloured flame, and was completely dissipated in fumes, which when collected proved to be the purple oxide of gold. This combustion succeeded not only in common air, but also when the wire was suspended in hydrogen gas and other gases which are not capable of supporting combustion. The reason of this is, that electricity has the property of decomposing water, a certain portion of which is constantly combined with these gases. It is probably the oxygen of this water which burns and oxidates the gold.

2. Yellow.

By these processes the purple oxide only is obtained. The yellow oxide may be procured in the following manner: Equal parts of nitric and muriatic acids are mixed together*, and poured upon gold; an effervescence takes place, the gold is gradually dissolved, and the liquid assumes a yellow colour. It is easy to see in what manner this solution is produced. No metal is soluble in acids till it has been reduced to the state of an oxide. There is a strong affinity between the oxide of gold and muriatic acid. The nitric acid furnishes oxygen to the gold, and the muriatic acid dissolves the oxide as it forms. When nitric acid is deprived of the greater part of its oxygen, it assumes a gaseous form, and is then called *nitrous gas*. It is the emission of this gas which causes the effervescence. The oxide of gold may be precipitated from the nitro-mu-

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* This mixture, from its property of dissolving gold, was formerly called *aqua regia* (for gold, among the alchymists, was the king of metals); it is now called *nitro-muriatic acid.*

riatic acid, by pouring in a little potass dissolved in water, or, which is much better, a little lime; both of which have a stronger affinity for muriatic acid than the oxide has.

The oxides of gold may be decomposed in close vessels by the application of heat. The gold remains fixed, and the oxygen assumes the gaseous form. They may be decomposed, too, by all the substances which have a stronger affinity for oxygen than gold has.

Phosphuret of gold.

Gold does not seem capable of combining with sulphur, carbon, hydrogen, nor azot. Mr Pelletier combined it with phosphorus, by melting together in a crucible half an ounce of gold and an ounce of phosphoric glass *, surrounded with charcoal. The *phosphuret of gold* thus produced was brittle, whiter than gold, and had a crystallized appearance. It was composed of 23 parts of gold and one of phosphorus †. He formed the same compound by dropping small pieces of phosphorus into gold in fusion ‡.

Gold is also capable of combining with most of the metals.

The affinities of gold and its oxides are placed by Bergman in the following order:

Affinities.

GOLD.	OXIDE OF GOLD.
Mercury,	Muriatic acid,
Copper,	Nitric,
Silver,	Sulphuric,
Lead,	Arsenic,
Bismuth,	Fluoric,
Tin,	Tartarous,

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* Phosphoric acid evaporated to dryness, and then fused.

† *Ann. de Chim.* i. 71.

‡ Ibid. xiii. 104.

Antimony,
Iron,
Platinum,
Zinc,
Nickel,
Arsenic,
Cobalt,
Manganese,
Phosphorus?
Sulphurets of alkalies.

Phosphoric,
Sebacic,
Prussic,
Fixed alkali,
Ammonia.

SECT. II.

OF PLATINUM.

Gold, the metal just described, was known in the earliest ages, and has been always in high estimation, on account of its scarcity, beauty, ductility, and indestructibility. But platinum, though perhaps inferior in few of these qualities, and certainly far superior in others, was unknown, as a distinct metal, before the year 1752*.

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* Father Cortinovis, indeed, has attempted to prove, that this metal was the *electrum* of the ancients. See the *Chemical Annals of Brugnatelli*, 1790. That the *electrum* of the ancients was a metal, and a very valuable one, is evident from many of the ancient writers, particularly Homer. The following lines of Claudian are alone sufficient to prove it:

> " Atria cinxit ebur, trabibus solidatur ahenis
> " Culmen et in celsas surgunt *electra* columnas." L. I. v. 164.

Pliny gives us an account of it in his Natural History. He informs us that it was a composition of silver and gold; and that by candle-light it

Book I.

History of platinum.

It has hitherto been found only in America in Choco in Peru, and in the mine of Santa Fe, near Carthagena*. The workmen of these mines must no doubt have been early acquainted with it; but they seem to have paid very little attention to it. It was unknown in Europe till Mr Wood brought some of it from Jamaica in 1741. In 1748 it was noticed by Don Antonio de Ulloa, a Spanish mathematician, who had accompanied the French academicians to Peru in their voyage to measure a degree of the meridian. Several papers on it were published by Dr Watson in the 46th volume of the Philosophical Transactions. These immediately attracted the attention of the most eminent chemists. In 1752, Mr Scheffer of Sweden published the first accurate examination of its properties. He proved it to be

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shone with more splendor than silver. The ancients made cups, statues, and columns of it. Now, had it been our platinum, is it not rather extraordinary that no traces of a metal, which must have been pretty abundant, should be perceptible in any part of the old continent?

As the passage of Pliny contains the fullest account of electrum to be found in any ancient author, I shall give it in his own words, that every one may have it in his power to judge whether or not the description will apply to the platinum of the moderns.

"Omni auro inest argentum vario pondere.—Ubicunque quinta argenti portio est, *electrum* vocatur. Scrobes eæ reperiuntur in Canaliensi. Fit et cura electrum argento addito. Quod si quintam portionem excessit, incudibus non restitit. Et electro auctoritas, Homero teste, qui Menelai regiam auro, electro, argento, ebore fulgere tradit. Minervæ templum habet Lindos insulæ Rhodiorum in quo Helena sacravit calicem ex electro.—Electri natura est ad lucernarum lumina clarius argento splendere. Quod est nativum, et venena deprehendit. Namque discurrunt in calicibus arcus cœlestibus similes cum igneo stridore, et gemina ratione prædicunt."—Lib. xxxiii. cap. iv.

* A platinum mine is said to have been lately discovered in South America.

a new metal, approaching very much to the nature of gold, and therefore gave it the name of *aurum album*, "white gold." Dr Lewis published a still more complete set of experiments on it in 1754[*]. Soon after dissertations were published on it by Margraf[†]; Macquer and Beaumé[‡]; Buffon, Tillet and Morveau[§]; Sickingen[||]; Bergman[¶]; and more lately by Mussin Puschkin[**], and Morveau[††], and several other chemists of eminence.

Its properties.

Platinum, when pure, is of a white colour like silver, but not so bright[‡‡]. It has no taste nor smell.

Its hardness is 8. Its specific gravity, after being hammered, is 23.000; so that it is by far the heaviest body known[§§].

It is exceedingly ductile and malleable; it may be hammered out into very thin plates, and drawn into wires not exceeding $\frac{1}{1940}$ inch in diameter. In these properties it is probably inferior to gold, but it seems to surpass all the other metals.

Its tenacity is such, that a wire of platinum $\frac{1}{12.6}$ inch in diameter is capable of supporting a weight of 497 lbs. without breaking[||||].

It is the most infusible of all the metals, and cannot

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[*] *Phil. Trans.* xlviii. 638. and l. 148.

[†] *Mem. Berlin*, 1757, p. 314.

[‡] *Mem. Par.* 1758, p. 119.

[§] *Journ. de Phys.* iii. 324.

[||] Macquer's *Dictionary*.

[¶] *Opusc.* ii. 166.

[**] *Ann. de Chim.* xxiv. 205.

[††] *Ann. de Chim.* xxv. 3.

[‡‡] To this colour it owes its name. *Plata*, in Spanish, is "silver;" and *platina*, "little silver," was the name first given to the metal. Bergman changed that name into *platinum*, that the Latin names of all the metals might have the same termination and gender. It had been, however, called *platinum* by Linnæus long before.

[§§] Kirwan's *Miner.* ii. 103.

[||||] Morveau, *Ann. de Chim.* xxv. 7.

be melted, in any quantity at least, by the strongest artificial heat which can be produced. Macquer and Beaumé melted small particles of it by means of a blow pipe, and Lavoisier by exposing them on red hot charcoal to a stream of oxygen gas. It may indeed be melted without difficulty when combined or mixed with other bodies, but then it is not in a state of purity. Pieces of platinum, when heated to whiteness, may be welded together by hammering in the same manner as hot iron.

This metal is not in the smallest degree altered by the action of air or water.

Oxide.

It cannot be combined with oxygen and converted into an oxide by the strongest artificial heat to which it has been possible to expose it. Platinum, indeed, in the state in which it is brought from America, may be partially oxidated by exposure to a violent heat, as numerous experiments have proved; but in that state it is not pure, but combined with a quantity of iron. It cannot be doubted, however, that if we could subject it to a sufficient heat, platinum would burn and be oxidadated like other metals: For when Van Marum exposed a wire of platinum to the action of his powerful electrical machine, it burnt with a faint white flame, and was dissipated into a species of dust, which proved to be the oxide of platinum. This metal may be oxidated in any quantity by boiling it in sixteen times its weight of nitro-muriatic acid. The acid dissolves it, and assumes first a yellow, and afterwards a deep red or rather brown colour. On the addition of lime to the solution, a yellow powder falls to the bottom. This powder is the *oxide* of platinum. Its properties have not been examined with sufficient accuracy. It seems to contain but a small proportion of oxygen; probably not more than 0.07[*].

This oxide may be decomposed, and the oxygen driven off by exposing it to a violent heat[†].

Phosphuret of platinum.

Neither sulphur, carbon, hydrogen, nor azot, can be combined with platinum ; but it unites without difficulty to phosphorus. By mixing together an ounce of platinum, an ounce of phosphoric glass, and a dram of powdered charcoal, and applying a heat of about 32° Wedgewood, Mr Pelletier formed a *phosphuret of platinum* weighing more than an ounce. It was partly in the form of a button, and partly in cubic crystals. It was covered above by a blackish glass. It was of a silver white colour, very brittle, and hard enough to strike fire with steel. When exposed to a fire strong enough to melt it, the phosphorus was disengaged, and burnt on the surface[‡].

He found also, that when phosphorus was projected on red hot platinum, the metal instantly fused and formed a phosphuret. As heat expels the phosphorus, Mr Pelletier has proposed this as an easy method of purifying platinum[§].

Alloy of gold and platinum.

When gold and platinum are exposed to a strong heat, they combine, and form an *alloy* of gold and platinum. If the platinum exceed $\frac{1}{17}$ of the gold, the colour of the alloy is much paler than gold ; but if it be under $\frac{1}{17}$, the colour of the gold is not sensibly altered. Neither is there any alteration in the ductility of the gold. But the other properties of this alloy have not been examined.

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[*] Fourcroy, vi. 428.

[†] Macquer's *Dictionary*.

[‡] *Ann. de Chim.* i. 71.

[§] *Ibid.* xiii. 105.

Neither the affinities of platinum nor of its oxide are at present known.

If this metal could be obtained at a cheap rate, it would furnish very precious vessels; as they would not be acted upon by almost any body, would not be liable to be broken, and might be exposed to the greatest heat without alteration. It might be employed too with very great advantage instead of silver, to cover the surface of copper and iron utensils.

SECT. III.

OF SILVER.

Properties of silver.

Silver seems to have been known almost as early as gold. It is a metal of a fine white colour, without either taste or smell; and in point of brilliancy, is perhaps inferior to none of the metallic bodies, if we except polished steel.

Its hardness is 7. When melted, its specific gravity is 10.478; when hammered, 10.609.

In malleability, it is inferior to none of the metals, if we except gold, and perhaps also platinum. It may be beat out into leaves only $\frac{1}{160000}$ inch thick. Its ductility is equally remarkable: it may be drawn out into wire much finer than a human hair; so fine indeed, that a single grain of silver may be extended about 400 feet in length.

Its tenacity is such, that a wire of silver $\frac{1}{12.6}$ inch in diameter is capable of supporting a weight of 337 lb. without breaking[*].

Silver melts when it is heated completely red hot; and while melted its brilliancy is much increased. According to the calculation of Bergman and Mortimer, its fusing point is 1000° of Fahrenheit. It continues melted at 28° Wedgewood, but requires a greater heat to bring it to fusion[†]. If the heat be increased after the silver is melted, the liquid metal boils, and may be volatilized; but a very strong and long continued heat is necessary.

When cooled slowly, its surface exhibits the appearance of crystals; and if the liquid part of the metal be poured out as soon as the surface congeals, pretty large crystals of silver may be obtained. By this method Tillet, and Mongez junior, obtained it in four-sided pyramids, both insulated and in groups.

Oxides.

Silver is not oxidated by exposure to the air: it gradually indeed loses its lustre, and becomes tarnished; but this is owing to a different cause. Neither is it altered by being kept under water. But if it be kept for a long time melted in an open vessel, it gradually attracts the oxygen from the atmosphere, and is converted into an oxide. This experiment was first made by Junker, who converted a quantity of silver into a vitriform oxide. It was afterwards confirmed by Macquer and Darcet. Macquer, by exposing silver 20 times successively to the heat of a porcelain furnace, obtained a *glass*[‡] of an olive green colour[§]. Nay, if

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[*] *Ann. de Chim.* xxv. 7.

[†] Kirwan's *Miner.* ii. 107.

[‡] Metallic oxides, after fusion, are called *glass*, because they acquire a good deal of resemblance, in some particulars, to common glass.

[§] Macquer's *Dictionary*.

the heat be sufficient, the silver even takes fire and burns like other combustible bodies. Van Marum made electric sparks from his powerful Teylerian machine pass through a silver wire; the wire exhibited a greenish white flame, and was dissipated into smoke.

The oxide of silver, obtained by means of heat, is of a greenish or yellowish grey colour; and is easily decomposed by the application of heat in close vessels, or even by exposing it to the light. When silver is dissolved in nitric acid, and precipitated by lime water, it falls to the bottom under the form of a powder, which is at first white, but very soon assumes the colour of the oxide obtained by heat. Whether the white powder be a different oxide, and contains more oxygen than the other, has not been ascertained. From the experiments of Wenzel and Bergman it follows, that the greenish or yellowish grey oxide is composed of about 90 parts of silver and 10 of oxygen*. When this oxide is exposed to the light, part of its oxygen is separated, as Scheele first ascertained, and it is converted into a black powder known by the name of the *black oxide* of silver. The black oxide contains but a very small portion of oxygen.

Neither carbon, hydrogen, nor azot, have been combined with silver; but it combines readily with sulphur and phosphorus.

Sulphuret. When thin plates of silver and sulphur are laid alternately above each other in a crucible, they melt readily in a low red heat, and form *sulphuret of silver*. It is of a black or very deep violet colour; brittle, but capable of being cut with a knife; often crystallized in

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* Kirwan's *Miner.* ii. 493

small needles; and much more fusible than silver. If sufficient heat be applied, the sulphur is slowly volatilized, and the metal remains behind in a state of purity. It is very difficult to determine the proportion of the ingredients which enter into the composition of this substance, because there is an affinity between silver and its sulphuret, which disposes them to combine together. The greatest quantity of sulphur, which a given quantity of silver is capable of taking up, is according to Wenzel $\frac{13}{100}$[*].

It is well known, that when silver is long exposed to the air, especially in frequented places, as churches, theatres, &c. it acquires a covering of a violet colour, which deprives it of its lustre and malleability. This covering, which forms a thin layer, can only be detached from the silver by bending it, or breaking it in pieces with a hammer. It was examined by Mr Proust, and found to be *sulphuret of silver*[†].

Phosphuret.

Silver was first combined with phosphorus by Mr Pelletier. If one ounce of silver, one ounce of phosphoric glass, and two drams of charcoal, be mixed together, and heated in a crucible, *phosphuret of silver* is formed. It is of a white colour, and appears granulated, or as it were crystallized. It breaks under the hammer, but may be cut with a knife. It is composed of four parts of silver and one of phosphorus. Heat decomposes it by separating the phosphorus[‡]. Pelletier has observed, that silver in fusion is capable of combining with more phosphorus than solid silver: for when phosphuret of silver is formed by projecting phosphorus into melted

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[*] Kirwan's *Miner.* ii. 492.

[†] *Ann. de Chim.* i. 142.

[‡] Pelletier, *Ann. de Chim.* i. 73.

silver, after the crucible is taken from the fire, a quantity of phosphorus is emitted the moment the metal congeals*.

Silver combines readily with the greater number of metallic bodies.

Alloys.

When silver and gold are kept melted together, they combine, and form an alloy composed, as Homberg ascertained, of one part of silver and five of gold. He kept equal parts of gold and silver in gentle fusion for a quarter of an hour, and found, on breaking the crucible, two masses, the uppermost of which was pure silver, the undermost the whole gold combined with $\frac{1}{6}$ of silver. Silver, however, may be mixed with gold in almost any proportion. But there is a great difference between the mixture of two substances and their chemical combination. Metals which melt nearly at the same temperature, may be mixed from that very circumstance in any proportion; but substances can combine chemically only in one proportion. This observation, which is certainly of importance, was first made by Mr Keir †.

The alloy of gold and silver is harder and more sonorous than gold. Its hardness is a maximum when the alloy contains two parts of gold and one of silver ‡. The density of these metals is but little increased §; but the colour of the gold is much altered, even when the proportion of the silver is small; one part of silver produces a sensible whiteness in twenty parts of gold. The colour is not only pale, but it has also a very sensible greenish tinge, as if the light reflected by the sil-

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* *Ann de Chim.* xiii. 110.

† Translation of Macquer's *Dictionary*, art. *Allay*.

‡ Muschenbroeck.

§ Gellert.

ver passed through a very thin covering of gold. This alloy being more fusible than gold, is employed to solder pieces of that metal together.

Whether silver and platinum combine chemically has not yet been properly ascertained. When fused together (for which a very strong heat is necessary), they form a mixture, not so ductile as silver, but harder and less white. The two metals are separated by keeping them for some time in the state of fusion; the platinum sinking to the bottom from its weight. This circumstance would induce one to suppose that there is very little affinity between them.

The affinities of silver, and its oxides, are placed by Bergman in the following order:

Affinities.

SILVER.	OXIDE OF SILVER.
Lead,	Muriatic acid,
Copper,	Sebacic,
Mercury,	Oxalic,
Bismuth,	Sulphuric,
Tin,	Mucous,
Gold,	Phosphoric,
Antimony,	Sulphurous,
Iron,	Nitric,
Manganese,	Arsenic,
Zinc,	Fluoric,
Arsenic,	Tartarous,
Nickel,	Citric,
Platinum,	Formic,
Sulphur,	Lactic,
Phosphorus.	Acetous,
	Succinic,
	Prussic,
	Carbonic,
	Ammonia.

SECT. IV.

OF MERCURY.

MERCURY, called also QUICKSILVER, was known in the remotest ages, and seems to have been employed by the ancients in gilding and in separating gold from other bodies, just as it is by the moderns.

Properties of mercury.

Its colour is white, and similar to that of silver; hence the names *hydrargyrum*, *argentum vivum*, *quicksilver*, by which it has been known in all ages. It has no taste nor smell. It possesses a good deal of brilliancy; and when its surface is not tarnished, makes a very good mirror.

Its specific gravity is 13.568 *.

At the common temperature of the atmosphere it is always in a state of fluidity. In this respect it differs from all other metals. But it becomes solid when exposed to a sufficient degree of cold. The temperature necessary for freezing this metal is —39°, as was ascertained by the experiments of Mr Macnab at Hudson's Bay. The congelation of mercury was accidentally discovered by the Petersburgh academicians in 1759. Taking the advantage of a very severe frost, they plunged a thermometer into a mixture of snow and salt, in order to ascertain the degree of cold thereby produced. Observing the mercury stationary, even after it was removed from the mixture, they broke the bulb of the ther-

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* Cavendish and Brisson.

Chap. III.

mometer, and found the metal frozen into a solid mass. This experiment has been repeated very often since, especially in Britain[*]. Mercury contracts considerably at the instant of freezing; a circumstance which misled the philosophers who first witnessed its congelation. The mercury in their thermometers sunk so much before it froze, that they thought the cold to which it had been exposed much greater than it really was. It was in consequence of the rules laid down by Mr Cavendish, that Mr Macnab was enabled to ascertain the real freezing point of the metal.

Solid mercury may be subjected to the blows of a hammer, and may be extended without breaking. It is therefore malleable; but neither the degree of its malleability, nor its ductility, nor its tenacity, have been ascertained.

Mercury boils when heated to 600°. It may therefore be totally evaporated, or distilled from one vessel into another. It is by distillation that mercury is purified from various metallic bodies with which it is often contaminated. The vapour of mercury is invisible and elastic like common air; like air, too, its elasticity is indefinitely increased by heat, so that it breaks through the strongest vessel. Geoffroy, at the desire of an alchymist, inclosed a quantity of it in an iron globe strongly secured by iron hoops, and put the apparatus into a furnace. Soon after the globe became red hot it burst with all the violence of a bomb, and the whole of the mercury was dissipated[†].

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[*] The method of performing this experiment will be described in the Fifth Chapter of Part I. of this Treatise.

[†] Macquer's *Chemistry.*

Mercury is not altered by being kept under water. When exposed to the air, its surface is gradually tarnished, and covered with a black powder, owing to its combining with the oxygen of the atmosphere. But this change goes on very slowly, unless the mercury be either heated or agitated, by shaking it, for instance, in a large bottle full of air. By either of these processes, the metal is converted into an oxide. By the first, into a black oxide; and by the second, into a red oxide.

Oxides. The oxides of mercury at present known are three; the *black*, the *yellow*, and the *red*.

1. The *black* oxide was first described with accuracy by Boerhaave. He formed it by putting a little mercury into a bottle, and tying it to the spoke of a mill wheel. By the constant agitation which it thus underwent, it was converted into a black powder, to which he gave the name of *ethiops per se*. When this oxide is heated, it gives out oxygen gas, and is converted into pure mercury. It seems to be composed of about 96 parts of mercury and 4 of oxygen. It is this oxide of mercury which is formed when mercury is triturated with oily or mucilaginous bodies.

2. The *yellow* oxide of mercury may be obtained by boiling 1 part of mercury in 1½ parts of sulphuric acid almost to dryness, and then pouring hot water upon the mass. A yellow powder is obtained, which was formerly called *turbith mineral*. This is the yellow oxide; but it is never pure, containing always $\frac{1}{10}$ of its weight of sulphuric acid. Nor is there any process known by which it can be obtained in a state of purity. Of course the properties of the yellow oxide are unknown. The quantity of oxygen which it contains has

not been ascertained. From the observations of Bergman it would follow, that it is composed of about 96.8 parts of mercury, and 3.2 of oxygen[*]. The experiments of Fourcroy, on the other hand, give us 87 parts of mercury and 13 of oxygen for its component parts[†]: but neither of these determinations can be accurate[‡].

3. The *red* oxide, which was well known to the alchymists, may be formed two different ways. 1. By putting a little mercury into a flat bottomed glass bottle or matrass, the neck of which is drawn out into a very narrow tube, putting the matrass into a sand bath, and keeping it constantly at the boiling point. The height of the matrass, and the smallness of its mouth, prevents the mercury from making its escape, while it affords free access to the air. The surface of the mercury becomes gradually black, and then red, by combining with the oxygen of the air: and at the end of several months, the whole is converted into a red powder, or rather into small crystals, of a very deep red colour. The oxide, when thus obtained, was formerly called *precepitate per se.* 2. When mercury is dissolved in nitric acid, and then heated to dryness in close vessels, it is converted into small scales of a brilliant red colour, formerly called *red precipitate*, and possessing exactly the properties of the oxide obtained by the former process.

The red oxide of mercury, however prepared, is a very acrid substance, acting as an escharotic when ap-

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[*] Kirwan's *Miner.* ii. 489.

[†] Fourcroy, v. 316.

[‡] It is probably the same, or nearly so, with the white oxide of mercury, which may be obtained by dissolving that metal in nitric acid, and precipitating it by an alkali or lime. This oxide likewise carries along with it a portion of the acid in which it was dissolved.

plied to the skin, and possessing poisonous qualities. When heated to redness in a retort, it gives out oxygen gas, and the oxide is reduced to the metallic state. It is to this experiment, repeated by Dr Priestley in 1774, that we are indebted for the original discovery of oxygen gas. When triturated with mercury, it gives out part of its oxygen, and the whole is converted into black oxide*. From the experiments of Lavoisier it follows, that it is composed of about 90 parts of mercury and 10 of oxygen.

Mercury has never been combined with carbon, hydrogen, nor azot. Its oxides combine with sulphur and phosphorus; but it has not been proved that these combustible bodies are capable of combining with mercury in its metallic state.

Black sulphurated oxide.

When two parts of sulphur and one of mercury are triturated together in a mortar, the mercury gradually disappears, and the whole assumes the form of a black powder, formerly called *ethiops mineral.* It is scarcely possible by this process to combine the sulphur and mercury so completely, that small globules of the metal may not be detected by a microscope. When mercury is added slowly to its own weight of melted sulphur, and the mixture is constantly stirred, the same black compound is formed.

Fourcroy has suggested, that in this compound the mercury is in the state of black oxide, absorbing the necessary portion of oxygen from the atmosphere during its combination with the sulphur†. This theory has not been demonstrated by direct experiment, but it is extremely probable. Ethiops mineral therefore ought

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* Fourcroy, v. 296.

† Ibid. 298.

to be denominated *black sulphurated oxide of mercury*. It may be formed also by triturating together sulphur and red oxide of mercury [*].

Cinnabar, or red sulphurated oxide.

When this black sulphurated oxide is heated, part of the sulphur takes fire and is dissipated, and the mercury seems to absorb more oxygen. The residuum assumes a deep violet colour. When heated red hot, it sublimes; and if a proper vessel be placed to receive it, a cake is obtained of a fine red colour. This cake was formerly called *cinnabar;* and when reduced to a fine powder, is well known in commerce under the name of *vermilion* [†]. It seems to be composed of about 90 parts of the red oxide of mercury and 10 parts of sulphur, and is therefore denominated *red sulphurated oxide of mercury*. It may be prepared by various other processes. One of the simplest of these is the following, lately discovered by Mr Kirchoff. When 300 grains of mercury and 68 of sulphur, with a few drops of solution of potass to moisten them, are triturated for some time in a porcelain cup by means of a glass pestle, black sulphurated oxide of mercury is produced. Add to this 160 grains of potass, dissolved in as much water. Heat the vessel containing the ingredients over the flame of a candle, and continue the trituration without interruption during the heating. In proportion as the liquid evaporates, add clear water from time to time, so that the oxide

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[*] Fourcroy, v. 298.

[†] The word *vermilion* is derived from the French word *vermeil*, which comes from *vermiculus* or *vermiculum;* names given in the middle ages to the *kermes* or *coccus ilicis*, well known as a red dye. *Vermilion* originally signified the red dye of the kermes. See *Beckmann's History of Discoveries*, ii. 180.

may be constantly covered to the depth of near an inch. The trituration must be continued about two hours: at the end of which time the mixture begins to change from its original black colour to a brown, which usually happens when a large part of the fluid is evaporated. It then passes very rapidly to a red. No more water is to be added; but the trituration is to be continued without interruption. When the mass has acquired the consistence of a gelly, the red colour becomes more and more bright, with an incredible degree of quickness. The instant the colour has acquired its utmost beauty, the heat must be withdrawn, otherwise the red passes to a dirty brown. Count de Moussin Pouschkin has discovered, that its passing to a brown colour may be prevented by taking it from the fire as soon as it has acquired a red colour, and placing it for two or three days in a gentle heat, taking care to add a few drops of water, and to agitate the mixture from time to time. During this exposure, the red colour gradually improves, and at last becomes excellent. He discovered also, that when this sulphuret is exposed to a strong heat, it becomes instantly brown, and then passes into a dark violet; when taken from the fire it passes instantly to a beautiful carmine red *.

Cinnabar is not altered by exposure to the air. It may be sublimed in a close vessel without alteration; but when heated slowly in an open vessel, the sulphur gradually sublimes, and the mercury is reduced. Its use as a paint is well known.

Black phosphurated oxide.

Mr Pelletier, after several unsuccessful attempts to combine phosphorus and mercury, at last succeeded by

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* Nicholson's *Journal*, ii. 1.

Chap. III.

distilling a mixture of red oxide of mercury and phosphorus. Part of the phosphorus combined with the oxygen of the oxide, and was converted into an acid; the rest combined with the mercury. He observed that the mercury was converted into a black powder before it combined with the phosphorus. On making the experiment, I found that phosphorus combines very readily with the black oxide of mercury, when melted along with it in a retort filled with hydrogen gas to prevent the combustion of the phosphorus. As Pelletier could not succeed in his attempts to combine phosphorus with mercury in its metallic state, we must conclude that it is not with mercury, but with the black oxide of mercury, that the phosphorus combines. The compound therefore is not *phosphuret of mercury*, but *black phosphurated oxide of mercury*.

It is of a black colour, of a pretty solid consistence, and capable of being cut with a knife. When exposed to the air, it exhales vapours of phosphorus*.

Amalgams.

Mercury combines with the greater number of metals. These combinations are known in chemistry by the name of *amalgams*†.

1. The amalgam of gold is formed very readily, because there is a very strong affinity between the two metals. If a bit of gold be dipped into mercury, its surface, by combining with mercury, becomes as white as silver. The easiest way of forming this amalgam is to throw small pieces of red hot gold into mercury. The proportions of the ingredients are not easily determi-

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[*] *Ann. de Chim.* xiii. 122.

[†] This word is supposed to be derived from ἅμα and γαμεω; of course it signifies literally *intermarriage*.

Book I.

ned, because the amalgam has an affinity both for the gold and the mercury; in consequence of which they appear to combine in any proportion. This amalgam is white with a shade of yellow; and when composed of six parts of mercury and one of gold, it may be obtained crystallized in four-sided prisms. It melts at a moderate temperature; and when heated sufficiently, the mercury evaporates, and leaves the gold in a state of purity. It is much used in gilding. The amalgam, composed of ten parts of mercury and one of gold, is spread upon the metal which is to be gilt; and then, by the application of a gentle and equal heat, the mercury is driven off and the gold left adhering to the metallic surface: this surface is then rubbed with a brass wire brush under water, and afterwards burnished *.

2. Dr Lewis attempted to form an amalgam of platinum, but hardly succeeded after a labour which lasted for several weeks. Guyton Morveau succeeded by means of heat. He fixed a small cylinder of platinum at the bottom of a tall glass vessel, and covered it with mercury. The vessel was then placed in a sand-bath, and the mercury kept constantly boiling. The mercury gradually combined with the platinum; the weight of the cylinder was doubled, and it became brittle. When heated strongly, the mercury evaporated, and left the platinum partly oxidated. It is remarkable that the platinum, notwithstanding its superior specific gravity, always swam upon the surface of the mercury, so that Morveau was under the necessity of fixing it down †.

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* Gellert's *Metallurgic Chemistry*, 375.

† *Ann. de Chim.* xxv. 12.

But the most expeditious method of amalgamating platinum, or rather its oxide, has been discovered by Count Moussin Pouschkin. He took a dram of the orange-coloured salt, obtained by precipitating platinum from its solution in nitro-muriatic acid by ammonia[*], and triturated it with an equal weight of mercury in a mortar of chalcedony. In a few minutes the salt became brown, and afterwards acquired a greenish shade. The matter was reduced to a very fine powder. Another dram of mercury was added, and the trituration continued: The matter became grey. A third dram of mercury began to form an amalgam; and six drams made the amalgam perfect. The whole operation scarcely lasted twenty minútes. Mercury was added till it amounted to nine times the weight of the salt, and yet the amalgam continued very tenacious. It was easily spread out under the pestle; it received the impression of the most delicate seals, and had a very close and brilliant grain. This amalgam is decomposed, and the mercury passes to the state of black oxide by the simple contact of several of the metals and a great number of animal matters. This effect even takes place on rubbing it between the fingers[†].

3. The amalgam of silver is made in the same manner, and with equal ease. It forms dendritical crystals, which, according to the Dijon academicians, cóntain eight parts of mercury and one of silver. It is of a white colour, and is always of a soft consistence. Its specific gravity is greater than the mean of the two me-

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[*] Ammonia is an alkali hereafter to be described. It is often called, in English, *hartshorn*.

[†] *Ann. de Chim.* xxiv. 209.

tals. Gellert has even remarked that, when thrown into pure mercury, it sinks to the bottom of that liquid *. When heated sufficiently, the mercury is volatilized, and the silver remains behind pure.

Affinities

The affinities of mercury as ascertained by Morveau, and of its oxides as exhibited by Bergman, are in the following order:

MERCURY.	OXIDE OF MERCURY.
Gold,	Sebacic acid,
Silver,	Muriatic,
Tin,	Oxalic,
Lead,	Succinic,
Bismuth,	Arsenic,
Platinum,	Phosphoric,
Zinc,	Sulphuric,
Copper,	Mucous,
Antimony,	Tartarous,
Arsenic†,	Citric,
Iron.	Sulphurous,
	Nitric,
	Fluoric,
	Acetous,
	Boracic,
	Prussic,
	Carbonic.

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* Gellert's *Metallurgic Chemistry*, 142.

† These two are added from Bergman. Bergman places *lead* before tin, and zinc before bismuth.

Chap. III.

SECT. V.

OF COPPER.

If we except gold and silver, copper seems to have been more early known than any other metal. In the first ages of the world, before the method of working iron was discovered, copper was the principal ingredient in all domestic utensils and instruments of war. Even during the Trojan war, as we learn from Homer, the combatants had no other armour but what was made of bronze, which is a mixture of *copper* and *tin*. The word *copper* is derived from the island of Cyprus, where it was first discovered, or at least wrought to any extent, by the Greeks.

Properties of copper.

This metal is of a fine red colour, and has a great deal of brilliancy. Its taste is styptic and nauseous; and the hands, when rubbed for some time on it, acquire a peculiar and disagreeable odour.

Its hardness is 7.5. Its specific gravity, when melted, is 8.667; but after being hammered it is 8.9.

Its malleability is very considerable: it may be hammered out into leaves so thin as to be blown about by the slightest breeze. Its ductility is also considerable. Its tenacity is such, that a copper wire $\frac{1}{12.8}$ inch in diameter is capable of supporting 546 pounds without breaking*.

When heated to the temperature of 27° Wedgewood,

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* Sickingen.

or, according to the calculation of Mortimer* to 1450° Fahrenheit, it melts; and if the heat be increased, it evaporates in visible fumes. When allowed to cool slowly, it assumes a crystalline form. The Abbé Mongez, to whom we owe many valuable experiments on the crystallization of metals, obtained it in quadrangular pyramids, often inserted into one another.

Copper is not altered by water: it is incapable of decomposing it even at a red heat, unless air have free access to it at the same time; in that case the surface of the metal becomes oxidated. Every one must have remarked, that when water is kept in a copper vessel, a green crust of *verdegris*, as it is called, is formed on that part of the vessel which is in contact with the surface of the water.

Oxide.

When copper is exposed to the air, its surface is gradually tarnished; it becomes brown, and is at last covered with a dark green crust. This crust consists of oxide of copper combined with carbonic acid gas. At the common temperature of the air, this oxidation of copper goes on but slowly; but when a plate of metal is heated red hot, it is covered in a few minutes with a crust of oxide, which separates spontaneously in small scales when the plate is allowed to cool. The copper-plate contracts considerably in cooling, but the crust of oxide contracts but very little; it is therefore broken to pieces and thrown off, when the plate contracts under it. Any quantity of this oxide may be obtained by heating a plate of copper and plunging it alternately into cold water. The scales fall down to the bottom of the water.

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* *Phil. Trans.* xliv. 672.

This oxide is of a brown colour, and sometimes of a fine dark red. When kept red hot for some time, it becomes almost perfectly black. Proust has ascertained, that it is composed of 80 parts of copper and 20 of oxygen. These brown and black powders, then, are not two different oxides, as was formerly supposed, but merely two different states of the same oxide*.

There is another oxide of copper of an orange colour, and therefore called *orange oxide*, which was first discovered by Proust; but we are indebted to Mr Chenevix, who found it native in Cornwall, for the investigation of its properties. It may be prepared by mixing together 57.5 parts of black oxide of copper, and 50 parts of copper reduced to a fine powder by precipitating it from muriatic acid by an iron plate. This mixture is to be triturated in a mortar, and put with muriatic acid into a well stopped phial. Heat is disengaged, and almost all the copper is dissolved. When potass is dropt into this solution, the orange oxide of copper is precipitated. It may also be obtained by heating to redness a mixture of 57.5 parts of black oxide and 50 parts of copper. This oxide is composed of 88.5 parts of copper and 11.5 of oxygen†. These two are the only oxides of copper at present known.

When copper is dissolved in nitric acid, and a sufficient quantity of potass added to the solution, a blue powder falls to the bottom, which was formerly considered as a peculiar oxide of copper, and accordingly called *blue oxide of copper*. But Mr Proust has endeavoured to prove, that it is nothing else than the black

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* *Ann. de Chim.* xxxii. 26.

† Chenevix, *Phil. Trans.* 1801. p. 227.

Hydrat of copper.

oxide combined with water, and has therefore called it *hydrat of copper*. His proofs are, that when distilled, 100 parts of it yield 25 parts of water, and there remain behind 75 parts of black oxide; and that copper is only capable of combining with one portion of oxygen. As he has not detailed to us the experiments by means of which he ascertained these points, and as they have not been repeated by other chemists, his conclusions must be admitted with some hesitation; though the well-known accuracy of this celebrated philosopher is sufficient to assure us that his experiments would be performed with the greatest care and precision.

When this blue powder is exposed moist to the atmosphere, it gradually becomes green. This was formerly supposed to be owing to the absorption of oxygen; accordingly the green powder was called *green oxide of copper*. But Mr Proust has shown that this change is not owing to the absorption of oxygen, but to the combination of the black oxide of copper with carbonic acid.

The oxide of copper is easily reduced to the metallic state when heated along with charcoal, oils, or other fatty bodies; and even with some of the metals, especially zinc.

Copper has never been combined with carbon, hydrogen, nor azot; but it combines readily with sulphur and phosphorus, and forms with them compounds called *sulphuret* and *phosphuret of copper*.

Sulphuret.

When equal parts of sulphur and copper are stratified alternately in a crucible, they melt, and combine at a red heat. Sulphuret of copper, thus obtained, is a brittle mass, of a black or very deep blue grey colour, much more fusible than copper, and composed, according to the experiments of Mr Kirwan, of 81 parts of copper and 19 of sulphur [*]. The same compound may be formed by mixing copper filings and sulphur together, and making them into a paste with water, or even by merely mixing them together without any water, and allowing them to remain a sufficient time exposed to the air, as I have ascertained by experiment.

If eight parts by weight of copper filings, mixed with three parts of flowers of sulphur, be put into a glass receiver, and placed upon burning coals, the mixture first melts, then a kind of explosion takes place; it becomes red hot, and when taken from the fire, continues to glow for some time like a live coal. If we now examine it, we find it converted into *sulphuret of copper.* This curious experiment was first made by the associated Dutch chemists Deiman, Troostwyk, Nieuwland, Bondt, and Laurenburg, in 1793 [†]. They found that the combustion succeeds best when the substances are mixed in the proportions mentioned above: that it succeeds equally, however pure and dry the sulphur and copper be, and whatever air be present in the glass vessel, whether common air, or oxygen gas, or hydrogen, or azotic gas, or even when the receiver is filled with water or mercury. This experiment has excited great attention, and has been very often repeated; because it is the only instance known of apparent combustion without the presence of oxygen. The different attempts to explain it will be considered in a succeeding Chapter.

Phosphuret.

Mr Pelletier formed *phosphuret of copper* by melting together 16 parts of copper, 16 parts of phosphoric

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[*] Kirwan's *Miner.* ii. 508.

[†] *Jour. de Min.* N° 2. 85.

glass, and one part of charcoal*. Margraf was the first person who formed this phosphuret. His method was to distil phosphorus and oxide of copper together. It is formed most easily by projecting phosphorus into red hot copper. It is of a white colour; and, according to Pelletier, is composed of 20 parts of phosphorus and 80 of copper†. This phosphuret is harder than iron: It is not ductile, and yet cannot easily be pulverised. Its specific gravity is 7.1220. It crystallizes in four-sided prisms‡. It is much more fusible than copper. When exposed to the air, it loses its lustre, becomes black, falls to pieces, the copper is oxidated, and the phosphorus converted into phosphoric acid. When heated sufficiently, the phosphorus burns, and leaves the copper under the form of black scoriæ§.

Copper is capable of combining with most of the metals; and some of its alloys are much employed for useful purposes. Alloys.

1. The alloy of gold and copper is easily formed by melting the two metals together. This alloy is much used, because copper has the property of increasing the hardness of gold without injuring its colour. Muschenbroeck has ascertained, that the hardness of this alloy is a maximum when it is composed of seven parts of gold and one of copper. The gold coin both in Britain and France is an alloy containing eleven parts of gold and one of copper. Its specific gravity is considerably above the mean; consequently the density of the metals is increased by alloying them together. It ought to be 17.153, but it actually is 17.486; so that the den-

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* *Ann. de Chim.* i. 74.

† *Ibid.* xiii. 3.

‡ Sage, *Jour. de Phys.* xxxviii. 468.

§ Fourcroy, vi. 252.

sity is increased $\frac{1}{38}$ part*. This alloy being more fusible than gold, is employed as a solder to join pieces of that metal together.

2. Platinum may be alloyed with copper by fusion, but a strong heat is necessary. The alloy is ductile, hard, takes a fine polish, and is not liable to tarnish. This alloy has been employed with advantage for composing the mirrors of reflecting telescopes.

3. Silver is easily alloyed with copper by fusion. This alloy is harder and more sonorous than silver, and yet the density of the metals is diminished. Thus when 137 parts of silver and 7 of copper are alloyed together, the specific gravity ought to be 10.3016, but it actually is 10.1752; consequently the bulk of the two metals is increased by alloying them together about $\frac{1}{81}$ part†. When the proportion of copper is small, the colour of the silver is not altered. The silver coin of this country is composed of 1 part of copper and 15 of silver; that of France of 7 parts of copper and 137 of silver, or 1 part copper and 19.57. silver‡. The French silver coin therefore is purer than the British.

4. The amalgam of copper cannot be formed by simply mixing that metal with mercury, nor even by the application of heat; because the heat necessary to melt copper sublimes mercury. Dr Lewis has given us several processes for forming this amalgam. One of the simplest is to triturate mercury with a quantity of common salt and verdigris; a substance composed of oxide of copper and vinegar. The theory of this process is not very obvious. It may be formed also by keeping plates of copper in a solution of mercury in nitric acid.

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* Brisson.

† Hauy, *Jour. de Min.* An. v. p. 471.

‡ *Ibid.*

The plate is soon impregnated with mercury. The amalgam of copper is of a reddish white colour, and so soft at first that it takes the most delicate impressions; but it soon becomes harder when exposed to the air. It is easily decomposed by heat; the mercury evaporates, and leaves the copper.

The affinities of copper and its oxides are exhibited by Bergman in the following order:

Affinities.

COPPER.	OXIDE OF COPPER.
Gold,	Oxalic acid,
Silver,	Tartarous,
Arsenic,	Muriatic,
Iron,	Sulphuric,
Manganese,	Mucous,
Zinc,	Nitric,
Antimony,	Sebacic,
Platinum,	Arsenic,
Tin,	Phosphoric,
Lead,	Succinic,
Nickel,	Fluoric,
Bismuth,	Citric,
Cobalt,	Formic,
Mercury,	Lactic,
Sulphuret of alkali,	Acetous,
Sulphur,	Boracic,
Phosphorus.	Prussic,
	Carbonic,
	Fixed alkalies,
	Ammonia,
	Fixed oils.

SECT. VI.

OF IRON.

IRON, the most abundant and most useful of all the metals, was neither known so early, nor wrought so easily, as gold, silver, and copper. For its discovery we must have recourse to the nations of the East, among whom, indeed, almost all the arts and sciences first sprung up. The writings of Moses (who was born about 1635 years before Christ) furnish us with the amplest proof at how early a period it was known in Egypt and Phœnicia. He mentions furnaces for working iron[*], ores from which it was extracted[†]; and tells us, that swords[‡], knives[§], axes[||], and tools for cutting stones[¶], were then made of that metal. How many ages before the birth of Moses iron must have been discovered in these countries, we may perhaps conceive, if we reflect, that the knowledge of iron was brought over from Phrygia to Greece by the Dactyli[**], who settled in Crete during the reign of Minos I. about 1431 years before Christ; yet during the Trojan war, which happened 200 years after that period, iron was in such high estimation, that Achilles proposed a ball of it as one of his prizes during the games which he celebrated in honour of Patroclus. At that period none

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[*] Deut. iv. 20.
[†] Ibid. viii. 9.
[‡] Numb. xxxv. 16.
[§] Levit. i. 17.
[||] Deut. xviii. 5.
[¶] Ibid. xxvii 5.
[**] Hesiod, as quoted by Pliny, lib. vii. c. 57.

of their weapons were formed of iron. Now if the Greeks in 200 years had made so little progress in an art which they learned from others, how long must it have taken the Egyptians, Phrygians, Chalybes, or whatever nation first discovered the art of working iron, to have made that progress in it which we find they had done in the days of Moses?

Properties of iron.

Iron is of a bluish white colour; and when polished, has a great deal of brilliancy. It has a styptic taste, and emits a smell when rubbed.

Its hardness is 9. Its specific gravity varies from 7.6 to 7.8.

It is attracted by the magnet or loadstone, and is itself the substance which constitutes the loadstone. But when iron is perfectly pure, it retains the magnetic virtue a very short time.

It is malleable in every temperature, and its malleability increases in proportion as the temperature augments; but it cannot be hammered out nearly so thin as gold or silver, or even copper. Its ductility, however, is more perfect; for it may be drawn out into wire as fine at least as a human hair. Its tenacity is such, that an iron wire $\frac{1}{12.6}$ of an inch in diameter is capable of supporting 995 pounds without breaking*.

When heated to about 158° Wedgewood, as Sir George M'Kenzie has ascertained†, it melts. This temperature being nearly the highest to which it can be raised, it has been impossible to ascertain the point at which this melted metal begins to boil and to evaporate. Neither has the form of its crystals been examined: but it is well known that the texture of iron is fibrous; that

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* Sickingen.

† Nicholson's *Journal*, iv. 109.

s, it appears when broken to be composed of a number of fibres or strings bundled together.

When exposed to the air, its surface is soon tarnished, and it is gradually changed into a brown or yellow powder, well known under the name of *rust*. This change takes place more rapidly if the atmosphere be moist. It is occasioned by the gradual combination of the iron with the oxygen of the atmosphere, for which it has a very strong affinity.

Decomposes water.

When iron filings are kept in water, provided the temperature be not under 70°, they are gradually converted into a black powder, while a quantity of hydrogen gas is emitted. This is occasioned by the slow decomposition of the water. The iron combines with its oxygen, while the hydrogen makes its escape under the form of gas*. If the water be made to boil, it is decomposed much more speedily. Very perceptible bubbles of hydrogen gas rise from the iron, and may be collected at the top of the vessel. This experiment may be made in a glass retort. The iron filings are to be put in first, and then the retort is to be completely filled with water, and its beak plunged into an open vessel of water. The retort is then to be made to boil by applying under it a lamp.

If the steam of water be made to pass through a red hot iron tube, it is decomposed instantly. The oxygen combines with the iron, and the hydrogen gas passes through the tube, and may be collected in proper vessels. This is one of the easiest methods of procuring pure hydrogen gas.

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[*] This fact was known to Bergman (*Opusc.* iii. 95.), and to Scheele (*on Fire*, p. 180.); but it was first explained by Lavoisier.

Combustible.

These facts are sufficient to show that iron has a strong affinity for oxygen, since it is capable of taking it from air and water. So strong is this affinity, that iron is capable of taking fire and burning with great rapidity. Twist a small iron wire into the form of a cork screw, by rolling it round a cylinder; fix one end of it into a cork, and attach to the other a small bit of cotton thread dipt in melted tallow. Set fire to the cotton, and plunge it while burning into a jar filled with oxygen gas. The wire catches fire from the cotton and burns with great brilliancy, emitting very vivid sparks in all directions. For this very splendid experiment we are indebted to Dr Ingenhousz. During this combustion the iron combines with oxygen, and is converted into an oxide.

Oxides two;

Mr Proust has proved that there are only two oxides of iron; namely, 1. The *black* or the *green;* 2. The *red* or the *brown.*

1. Black or green;

The first of these oxides may be obtained by four different processes. 1. By keeping iron filings a sufficient time in water at the temperature of 70°. The oxide thus formed is a black powder, formerly much used in medicine under the name of *martial ethiops*, and seems to have been first examined by Lemeri. 2. By making steam pass through a red hot iron tube. The iron is changed into a black brittle substance, precisely similar to martial ethiops. This experiment was first made by Lavoisier. 3. By burning iron wire in oxygen gas. The wire as it burns is melted, and falls in drops to the bottom of the vessel, which ought to be covered with water, and to be of copper. These metallic drops are brittle, very hard, blackish, but retaining the metallic lustre. They were examined by La-

Chap. III.

voisier, and found precisely the same with martial ethiops*. They owe their lustre to the fusion which they underwent. 4. By dissolving iron in sulphuric acid, and pouring potass into the solution. A green powder falls to the bottom, which assumes the appearance of martial ethiops when dried quickly in close vessels. This first oxide of iron, however formed, is always composed of 73 parts of iron and 27 of oxygen, as Lavoisier and Proust have demonstrated†. It is attracted by the magnet, and is often itself magnetic‡. It is capable of crystallizing, and is often found native in that state.

2. Red or brown.

The red oxide of iron may be formed by keeping iron filings red hot in an open vessel, and agitating them constantly till they are converted into a dark red powder. This oxide was formerly called *saffron of Mars*. Common rust of iron is the red oxide combined with carbonic acid gas. The red oxide may be obtained also by exposing for a long time a diluted solution of iron in sulphuric acid to the atmosphere, and then dropping into it an alkali. The oxide is precipitated of a brown colour. This oxide is also found native in great abundance. Proust found that it is composed of 48 parts of oxygen and 52 of iron §. Consequently the green oxide, when converted into the red, absorbs nearly 0.51 of oxygen; or, which is the same thing, the red oxide is composed of 66 parts of black oxide and 34 parts of oxygen. One hundred parts of iron, when converted into black oxide, absorb 37 parts of oxygen, and the oxide weighs 137; when converted into red oxide,

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* *Ann. de Chim.* i. 19.

† Ibid. and xxiii. 87.

‡ Bergman, iii. 102.

§ *Ann. de Chim.* xxiii. 87

it absorbs 70 additional parts of oxygen, and the oxide weighs 207.

The red oxide cannot be decomposed by heat; but when heated along with its own weight of iron filings, the whole, as Vauquelin first observed, is converted into black oxide. The reason of this conversion is evident: The 100 parts of red oxide are composed of 48 parts of iron, combined with two different doses of oxygen: 1. With 18 parts, which, with the iron, make 66 of green oxide: 2. With 34 parts, which, with the green oxide, make 100 parts of red oxide. Now, the first of these doses has a much greater affinity for the iron than the second has. Consequently the 34 parts of oxygen, which constitute the second dose, being retained by a weak affinity, are easily abstracted by the 100 parts of pure iron; and combining with the iron, the whole almost is converted into black oxide. For 100 parts of iron, to be converted into black oxide, require only 37 parts of oxygen.

The red oxide of iron is not magnetic. It is converted into black oxide by sulphurated hydrogen gas and many other substances; which deprive it of the second dose of oxygen, for which they have a stronger affinity, though they are incapable of decomposing the black oxide.

Action of combustibles.

Iron combines with the greater number of combustible bodies; azot is almost the only one which has no action on it at all. Hydrogen, indeed, has never been combined with it in a solid state; but when hydrogen gas is obtained by the solution of iron filings in diluted sulphuric acid, it carries along with it a little of the iron, which is gradually deposited in the form of a brown powder on the sides of the jars in which the hydrogen gas is confined. With sulphur, phosphorus, and carbon, it forms compounds known by the name of *sulphuret*, *phosphuret*, and *carburet* of iron.

Sulphuret.

Sulphuret of iron may be formed by melting together in a crucible equal parts of iron filings and powdered sulphur. It is of a black or very deep grey colour, brittle, and remarkably hard. When reduced to powder, and moistened with water, the sulphur is gradually converted into sulphuric acid by absorbing oxygen, while at the same time the iron is oxidated. The same compound may be formed by mixing together three parts (by weight) of iron filings, and one part of powdered sulphur, and putting the mixture in a glass vessel upon burning coals. This mixture, as the Dutch chemists first ascertained, melts, explodes, and burns without the presence of air, just as copper filings and sulphur, though not with such brilliancy *.

If equal quantities of iron filings and sulphur be mixed together, and formed into a paste with water, the sulphur decomposes the water, and absorbs oxygen so rapidly that the mixture sometimes takes fire, even though it be buried under ground. This phenomenon was first discovered by Lemeri; and it was considered by him as affording an explanation of the origin of volcanoes †. The native sulphurated oxide of iron, or *pyrites*, has been observed more than once to take fire on being suddenly moistened with water.

Phosphuret.

Phosphuret of iron may be formed by fusing in a crucible 16 parts of phosphoric glass, 16 parts of iron,

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* *Jour. de Min.* N° ii. 91.

† When this experiment was repeated by Bucquet, it did not succeed. Fourcroy's *Systeme des Connaiss. Chim.* vi. 171.

and half a part of charcoal powder. It is magnetic, very brittle, and appears white when broken. When exposed to a strong heat, it melts, and the phosphorus is dissipated [*]. It may be formed also by melting together equal parts of phosphoric glass and iron filings. Part of the iron combines with the oxygen of the phosphoric glass, and is vitrified; the rest forms the phosphuret, which sinks to the bottom of the crucible. It may be formed also by dropping small bits of phosphorus into iron filings heated red hot [†]. The proportions of the ingredients of this phosphuret have not yet been determined. It was first discovered and examined by Bergman, who took it for a new metal, and gave it the name of *siderum*.

There is a particular kind of iron, known by the name of *cold short iron*, because it is brittle when cold, though it be malleable when hot. Bergman [‡] was employed at Upsal in examining the cause of this property, while Meyer [§] was occupied at Stetin with the same investigation; and both of them discovered, nearly at the same time, that, by means of sulphuric acid, a white powder could be separated from this kind of iron, which by the usual process they converted into a metal of a dark steel grey, exceedingly brittle, and not very soluble in acids. Its specific gravity was 6.700; it was not so fusible as copper; and when combined with iron rendered it *cold short*. Both of them concluded that this substance was a new metal: Bergman gave it the

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[*] Pelletier, *Ann. de Chim.* i. 104.

[†] Id. *Ibid.* xiii. 113.

[‡] *Opusc.* iii. 109.

[§] *Schriften der Berliner Gesellsch. Naturf. Freunde*, 1780, ii. 334. and iii. 380.

name of *siderum*, and Meyer of *hydrosiderum*. But Klaproth soon after recollecting that the salt composed of phosphoric acid and iron bore a great resemblance to the white powder obtained from cold short iron, suspected the presence of phosphoric acid in this new metal. To decide the point, he combined phosphoric acid and iron, and obtained, by heating it in a crucible along with charcoal powder*, a substance exactly resembling the new metal†. Meyer, when Klaproth communicated to him this discovery, informed him that he had already satisfied himself, by a more accurate examination, that siderum contained phosphoric acid‡. Soon after this, Scheele actually decomposed the white powder obtained from cold short iron, and thereby demonstrated, that it is composed of phosphoric acid and iron §. The siderum of Bergman, however, is composed of phosphorus and iron, or it is phosphuret of iron; the phosphoric acid being deprived of its oxygen during the *reduction*.

Carburet of iron or plumbago.

Carburet of iron is found native, and has been long known under the names of *plumbago* and *black lead*. It is of a dark iron grey or blue colour, and has something of a metallic lustre. It has a greasy feel, and blackens the fingers, or any other substance to which it is applied. It is found in many parts of the world, especially in Britain, where it is manufactured into pencils. It is not affected by the most violent heat as long as air is excluded, nor is it in the least altered by simple exposure to the air or to water. A moderate heat has no

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* This process in chemistry is called *reduction*.

† Crell's *Annals*, 1784, i. 390

‡ Ibid. 195.

§ Crell, i. 112. Engl. Trans.

effect upon it; but when heated very strongly in an open vessel, it burns all away slowly except about $\frac{1}{10}$ of a residuum, which is oxide of iron[*]. Its nature was first investigated by Scheele; who proved, by a very ingenious analysis, published in the Stockholm Transactions for 1779, that it can be converted by combustion almost wholly into carbonic acid gas, and that the small residuum is iron[†]. He concluded from his analysis, that it is composed of carbonic acid and phlogiston: but the experiments of Pelletier, and, above all, of Vandermonde, Monge, and Berthollet, have demonstrated, that it is a compound of about nine parts of iron and one of carbon[‡]. The difficult combustion of plumbago is not merely owing to the presence of the iron, but to the state of the carbon, which appears to be nearly pure, or at least to be combined with only a very small portion of oxygen.

Varieties of iron.

There are a great many varieties of iron, which artists distinguish by particular names; but all of them may be reduced under one or other of the three following classes—*Cast Iron*, *Wrought* or *Soft Iron*, and *Steel.*

Cast iron.

CAST IRON, or PIG IRON, is the name of the metal when first extracted from its ores. The ores from which iron is usually obtained are composed of oxide of iron and clay. The object of the manufacturer is to reduce the oxide to the metallic state, and to separate all the clay with which it is combined. These two objects are accomplished at once, by mixing the ore reduced to small pieces with a certain portion of limestone and of

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[*] Gahn.

[†] Scheele, ii. 20. French Transl.

[‡] *Mem. Par.* 1786.

charcoal, and subjecting the whole to a very violent heat in furnaces constructed for the purpose. The charcoal absorbs the oxygen of the oxide, flies off in the state of carbonic acid gas, and leaves the iron in the metallic state; the lime combines with the clay, and both together run into fusion, and form a kind of fluid glass; the iron is also melted by the violence of the heat, and being heavier than the glass, falls down, and is collected at the bottom of the furnace. Thus the contents of the furnace are separated into two portions; the glass swims at the surface, and the iron rests at the bottom. A hole at the lower part of the furnace is now opened, and the iron allowed to flow out into moulds prepared for its reception.

The cast iron thus obtained is distinguished by the following properties: It is scarcely malleable at any temperature. It is generally so hard as to resist the file. It can neither be hardened nor softened by ignition and cooling. It is exceedingly brittle. It melts at 130° Wedgewood. It is more sonorous than steel*. For the most part, it is of a dark grey or blackish colour; but sometimes it is whitish, and then it contains a quantity of phosphuret of iron, which considerably impairs its qualities. A great number of utensils are formed of iron in this state.

Wrought iron.

To convert it into WROUGHT IRON, it is put into a furnace, and kept melted, by means of the flame of the combustibles, which is made to play upon its surface. While melted, it is constantly stirred by a workman, that every part of it may be exposed to the air. In about an hour the hottest part of the mass begins to

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* Dr Pearson on *Wootz*, *Phil. Trans.*

heave and swell, and to emit a lambent blue flame. This continues nearly an hour; and by that time the conversion is completed. The heaving is evidently produced by the emission of an elastic fluid *. As the process advances, the iron gradually acquires more consistency; and at last, notwithstanding the continuance of the heat, it congeals altogether. It is then taken while hot, and hammered violently, by means of a heavy hammer driven by machinery. This not only makes the particles of iron approach nearer each other, but drives away several impurities which would otherwise continue attached to the iron.

In this state it is the substance described in this Section under the name of IRON. As it has never yet been decomposed, it is considered at present when pure as a simple body; but it has seldom or never been found without some small mixture of foreign substances. These substances are either some of the other metals, or oxygen, carbon, or phosphorus.

Steel.

When small pieces of iron are stratified in a close crucible, with a sufficient quantity of charcoal powder, and kept in a strong red heat for eight or ten hours, they are converted into STEEL †, which is distinguished from iron by the following properties.

It is so hard as to be unmalleable while cold, or at least it acquires this property by being immersed while ignited into a cold liquid: for this immersion, though it has no effect upon *iron*, adds greatly to the hardness of *steel*.

It is brittle, resists the file, cuts glass, affords sparks

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* Beddoes, *Phil. Trans.* 1791.

† This process is called *cementation*.

with flint, and retains the magnetic virtue for any length of time.

It loses this hardness by being ignited and cooled very slowly.

It melts at above 130° Wedgewood. It is malleable when red hot, but scarcely so when raised to a white heat.

It may be hammered out into much thinner plates than iron. It is more sonorous; and its specific gravity, when hammered, is greater than that of iron.

By being repeatedly ignited in an open vessel, and hammered, it becomes *wrought iron*[*].

Nature of these varieties

These different kinds of iron have been long known, and the converting of them into each other has been practised in very remote ages. Many attempts have been made to explain the manner in which this conversion is accomplished. According to Pliny, steel owes its peculiar properties chiefly to the water into which it is plunged in order to be cooled[†]. Beccher supposed that fire was the only agent; that it entered into the iron, and converted it into steel. Reaumur was the first who attended accurately to the process; and his numerous experiments have certainly contributed to elucidate the subject. He supposed that iron is converted into steel by combining with saline and oily or sulphureous particles, and that these are introduced by the fire. But it was the analysis of Bergman, published in 1781, that first paved the way to the explanation of the nature of these different species of iron[‡].

By dissolving in diluted sulphuric acid 100 parts of

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[*] Dr Pearson on *Wootz*, *Phil. Trans.*

[†] Pliny, lib. xxxiv. 14.

[‡] *Opusc.* iii. 1.

cast iron, he obtained, at an average, 42 ounce measures of hydrogen gas; from 100 parts of steel he obtained 48 ounce measures; and from 100 parts of wrought iron, 50 ounce measures. From 100 parts of cast iron, he obtained, at an average, 2.2 of plumbago, or $\frac{1}{45}$; from 100 parts of steel, 0.5, or $\frac{1}{200}$; and from 100 parts of wrought iron, 0.12, or $\frac{1}{900}$. From this analysis he concluded, that cast iron contains the least phlogiston, steel more, and wrought iron most of all: for the hydrogen gas was at that time considered as an indication of the phlogiston contained in the metal. He concluded, too, that cast iron and steel differ from pure iron in containing plumbago. Mr Grignon, in his notes on this analysis, endeavoured to prove, that plumbago is not essentially a part of cast iron and steel, but that it was merely accidentally present. But Bergman, after considering his objections, wrote to Morveau on the 18th November 1783. "I will acknowledge my mistake whenever Mr Grignon sends me a single bit of cast iron or steel, which does not contain plumbago; and I beg of you, my dear friend, to endeavour to discover some such, and to send them to me; for if I am wrong, I wish to be undeceived as soon as possible *. This was almost the last action of the illustrious Bergman. He died a few months after at the age of 49, leaving behind him a most brilliant reputation, which no man ever more deservedly acquired. His industry, his indefatigable, his astonishing industry, would alone have contributed much to establish his name; his extensive knowledge would alone have attracted the attention of philosophers; his ingenuity,

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* Morveau, *Encyc. Method. Chim.* i. 448,

penetration, and accurate judgment, would alone have secured the applause; and his candour and love of truth procured him the confidence and the esteem of the world—But all these qualities were united in Bergman, and conspired to form one of the noblest characters that ever adorned human nature.

The experiments of Bergman were repeated, varied, and extended, by Vandermonde, Monge, and Berthollet, who published an admirable dissertation on the subject in the Memoirs of the French Academy for 1786. These philosophers, by an ingenious application of the theoretical discoveries of Mr Lavoisier and his associates, were enabled to explain the nature of these three substances in a satisfactory manner. By their experiments, together with the subsequent ones of Clouet, Vauquelin, and Morveau, the following facts have been established.

Explained.

1. *Wrought iron* is a simple substance, and if perfectly pure would contain nothing but *iron.*

2. *Steel* is iron combined with a small portion of carbon, and has been for that reason called *carbonated iron.* The proportion of carbon has not been ascertained with much precision. From the analysis of Vauquelin, it amounts, at an average, to $\frac{1}{140}$th part[*]. Mr Clouet seems to affirm that it amounts to $\frac{1}{32}$ part; but he has not published the experiments which led him to a proportion, which so far exceeds what has been obtained by other chemists[†].

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[*] *Ann. de Chim.* xxii. 1.

[†] Mr Clouet's words are as follows: "Le charbon s'unit au fer en différentes proportions; et à mesure que ces proportions varient, les produits varient aussi. Un trente-deuxième de charbon suffit pour rendre

That steel is composed of iron combined with pure carbon, and not with charcoal, has been demonstrated by Morveau, who formed steel by combining together directly iron and diamond. At the suggestion of Clouet, he inclosed a diamond in a small crucible of pure iron, and exposed it completely covered up in a common crucible to a sufficient heat. The diamond disappeared, and the iron was converted into steel. The diamond weighed 907 parts, the iron 57800, and the steel obtained 56384; so that 2313 parts of the iron had been lost in the operation*. From this experiment it follows, that steel contains about $\frac{1}{60}$ of its weight of carbon. This experiment was objected to by Mr Mushet, but the objections were fully refuted by Sir George M'Kenzie†.

Rinman, long ago, pointed out a method by which steel may be distinguished from iron. When a little diluted nitric acid is dropt upon a plate of steel, allowed to remain a few minutes, and then washed off, it leaves behind it a black spot; whereas the spot formed by nitric acid on iron is whitish green. We can easily see the reason of the black spot: it is owing to the carbon of the iron which is converted into charcoal by the acid. This experiment shows us, that carbon is much more readily oxidated when combined with iron than when crystallized in the diamond.

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le fer acier; cette dose varie cependant dans les expériences, à cause de l'inégale intensité du feu et de la porosité des creusets: en augmentant la dose de charbon, la qualité de l'acier augmente aussi; mais il devient toujours de plus en plus difficile à forger, et plus facile à ramollir au feu." *Jour. de Min.* An. vii. 3.

* *Ann. de Chim.* xxxi 328.

† Nicholson's *Journal*, iv. 103.

3. *Cast iron*, is iron combined with a still greater proportion of carbon than is necessary for forming steel. The quantity has not yet been ascertained with precision: Mr Clouet makes it amount to $\frac{1}{8}$ of the iron. The blackness of the colour, and the fusibility of cast iron, are proportional to the quantity of carbon which it contains. Cast iron is almost always contaminated with foreign ingredients: These are chiefly oxide of iron, phosphuret of iron, and silica*.

It is easy to see why iron is obtained from its ore in the state of cast iron. The quantity of charcoal, along with which the ore is fused, is so great, that the iron has an opportunity of saturating itself with it.

The conversion of cast iron into wrought iron is effected by burning away the whole of the charcoal, and depriving the iron wholly of oxygen: this is accomplished by heating it violently while exposed to the air†. Mr Clouet has found, that when cast iron is mixed with $\frac{1}{4}$ of its weight of black oxide of iron, and heated violently, it is equally converted into pure iron. The oxygen of the oxide, and the carbon of the cast iron, combine, and leave the iron in a state of purity‡.

The conversion of iron into steel is effected by combining it with carbon. This combination is performed in the large way by three different processes, and the products are distinguished by the names of *natural steel, steel of cementation*, and *cast steel*.

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* A substance which shall be described in the next book.

† A detailed account of the processes used at Sheffield for converting cast iron into pure iron, has been published by Mr Collier in the 5th volume of the *Manchester Memoirs*, p. 111.

‡ *Jour. de Min.* An. vii. p. 8.

Natural steel.

Natural steel is obtained from the ore by converting it first into cast iron, and then exposing the cast iron to a violent heat in a furnace while its surface is covered with a mass of melted scoriæ five or six inches deep. Part of the carbon combines with the oxygen which cast iron always contains, and flies off in the state of carbonic acid gas. The remainder combines with the pure iron, and constitutes it steel*. This steel is inferior to the other species; its quality is not the same throughout, it is softer, and not so apt to break; and as the process by which it is obtained is less expensive, it is sold at a lower price than the other species.

Steel of cementation.

Steel of cementation is made by stratifying bars of pure iron and charcoal powder alternately in large earthen troughs or crucibles, the mouths of which are carefully closed up with clay. These troughs are put into a furnace, and kept sufficiently hot till the bars of iron are converted into steel, which usually requires eight or ten days†. This process was invented, or at least first practised to any extent, in Britain. The bars of steel thus formed, are known in this country by the name of *blistered steel*, because their surface is covered here and there with a kind of blister of the metal, as if an elastic fluid had been confined in different parts of it. When drawn out into smaller bars by the hammer, it receives the name of *tilted steel*, from the hammer employed. When broken to pieces, and welded repeated-

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* A detailed account of this process, as performed in different iron works, may be seen in the *Journal de Mines*, N° iv. p. 3.

† The process is described at large by Mr Collier in the *Manchester Memoirs*, v. 117.

ly in a furnace, and then drawn out into bars, it is called *German* or *shear steel**. Steel of cementation has a fine grain, is equable, harder, and more elastic than *natural steel.*

Cast steel.

Cast steel is the most valuable of all, as its texture is most compact, and it admits of the finest polish. It is used for razors, surgeons instruments, and other similar purposes. It is more fusible than common steel, and for that reason cannot be welded with iron: it melts before it can be heated high enough. The method of making it was discovered about 1750 by Mr Huntsman of Sheffield, who still continues to manufacture it. The process was for some time kept secret; but it is now well known in this country, and other manufacturers succeed in it equally well with the original discoverer. It consists in fusing blistered steel in a close crucible, mixed with a certain proportion of pounded glass and charcoal powder. It may be formed also, according to the experiments of Clouet, by melting together 30 parts of iron, one part of charcoal, and one part of pounded glass; or, by surrounding iron in a crucible with a mixture of equal parts of chalk and clay, and heating the crucible gradually to a white heat, and keeping it a sufficient time in that state†. By this last process very good cast steel may be obtained. The carbon is obtained by the decomposition of the carbonic acid, which exists abundantly in the chalk. One part of the iron combines with the oxide of this acid, while the other part combines with the iron‡. From the experiments of Clouet it does not appear that the pre-

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* Collier, *Manchester Memoirs*, v. 117.

† *Jour. de Min.* An. vii. 3.

‡ Guyton and Darcet, Ibid. An. vi. 703.

sence of glass is necessary to constitute cast steel; the only essential ingredients seem to be iron and carbon: but the quantity of carbon is greater than in common steel, and this seems to constitute the difference between these two substances.

Iron combines with most metals.

Alloys of iron.

1. The alloy of gold and iron is very hard, and might, according to Dr Lewis who examined it, be employed with advantage in forming cutting instruments. When these metals are combined in equal proportions, the colour of the alloy is grey: Four parts of iron and one of gold give an alloy almost of the colour of silver. Its specific gravity is less than the mean *. Gold has been proposed as an excellent solder for steel.

2. Platinum is usually found alloyed with iron. Dr Lewis did not succeed in his attempts to unite these metals by fusion, but he melted together cast iron and platinum. The alloy was excessively hard, and possessed ductility.

3. Equal parts of silver and iron, according to Wallerius, form an alloy of the colour of silver, but harder, pretty ductile, and attracted by the magnet.

4. Iron is not acted upon by mercury. There seems to be very little affinity between these metals; accordingly no amalgam of iron is known.

5. Iron may be united to copper by fusion, but not without considerable difficulty. The alloy has been applied to no use. It is of a grey colour, has but little ductility, and is much less fusible than copper.

The affinities of iron, and its oxides, are arranged by Bergman as in the following table:

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* Gellert.

Chap. III.
Affinities.

Iron.	Oxide of Iron.
Nickel,	Oxalic acid,
Cobalt,	Tartarous,
Manganese,	Camphoric*,
Arsenic,	Sulphuric,
Copper,	Mucous,
Gold,	Muriatic,
Silver,	Nitric,
Tin,	Sebacic,
Antimony,	Phosphoric,
Platinum,	Arsenic,
Bismuth,	Fluoric,
Lead,	Succinic,
Mercury,	Citric,
Sulphuret of alkali,	Formic,
Carbon?	Lactic,
Phosphorus?	Acetous,
Sulphur?	Boracic,
	Prussic,
	Carbonic.

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* Bouillon La Grange.

SECT. VIII.

OF TIN.

TIN was known to the ancients in the most remote ages. The Phenicians procured it from Spain [*] and from Britain, with which nations they carried on a very lucrative commerce. At how early a period they imported this metal we may easily conceive, if we recollect that it was in common use in the time of Moses [†].

Properties of tin.

This metal has a fine white colour like silver; and when fresh, its brilliancy is very great. It has a strong disagreeable taste, and emits a peculiar smell when rubbed.

Its hardness is 6 [‡]. Its specific gravity is 7.291; after hammering, 7.299 [§].

It is very malleable: tin leaf, or *tinfoil* as it is called, is about $\frac{1}{1000}$ part of an inch thick, and it might be beat out into leaves as thin again if such were wanted for the purposes of art. Its ductility and tenacity are much inferior to that of any of the metals hitherto described. A tin wire $\frac{1}{12.6}$ inch in diameter is capable of supporting a weight of 31 pounds only without breaking [‖]. Tin is very flexible, and produces a remarkable crackling noise when bended.

When heated to the temperature of 410° [¶], it melts;

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[*] Pliny, lib. 4. cap. 34. and lib. 34. cap. 47.

[†] Numbers xxxi. 22.

[‡] Kirwan's *Miner.* ii. 195.

[§] Brisson.

[‖] Muschenbroeck.

[¶] Lewis.

but a very violent heat is necessary to cause it to evaporate. When cooled slowly, it may be obtained crystallized in the form of a rhomboidal prism[*].

When exposed to the air, it very soon loses it lustre, and assumes a greyish white colour; but undergoes no farther change. Neither is it sensibly altered by being kept under cold water; but when the steam of water is made to pass over red hot tin, it is decomposed, the tin is oxidated, and hydrogen gas is evolved[†].

Oxides.

When tin is melted in an open vessel, its surface becomes very soon covered with a grey powder, which is an oxide of the metal. If the heat be continued, the colour of the powder gradually changes, and at last it becomes white. In this state it is known by the name of *putty*, and employed in polishing glass and other hard bodies. When tin is heated very violently in an open vessel, it takes fire, and is converted into a fine white oxide, which may be obtained in crystals.

Mr Proust has demonstrated, that tin is capable of combining with two different proportions of oxygen, and of forming two oxides, distinguished on account of their colour by the names of the *yellow* and the *white oxide*[‡]. The yellow oxide may be obtained by dissolving tin in diluted nitric acid without the assistance of heat, and then precipitating the oxide by pure potass. It is composed of about 20 parts of oxygen and 80 of tin. Putty is probably often the same with this oxide[§]. The white oxide may be obtained by heating tin in con-

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[*] Pajot, *Jour. de Phys.* xxxviii. 52.

[†] Bouillon La Grange, *Ann. de Chim.* xxxv. 28.

[‡] Ibid. xxviii. 213.

[§] And so, in all probability, are the brown crystals of tin, often found native.

centrated nitric acid. A violent effervescence ensues; and the whole of the tin is converted into a white powder, which is deposited at the bottom of the vessel. It is composed of about 28 parts of oxygen and 72 of tin. The white oxide, obtained by a violent heat, is probably the same with it.

Tin combines with sulphur and phosphorus; but it has never been combined with carbon, hydrogen, or azot.

Sulphuret.

Sulphuret of tin may be formed by throwing bits of sulphur upon the metal melted in a crucible, or by fusing the two ingredients together. It is brittle, heavier than tin, and not so fusible. It is of a bluish colour and lamellated structure, and is capable of crystallizing. According to Bergman, it is composed of 80 parts of tin and 20 of sulphur; according to Pelletier, of 85 parts of tin and 15 of sulphur*.

Sulphurated oxide.

When equal parts of white oxide of tin and sulphur are mixed together and heated gradually in a retort, some sulphur and sulphurous acid are disengaged, and there remains a substance composed of 40 parts of sulphur and 60 of white oxide of tin, formerly called *aurum musivum, musicum* or *mosaicum*, and now *sulphurated oxide of tin*. It consists of beautiful gold coloured flakes, which are used as a paint. The process for making this substance was formerly very complicated. Pelletier first demonstrated its real composition, and was hence enabled to make many important improvements in the manner of manufacturing it†.

Phosphuret.

Phosphuret of tin may be formed by melting in a crucible equal parts of filings of tin and phosphoric

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* *Ann. de Chim.* xiii. 287.

† See his Memoir, Ibid. 280.

glass. Tin has a greater affinity for oxygen than phosphorus has. Part of the metal therefore combines with the oxygen of the glass during the fusion, and flies off in the state of an oxide, and the rest of the tin combines with the phosphorus. The phosphuret of tin may be cut with a knife; it extends under the hammer, but separates in laminæ. When newly cut it has the colour of silver; its filings resemble those of lead. When these filings are thrown on burning coals, the phosphorus takes fire. This phosphuret may likewise be formed by dropping phosphorus gradually into melted tin. According to Pelletier, to whose experiments we are indebted for the knowledge of all the phosphurets, it is composed of about 85 parts of tin and 15 of phosphorus*. Margraf also formed this phosphuret, but he was ignorant of its composition.

Tin is capable of combining with most of the metals, and some of its alloys are much employed.

Alloys.

1. It mixes readily with gold by fusion; but the proportions in which these metals combine chemically are still unknown. When one part of tin and twelve of gold are melted together, the alloy is brittle, hard, and bad coloured. Twenty-four parts of gold and one of tin produce a pale coloured alloy, harder than gold, but possessed of considerable ductility. Gold alloyed with no more than $\frac{1}{7}$ of tin is scarcely altered in its properties, according to Mr Alchorne†; but Mr Tillet, who has lately examined this alloy, found, that whenever it was heated it broke into a number of pieces. It is very difficult to separate these metals from each other,

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* *Ann. de Chim.* xiii. 116.

† Alchorne, *Phil. Trans.*

Book I.

The best method is to fuse the alloy with sulphuret of antimony.

2. The alloy of platinum and tin is very fusible and brittle, at least when these metals are mixed in equal proportions*. Twelve parts of tin and one of platinum form an alloy possessed of considerable ductility, which becomes yellow when exposed to the air.

3. The alloy of silver and tin is very brittle, hard, and durable. The two metals can scarce be separated again. This alloy has been applied to no use.

4. Mercury dissolves tin very readily cold; and these metals may be combined in any proportion by pouring mercury into melted tin. The amalgam of tin, when composed of three parts of mercury and one of tin, crystallizes in the form of cubes, according to Daubenton; but, according to Sage, in grey brilliant square plates, thin towards the edges, and attached to each other so that the cavities between them are polygonal. It is used to silver the backs of glass mirrors.

5. Tin unites very readily with copper, and forms an alloy exceedingly useful for a great variety of purposes. Of this alloy cannons are made: bell metal, bronze, and the mirrors of telescopes are formed of different proportions of the same metals. The addition of tin diminishes the ductility of copper, and increases its hardness, tenacity, fusibility, and sonorousness. The specific gravity of the alloy is greater than the mean density of the two metals. It appears from the experiments of Mr Briche, that this augmentation of density increases with the tin; and that the specific gravity, when the alloy contains 100 parts of copper and 16 of

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* Dr Lewis.

tin, is a maximum: it is 8.87. The specific gravity of equal parts of tin and copper is 8.79, but it ought only to be 8; consequently the density is increased 1.79*. In order to mix the two metals exactly, they ought to be kept a long time in fusion, and constantly stirred, otherwise the greater part of the copper will sink to the bottom, and the greater part of the tin rise to the surface; and there will be formed two different alloys, one composed of a great proportion of copper combined with a small quantity of tin, the other of a great proportion of tin alloyed with a small quantity of copper.

Bronze and the metal of cannons are composed of from 6 to 12 parts of tin combined with 100 parts of copper. This alloy is brittle, yellow, heavier than copper, and has much more tenacity; it is much more fusible, and less liable to be altered by exposure to the air. It was this alloy which the ancients used for sharp-edged instruments before the method of working iron was brought to perfection. The χαλκος of the Greeks, and perhaps the *æs* of the Romans, was nothing else. Even their copper coins contain a mixture of tin†.

Bell metal is usually composed of three parts of copper and one part of tin. Its colour is greyish white; it is very hard, sonorous, and elastic. The greater part of the tin may be separated by melting the alloy, and then pouring a little water on it. The tin decomposes the water, is oxidated, and thrown upon the surface.

The mirrors of telescopes are formed by melting together three parts of tin and one part of copper. This alloy is very hard, of the colour of steel, and admits of

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* *Jour. de Min.* An. v. 881.

† See Dizé's Analysis, *Jour. de Phys.* 1790.

a fine polish. But besides this, there are many other compounds often used for the same purpose.

Vessels of copper, especially when used as kitchen utensils, are usually covered with a thin coat of tin to prevent the copper from oxidating, and to preserve the food which is prepared in them from being mixed with any of that poisonous metal. These vessels are then said to be *tinned*. Their interior surface is scraped very clean with an iron instrument, and rubbed over with sal ammoniac. The vessel is then heated, and a little pitch thrown into it, and allowed to spread on the surface. Then a bit of tin is applied all over the hot copper, which instantly assumes a silvery whiteness. The intention of the previous steps of the process is to have the surface of the copper perfectly pure and metallic; for tin will not combine with the oxide of copper. The coat of tin thus applied is exceedingly thin. Bayen ascertained, that a pan nine inches in diameter, and three inches three lines in depth, when tinned, only acquired an additional weight of 21 grains. Nor is there any method of making the coat thicker. More tin indeed may be applied; but a moderate heat melts it, and causes it to run off.

6. Tin does not combine readily with iron. An alloy, however, may be formed, by fusing them in a close crucible, completely covered from the external air. We are indebted to Bergman for the most precise experiments on this alloy. When the two metals were fused together, he always obtained two distinct alloys: the first, composed of 21 parts of tin and one part of iron; the second, of two parts of iron and one part of tin. The first was very malleable, harder than tin,

and not so brilliant; the second but moderately malleable, and too hard to yield to the knife*.

The formation of *tinplate* is a sufficient proof of the affinity between these two metals. This very useful alloy, known in Scotland by the name of *white iron*, is formed by dipping into melted tin thin plates of iron, thoroughly cleaned by rubbing them with sand, and then steeping them 24 hours in water acidulated by bran or sulphuric acid. The tin not only covers the surface of the iron, but penetrates it completely, and gives the whole a white colour.

Affinities.

The affinities of tin, and its oxides, are, according to Bergman, as follows:

TIN.	OXIDE OF TIN.
Zinc,	Sebacic acid,
Mercury,	Tartarous,
Copper,	Muriatic,
Antimony,	Sulphuric,
Gold,	Oxalic,
Silver,	Arsenic,
Lead,	Phosphoric,
Iron,	Nitric,
Manganese,	Succinic,
Nickel,	Fluoric,
Arsenic,	Mucous,
Platinum,	Citric,
Bismuth,	Formic,
Cobalt,	Lactic,
Sulphur,	Acetous,
Phosphorus.	Boracic,
	Prussic.

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* Bergman, iii. 471.

SECT. VIII.

OF LEAD.

LEAD appears to have been very early known. It is mentioned several times by Moses. The ancients seem to have considered it as nearly related to tin.

Properties of lead.

Lead is of a bluish white colour; and when newly melted is very bright, but it soon becomes tarnished by exposure to the air. It has scarcely any taste, but emits on friction a peculiar smell. It stains paper or the fingers of a bluish colour. When taken internally it acts as a poison.

Its hardness is $5\frac{1}{2}$; its specific gravity is 11.3523[*]. Its specific gravity is not increased by hammering, neither does it become harder, as is the case with other metals: a proof that the hardness which metals assume under the hammer is in consequence of an increase of density.

It is very malleable, and may be reduced to very thin plates by the hammer; it may be also drawn out into wire, but its ductility is not great. Its tenacity is such, that a lead wire $\frac{1}{12.6}$ inch diameter is capable of supporting only 18.4 pounds without breaking.

It melts, according to Sir Isaac Newton, when heated to the temperature of 540° Fahrenheit; but Morveau makes its fusing point as high as 594°. When a very strong heat is applied, the metal boils and evapo-

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[*] Brisson.

rates. If it be cooled slowly, it crystallizes. The Abbé Mongez obtained it in quadrangular pyramids, lying on one of their sides. Each pyramid was composed as it were of three layers. Pajot obtained it in the form of a polyhedron with 32 sides, formed by the concourse of six quadrangular pyramids*.

When exposed to the air, it soon loses its lustre, and acquires first a dirty grey colour, and at last its surface becomes almost white. This is owing to its gradual combination with oxygen, and conversion into an oxide: but this conversion is exceedingly slow; the external crust of oxide, which forms first, preserves the rest of the metal for a long time from the action of the air.

Water has no direct action upon lead; but it facilitates the action of the external air. For when lead is exposed to the air, and kept constantly wet, it is oxidated much more rapidly than it otherwise would be. Hence the reason of the white crust which appears upon the sides of leaden vessels containing water, just at the place where the upper surface of the water usually terminates.

Oxides.

Lead is capable of combining with four different proportions of oxygen, and of forming four oxides, distinguished by the names of *grey*, *white* or *yellow*, *red*, and *brown oxides*.

1. When lead is kept melted in an open vessel, its surface is soon covered with a grey coloured pellicle. When this pellicle is removed, another soon succeeds it; and by continuing the heat, the whole of the lead may soon be converted into this substance. If these pelli-

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* *Journ. de Phys.* xxxviii. 53.

Book I.

cles be heated and agitated for a short time in an open vessel, they assume the form of a grey powder, which is the *grey oxide of lead.* This oxide has not been analysed with accuracy; but it has been ascertained, that it contains only a small proportion of oxygen.

2. If we continue to expose this oxide to heat for some time longer in an open vessel, it absorbs more oxygen, assumes a yellow colour, and is then known in commerce by the name of *massicot.* This is the *yellow oxide of lead.*

When thin plates of lead are exposed to the vapour of warm vinegar, they are gradually corroded, and converted into a heavy white powder, used as a paint, and called *white lead.* This is the white oxide of lead. It may be obtained also by dissolving lead in nitric acid, and precipitating it by potass; or by boiling lead in strong nitric acid. In either case the white oxide is left behind. Mr Proust has shown that this oxide is composed of about 93 parts of lead and 7 parts of oxygen; and that, notwithstanding the difference of colour, the yellow oxide contains precisely the same proportion of oxygen, and is therefore the same substance.

3. If the yellow oxide of lead be ground to a fine powder, then put into a furnace and constantly stirred while the flame of the burning coals plays against its surface, it is in about 48 hours converted into a beautiful red powder known by the name of *minium* or *red lead.* This powder, which is likewise used as a paint, and for various other purposes, is the *red oxide of lead.* It is composed of about 91 parts of lead and 9 of oxygen *.

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* Fourcroy, vi. 89.

4. If nitric acid, of the specific gravity 1.260, be poured upon the red oxide of lead, 185 parts of the oxide are dissolved; but 15 parts remain in the state of a black or rather deep brown powder*. This is the *brown oxide of lead* which was first discovered by Scheele. The best method of preparing it is the following, which was pointed out by Proust, and afterwards still farther illustrated by Vauquelin: Put a quantity of red oxide of lead into a vessel partly filled with water, and make oxy-muriatic acid gas† pass into it. The oxide becomes deeper and deeper coloured, and is at last dissolved. Pour potass into the solution, and the brown oxide of lead precipitates. By this process 68 parts of brown oxide may be obtained for every 100 of red oxide employed‡. This oxide is composed of about 79 parts of lead and 21 of oxygen. It is of a brilliant flea-brown colour. When heated it emits oxygen gas, becomes yellow, and melts into a kind of glass. When rubbed along with sulphur in a mortar, it sets the sulphur on fire, and causes it to burn with a brilliant flame. When heated on burning coals the lead is reduced§.

Cupellation,

All the oxides of lead are very easily converted into glass; and in that state they oxidate and combine with almost all the other metals except gold, platinum, and silver. This property renders lead exceedingly useful in separating gold and silver from the baser metals with which they happen to be contaminated. The gold or silver to be purified is melted along with lead, and kept

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* Scheele, i. 113. and Proust, *Ann. de Chim.* xxiii. 98.

† This acid will be described in the subsequent Book.

‡ Fourcroy, iv. 91.

§ Vauquelin, *Fourcroy*, vi. 92.

for some time in that state in a flat cup, called a *cupel*, made of burnt bones. The lead is gradually vitrified and sinks into the cupel, carrying along with it all the metals which were mixed with the silver and gold, and leaving these metals on the cupel in a state of purity. This process is called *cupellation.* The lead employed is afterwards extracted from the cupels, and is known in commerce by the name of *litharge.* It is a half vitrified substance, of a whitish red colour, and composed of scales. It is merely an oxide of lead more or less contaminated with the oxides of other metals. But the best litharge is made by oxidating lead directly, and then increasing the heat till the oxide is fused. The more violent the fusing heat the whiter is the litharge.

Lead has not yet been combined with carbon, hydrogen, nor azot; but it combines readily with sulphur and phosphorus.

Sulphuret.

Sulphuret of lead may be formed either by stratifying its two component parts, and melting them in a crucible, or by dropping sulphur at intervals on melted lead. The sulphuret of lead is brittle, brilliant, of a deep blue grey colour, and much less fusible than lead. These two substances are often found naturally combined; the compound is then called *galena*, and is usually crystallized in cubes. Sulphuret of lead is composed, according to the experiments of Wenzel, of 86.8 parts of lead and 13.2 of sulphur*.

Phosphuret.

Phosphuret of lead may be formed by mixing together equal parts of filings of lead and phosphoric glass, and then fusing them in a crucible. It may be cut with a knife, but separates into plates when hammered. It is

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* Kirwan's *Miner.* ii. 492.

of a silver white colour with a shade of blue, but it soon tarnishes when exposed to the air. This phosphuret may also be formed by dropping phosphorus into melted lead. It is composed of about 12 parts of phosphorus and 88 of lead*.

Lead is capable of combining with most of the metals.

Alloys.

1. Lead may be easily alloyed with gold by fusion. The colour of the gold is injured, and its ductility diminished. This alloy is of no use; but it is often formed in order to purify gold by cupellation.

2. Platinum and lead unite in a strong heat: the alloy is brittle, of a purplish colour, and soon changes on exposure to the air†. Many experiments have been made with this alloy, in order, if possible, to purify platinum from other metals by cupellation, as is done successfully with silver and gold: But scarcely any of the experiments have succeeded; because platinum requires a much more violent heat to keep it in fusion than can be easily given.

3. Silver is often alloyed with lead in order to purify it by cupellation. This alloy is very fusible, much softer than silver, and has much less tenacity, elasticity, and sonorousness: its colour is nearly that of lead, and its specific gravity greater than the mean density of the metals alloyed.

4. Mercury amalgamates readily with lead in any proportion, either by triturating it with lead filings, or by pouring it upon melted lead. The amalgam is white and brilliant, and, when the quantity of lead is sufficient, assumes a solid form. It is capable of crystalli-

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* Pelletier, *Ann. de Chim.* xiii. 114.

† Fourcroy.

zing. The crystals are composed of one of part lead and one and a half of mercury[*].

5. Copper and lead may be easily combined by fusion. When the lead exceeds, the alloy is of a grey colour, and ductile while cold but brittle when hot. It is employed sometimes for the purpose of making printers types for very large characters[†].

6. Iron does not combine with lead.

7. Lead and tin may be combined in any proportion by fusion. This alloy is harder, and possesses much more tenacity than tin. Muschenbroeck informs us that these qualities are a maximum when the alloy is composed of 3 parts of tin and 1 of lead. What is called in this country *ley pewter* is often scarcely any thing else than this alloy. *Tinfoil*, too, almost always is a compound of tin and lead. This alloy, in the proportion of two parts of lead and one of tin, is more soluble than either of the metals separately. It is accordingly used by plumbers as a solder.

The affinities of lead and of its oxides are as follows:

Affinities.

LEAD.	OXIDE OF LEAD.
Gold,	Sulphuric acid,
Silver,	Sebacic
Copper,	Mucous,
Mercury,	Oxalic,
Bismuth,	Arsenic,
Tin,	Tartarous,
Antimony,	Muriatic,
Platinum,	Phosphoric,
Arsenic,	Sulphurous,

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[*] Dijon Academicians.

[†] Fourcroy, vi. 266.

Zinc,	Suberic,
Nickel,	Nitric,
Iron,	Fluoric,
Sulphuret of alkali,	Citric,
Sulphur,	Formic,
Phosphorus?	Lactic,
	Acetous,
	Boracic,
	Prussic,
	Carbonic,
	Fixed alkali.

THE ancients gave to the seven metals last described (omitting *platinum*, which they did not know) the names of the planets, and denoted each of them by particular marks, which represented both the planet and the metal.

Names and marks given to the metals by the ancients.

Gold was the Sun, and represented by ☉
Silver . . . . Moon, ... ☽
Mercury : . . Mercury, ... ☿
Copper . . . Venus, ... ♀
Iron . . . . . . Mars, ... ♂
Tin . . . . . . Jupiter, ... ♃
Lead . . . . . . Saturn, ... ♄

It seems most probable that these names were first given to the planets; and that the seven metals, the only ones then known, were supposed to have some relation to the planets or to the gods that inhabited them, as the number of both happened to be the same. It appears from a passage in Origen, that these names first arose among the Persians*. Why each particular metal was denominated by a particular planet it is not easy to see. Many conjectures have been made, but scarcely any of them are satisfactory.

As to the characters by which these metals were expressed, astrologers seem to have considered them as the attributes of the deities of the same name. The circle, in the earliest periods among the Egyptians, was the symbol of divinity and perfection; and seems with great propriety to have been chosen by them as the character

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* *Contra Celsum*, lib. vi. 22.—" Celsus de quibusdam Persarum mysteriis sermonem facit. Harum rerum, inquit, aliquod reperitur in Persarum doctrina Mithracisque eorum mysteriis vestigium. In illis enim duæ cælestes conversiones, alia stellarum fixarum, errantium alia, et animæ per eas transitus quodam symbolo representantur, quod hujusmodi est. Scala altas portas habens, in summa autem octava porta. Prima portarum plumbea, altera stannea, tertia ex ære, quarta ferrea, quinta ex ære mixto, sexta argentea, septima ex auro. *Κλιμαξ ὑψιπυλος, επι δ' αιτη πυλη ογδοη.* Ἡ *πρωτη των πυλων μολιβδου, ἡ δευτερα κασσιτερου, ἡ τριτη χαλκου, ἡ τεταρτη σιδηρου, ἡ πεμπτη καραστου νομισματος. ἡ ἑκτη αργυρου, χρυσου δ' ἡ ἑβδομη.* Primum assignant Saturno tarditatem illius sideris plumbo indicantes: alteram Veneri, quam referunt, ut ipsi quidem putant, stanni splendor et mollities; tertiam Jovi, aheneam illam quidem et solidam: quartam Mercurio, quia Mercurius et ferrum, uterque operum omnium tolerantes, ad mercaturam utiles, laborum patientissimi. Marti quintam, inæqualem illam et variam propter mixturam. Sextam, quæ argentea est, lunæ; septimam auream soli tribuunt, quia solis et lunæ colores hæc duo metalla referunt."

Borrichius suspects, with a good deal of probability, that the names of the gods in this passage have been transposed by transcribers, either through ignorance or design. He arranges them as follows: " Secundam portam faciunt Jovis, comparantes ei stanni splendorem et mollitiem; tertiam Veneris æratam et solidam; quartam Martis, est enim laborum patiens, æque ac ferrum, celebratus hominibus; quintam Mercurii propter misturam inæqualem ac variam et quia negotiator est; sextam Lunæ argenteam; septimam Solis auream."—*Ol. Borrichius de ortu et progressu Chemiæ.* Hafniæ, 1668, 4to, p. 29.

of the sun, especially as, when surrounded by small strokes projecting from its circumference, it may form some representation of the emission of rays. The semicircle is, in like manner, the image of the moon; the only one of the heavenly bodies that appears under that form to the naked eye. The character ♄ is supposed to represent the scythe of Saturn; ♃ the thunderbolts of Jupiter; ♂ the lance of Mars, together with his shield; ♀ the looking-glass of Venus; and ☿ the caduceus or wand of Mercury.

The alchymists, however, give a very different account of these symbols. Gold was the most perfect metal, and was therefore denoted by a circle. Silver approached nearest it; but as it was inferior, it was denoted only by a semicircle. In the character ☿ the adepts discovered gold with a silver colour. The cross at the bottom expressed the presence of a mysterious something, without which mercury would be silver or gold. This something is combined also with copper; the possible change of which into gold is expressed by the character ♀. The character ♂ declares the like honourable affinity also; though the semicircle is applied in a more concealed manner: for, according to the properest mode of writing, the point is wanting at the top, or the upright line ought only to touch the horizontal, and not to intersect it. Philosophical gold is concealed in steel; and on this account it produces such valuable medicines. Of tin, one half is silver, and the other consists of the unknown something; for this reason, the cross with the half moon appears in ♃. In lead this something is predominant, and a similitude is observed in it to silver. Hence in its character ♄ the cross stands at the top, and the silver character is only suspended on the right hand behind it.

Professor Beckmann, however, who has examined this subject with much attention, thinks, that these characters are mere abbreviations of the old names of the planets. " The character of Mars (he observes *), according to the oldest mode of representing it, is evidently an abbreviation of the word Θουρος, under which the Greek mathematicians understood that deity; or, in other words, the first letter Θ, with the last letter ς placed above it. The character of Jupiter was originally the initial letter of Ζευς; and in the oldest manuscripts of the mathematical and astrological works of Julius Firmicus, the capital Z only is used, to which the last letter ς was afterwards added at the bottom, to render the abbreviation more distinct. The supposed looking-glass of Venus is nothing else than the initial letter distorted a little of the word Φωσφορος, which was the name of that goddess. The imaginary scythe of Saturn has been gradually formed from the two first letters of his name Κρονος, which transcribers, for the sake of dispatch, made always more convenient for use, but at the same time less perceptible. To discover in the pretended caduceus of Mercury the initial letter of his Greek name Στιλβων, one needs only look at the abbreviations in the oldest manuscripts, where they will find that the Σ was once written as C; they will remark also that transcribers, to distinguish this abbreviation from the rest still more, placed the C thus ◡, and added under it the next letter τ. If those to whom this deduction appears improbable will only take the trouble

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* *History of Inventions*, English Transl. iii. 67.

to look at other Greek abbreviations, they will find many that differ still farther from the original letters they express than the present character ☿ from the C and τ united. It is possible also that later transcribers, to whom the origin of this abbreviation was not known, may have endeavoured to give it a greater resemblance to the caduceus of Mercury. In short, it cannot be denied that many other astronomical characters are real symbols, or a kind of proper hieroglyphics, that represent certain attributes or circumstances, like the characters of Aries, Leo, and others quoted by Saumaise."

SECT. IX.

OF NICKEL.

Discovery of nickel.

THERE is found in different parts of Germany a heavy mineral of a reddish brown colour, and not unlike tarnished copper. When exposed to the air, it soon loses its lustre, becomes at first brownish, and is at last covered with green spots. It was at first taken for an ore of copper; but as none of that metal can be extracted from it, the German miners gave it the name of *Kupfernickel*, or "false copper." Hierne, who may be considered as the father of the Swedish chemists, is the first person who mentions this mineral. He gives a description of it in a book published by him in 1694 on the art of detecting metals. It was generally considered by mineralogists as an ore of copper, till it was examined by the celebrated Cronstedt. He concluded

Book I.

from his experiments, which were published in the Stockholm Transactions for 1751 and 1754, that it contained a new metal, to which he gave the name of *nickel.*

This opinion was embraced by all the Swedes, and indeed by the greater number of chemical philosophers. Some, however, particularly Sage and Monnet, affirmed, that it contained no new metal, but merely a compound of various known metals, which could be separated from each other by the usual processes. These assertions induced Bergman to undertake a very laborious course of experiments, in order if possible to obtain *nickel* in a state of purity: for Cronstedt had not been able to separate a quantity of arsenic, cobalt, and iron, which adhered to it with much obstinacy. These experiments, which were published in 1775 *, fully confirmed the conclusions of Cronstedt. Bergman has shewn that nickel possesses peculiar properties; and that it can neither be reduced to any other metal, nor formed artificially by any combination of metals. It must therefore be considered as a peculiar metal. It may possibly be a compound, and so may likewise many other metals; but we must admit every thing to be a peculiar body which has peculiar properties, and we must admit every body to be simple till some proof be actually produced that it is a compound; otherwise we forsake the road of science, and get into the regions of fancy and romance. If any doubts still remained, they have been removed by the late experiments made by the *School of Mines* in Paris, which coincide exactly with those of Bergman.

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* Bergman, ii. 231.

Its properties.

Nickel, when perfectly pure[*], is of a fine white colour resembling silver; and, like that metal, it leaves a white trace when rubbed upon the polished surface of a hard stone[†].

Its hardness is 8½, so that it is rather softer than iron. Its specific gravity is 9[‡].

Its malleability, while cold, is rather greater than that of iron; but it cannot be heated without being oxidated, and in consequence rendered brittle[§].

It is attracted by the magnet as strongly as iron. Like that metal, it may be converted into a magnet; and in that state points to the north when freely suspended precisely as a common magnetic needle[||].

It requires for fusion a temperature at least equal to 150° Wedgewood[¶]. It has not hitherto been crystallized.

Oxide.

When heated in an open vessel, it combines with oxygen, and assumes a green colour; and if the heat be continued, acquires a tinge of purple[**]. The oxide of nickel, according to Klaproth, is composed of 77 parts of nickel and 33 of oxygen[††].

Nickel has not been combined with carbon, hydrogen, nor azot; but it combines readily with sulphur and phosphorus.

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[*] The method of obtaining the metals from their ores in a state of purity will be explained in the Second Part of this Work.

[†] Fourcroy, *Discours Preliminaire*, p. 117.

[‡] Bergman, ii. 267. and Fourcroy, Ibid.

[§] Fourcroy, Ibid.

[||] Bergman, Klaproth, Fourcroy, Ibid.

[¶] Bergman, ii. 269.

[**] Fourcroy, *Discours Preliminaire*, p. 117.

[††] Kirwan's *Miner.* ii. 490.

Sulphuret. Cronstedt found, that sulphuret of nickel may be easily formed by fusion. The sulphuret which he obtained was yellow and hard, with small sparkling facets; but the nickel which he employed was impure.

Phosphuret. Phosphuret of nickel may be formed either by fusing nickel along with phosphoric glass, or by dropping phosphorus into it while red hot. It is of a white colour; and when broke it exhibits the appearance of very slender prisms collected together. When heated, the phosphorus burns, and the metal is oxidated. It is composed of 83 parts of nickel and 17 of phosphorus *. The nickel, however, on which this experiment was made, was not pure.

Alloys. The alloys of this metal are but very imperfectly known.

With gold it forms a white and brittle alloy: with copper a white, hard, brittle alloy, easily oxidated when exposed to the air: with iron it combines very readily, and forms an alloy whose properties have not been sufficiently examined: with tin it forms a white, hard, brittle mass, which swells up when heated: with lead it does not combine without difficulty: with silver and mercury it refuses to unite: its combination with platinum has not been tried †.

The affinities of nickel, and its oxides, are, according to Bergman, as follows:

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* Pelletier, *Ann. de Chim.* xiii. 135.

† Cronstedt.

Affinities.

NICKEL.	OXIDE OF NICKEL.
Iron,	Oxalic acid,
Cobalt,	Muriatic,
Arsenic,	Sulphuric,
Copper,	Tartarous,
Gold,	Nitric,
Tin,	Sebacic,
Antimony,	Phosphoric,
Platinum,	Fluoric,
Bismuth,	Mucous,
Lead,	Succinic,
Silver,	Citric,
Zinc,	Formic,
Sulphuret of alkali,	Lactic,
Sulphur,	Acetous,
Phosphorus.	Arsenic,
	Boracic,
	Prussic,
	Carbonic,
	Ammonia.

SECT. X.

OF ZINC.

Discovery of zinc.

THE ancients were acquainted with a mineral to which they gave the name of *Cadmea*, from Cadmus, who first taught the Greeks to use it. They knew that when melted with copper it formed brass; and that when burnt, a white spongy kind of ashes was volatilized, which they used in medicine *. This mineral contain-

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* Pliny, lib. xxxiv. cap. 2. and 10.

Book I.

ed a good deal of zinc; and yet there is no proof remaining that the ancients were acquainted with that metal*. It is first mentioned in the writings of Albertus Magnus, who died in 1280; but whether he had seen it is not so clear, as he gives it the name of *marcasite of gold*, which implies, one would think, that it had a yellow colour†. The word *zinc* occurs first in

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* Grignon indeed says, that something like it was discovered in the ruins of an ancient Roman city in Champagne; but the substance which he took for it was not examined with any accuracy. It is impossible therefore to draw any inference whatever from his assertion. *Bulletin des fouilles d'une ville Romaine*, p. 11.

† The passages in which he mentions it are as follows: They prove, I think incontestibly, that it was not the metal, but the ores of the metal, with which Albertus was acquainted. *De Mineral.* lib. ii. cap. 11. "Marchasita, sive marchasida ut quidam dicunt, est lapis in substantia, et habet multas species, quare colorem accipit cujuslibet metalli, et sic dicitur marchasita argentea et aurea, et sic dicitur aliis. Metallum tamen quod colorat eum non distillat ab ipso, sed evaporat in ignem, et sic relinquitur cinis inutilis, et hic lapis notus est apud alchimicos, et in multis locis veniuntur.

Lib. iii. cap. 10. "Æs autem invenitur in venis lapidis, et quod est apud locum qui dicitur Goselaria est purissimum et optimum, et toti substantiæ lapidis incorporatum, ita quod totus lapis est sicut marchasita aurea, et profundatum est melius ex eo quod purius.

Lib. v. cap. 5. "Dicimus igitur quod marchasita duplicem habet in sui creatione substantiam, argenti vivi scilicet mortificati, et ad fixionem approximantis, et sulphuris adurentis. Ipsam habere sulphureitatem comperimus manifesta experientia. Nam cum sublimatur, ex illa emanat substantia sulphurea manifesta comburens. Et sine sublimatione similiter perpenditur illius sulphureitas.

"Nam si ponatur ad ignitionem, non suscipit illam priusquam inflammatione sulphuris inflammetur, et ardeat. Ipsam vero argenti vivi substantiam manifestatur habere sensibiliter. Nam albedinem præstat Veneri meri argenti, quemadmodum et ipsum argentum vivum, et colorem in ipsius sublimatione cælestium præstare, et luciditatem manifestam metallicam habere videmus, quæ certum reddunt artificem Alchimiæ, illam has substantias continere in radice sua."

the writings of Paracelsus, who died in 1541. He informs us very gravely, that it is a metal, and not a metal, and that it consists chiefly of the ashes of copper[*]. This metal has also been called *spelter*.

Zinc has never been found in Europe in a state of purity, and it was long before a method was discovered of extracting it from its ore[†]. Henkel pointed out one in 1721; Von Swab obtained it by distillation in 1742; and Margraf published a process in the Berlin Memoirs in 1746[‡].

Its properties.

Zinc is of a brilliant white colour, with a shade of blue, and is composed of a number of thin plates adhering together. When this metal is rubbed for some time between the fingers, they acquire a peculiar taste, and emit a very perceptible smell.

Its hardness is $6\frac{1}{2}$. When rubbed upon the fingers it tinges them of a black colour. Its specific gravity, after it has been melted, is 6.861; after it has been compressed, 7.1908[§]; so that its density is increased $\frac{1}{20}$.

This metal forms as it were the limit between the brittle and the malleable metals. Its malleability is by no means to be compared with that of the metals already described; yet it is not brittle, like the metals which are to follow. When struck with a hammer, it does not break, but yields, and becomes somewhat flatter; and by a cautious and equal pressure, it may be reduced to pretty thin plates, which are supple and elastic, but cannot be folded without breaking. This pro-

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[*] See vol. vi. of his Works in quarto.

[†] The real discoverer of this method appears to have been Dr Isaac Lawson. See *Pott*, iii. diss. 7. and Watson's *Chemical Essays*.

[‡] Bergman, ii. 309.

[§] Brisson.

perty of zinc was first ascertained by Mr Sage *. When heated to about 400°, it becomes so brittle, that it may be reduced to powder in a mortar.

It is not ductile. Its tenacity has not been ascertained.

When heated to the temperature of about 700° †, it melts; and if the heat be increased, it evaporates, and may be easily distilled over in close vessels. When allowed to cool slowly, it crystallizes in small bundles of quadrangular prisms, disposed in all directions. If they are exposed to the air while hot, they assume a blue changeable colour ‡.

When exposed to the air, its lustre is soon tarnished, but it scarcely undergoes any other change. When kept under water its surface soon becomes black, the water is slowly decomposed, hydrogen gas is emitted, and the oxygen combines with the metal. If the heat be increased, the decomposition goes on more rapidly; and if the steam of water is made to pass over zinc at a very high temperature, it is decomposed so rapidly, that very violent detonations take place §.

Oxide.

When zinc is kept melted in an open vessel, its surface is soon covered with a grey-coloured pellicle, in consequence of its combination with oxygen. When this pellicle is removed, another soon succeeds it; and in this manner may the whole of the zinc be oxidated. When these pellicles are heated and agitated in an open vessel, they soon assume the form of a grey powder, often having a shade of yellow. This powder has been called the *grey oxide of zinc*. When zinc is raised to

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* *Jour. de Min.* An. v. 595.

† Bergman.

‡ Mongez.

§ Lavoisier.

a very strong red heat in an open vessel, it takes fire, and burns with a very brilliant white flame, and at the same time emits a vast quantity of very light white flakes. These are merely an *oxide of zinc*. This oxide was well known to the ancients. Dioscorides describes the method of preparing it. The ancients called it *pompholyx;* the early chemists gave it the name of *nihil album*, *lana philosophica*, and *flowers of zinc*. Dioscorides compares it to wool*.

Mr Proust has lately shown, that zinc is only capable of combining with one proportion of oxygen, and of forming one oxide, namely, the *white oxide*. This oxide is composed of 80 parts of zinc and 20 of oxygen †. It may be formed not only by burning zinc, but also by dissolving it in diluted sulphuric or nitric acid, and precipitating it by potass. This oxide is used as a paint; but its colour must be perfectly white. When zinc happens to contain a little iron, which is almost always the case with the zinc of commerce, the oxide obtained has a tinge of yellow, because it is mixed with a little yellow oxide of iron. What is called the *grey oxide of zinc* is probably nothing more than the white oxide, mixed with a little zinc in the metallic state. It contains, at an average, about 85 parts of zinc and 15 of oxygen ‡.

The reduction of the oxide of zinc is an operation of great difficulty, in consequence of the strong affinity which exists between zinc and oxygen. It must be mixed with charcoal, and exposed to a strong heat in

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* *Εριων τολυπαις αφομοιουνται.* V. 85. p. 352.

† *Ann. de Chim.* xxxv. 51.

‡ Morveau, Kirwan's *Miner.* ii. 489.

vessels which screen it from the contact of the external air.

Azotic gas has no action on zinc. Hydrogen gas dissolves a little of it in certain situations. It is usual to procure hydrogen gas, by dissolving zinc in diluted sulphuric acid. The gas thus obtained is as pure as any which can be procured. It carries along with it, however, a little zinc in solution; but it deposits it again upon the sides of the glass jars, and on the surface of the water over which it stands. This gas also contains often a little carbonated hydrogen gas; a proof that zinc frequently contains carbon. When this metal is dissolved in sulphuric acid, it deposits a black insoluble powder, which the French chemists found to be carburet of iron *. It is uncertain whether it be this carburet, or carbon combined with zinc, which gives occasion to the production of the carbonated hydrogen gas.

Sulphurated oxide.

Sulphur does not seem capable of combining with zinc; but it combines with the oxide of zinc when melted along with it in a crucible. This was first discovered by Dehne in 1781 †. The experiment was afterwards repeated by Morveau ‡. The sulphurated oxide of zinc is of a dark brown colour, and brittle. It exists native in great abundance, and is known by the name of *blende*.

Zinc may be combined with phosphorus, by dropping

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* Proust has ascertained, that this black powder is often not carburet of iron, but a mixture of arsenic, copper, and lead. *Ann. de Chim.* xxxv. 51.

† *Chem. Journ.* p. 46. and Crell's *Annals*, 1786, i. 7.

‡ *Mem. de l'Acad. de Dijon*, 1783.

Phosphuret.

small bits of phosphorus into it while in a state of fusion. Pelletier, to whom we are indebted for the experiment, added also a little resin, to prevent the oxidation of the zinc. Phosphuret of zinc is of a white colour, a metallic splendor, but resembles lead more than zinc. It is somewhat malleable. When hammered or filed, it emits the odour of phosphorus. When exposed to a strong heat, it burns like zinc*.

Phosphurated oxide.

Phosphorus combines also with the oxide of zinc; a compound which Margraf had obtained during his experiments on phosphorus. When 12 parts of oxide of zinc, 12 parts of phosphoric glass, and 2 parts of charcoal powder, are distilled in an earthen ware retort, and a strong heat applied, a metallic substance sublimes of a silver white colour, which when broken has a vitreous appearance. This, according to Pelletier, is phosphurated oxide of zinc. When heated by the blowpipe, the phosphorus burns, and leaves behind a glass, transparent while in fusion, but opaque after cooling†.

Phosphurated oxide of zinc is obtained also when two parts of zinc and one part of phosphorus are distilled in an earthen retort. The products are, 1. Zinc; 2. Oxide of zinc; 3. A red sublimate, which is phosphurated oxide of zinc; 4. Needleform crystals, of a metallic brilliancy, and a bluish colour. These also Pelletier considers as phosphurated oxide of zinc ‡.

Alloys.

Zinc combines with almost all the metals, and some of its alloys are exceedingly useful.

1. It may be united to gold in any proportion by fusion. The alloy is the whiter and the more brittle the

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[*] *Ann. de Chim.* xiii. 129.

[†] Pelletier, Ibid. 128.

[‡] Ibid. 125.

greater quantity of zinc it contains. An alloy, consisting of equal parts of these metals, is very hard and white, receives a fine polish, and does not tarnish readily. It has therefore been proposed by Mr Malouin * as very proper for the specula of telescopes. One part of zinc is said to destroy the ductility of 100 parts of gold †.

2. Platinum combines very readily with zinc. The alloy is brittle, pretty hard, very fusible, of a bluish white colour, not so clear as that of zinc ‡.

3. The alloy of silver and zinc is easily produced by fusion. It is brittle, and has not been applied to any use.

4. Zinc may be combined with mercury, either by triturating the two metals together, or by dropping mercury into melted zinc. This amalgam is solid. It crystallizes when melted and cooled slowly into lamellated hexagonal figures, with cavities between them. They are composed of one part of zinc and two and a half of mercury §. It is used to rub on electrical machines, in order to excite electricity.

5. Zinc combines readily with copper, and forms one of the most useful of all the metallic alloys. The metals are usually combined together by stratifying plates of copper and a native oxide of zinc combined with carbonic acid, called *calamine*, and applying heat. When the zinc does not exceed a fourth part of the copper, the alloy is known by the name of *brass*. It is of a beautiful yellow colour, more fusible than copper, and not so apt to tarnish. It is malleable, and so ductile that it

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* *Mem. Acad. Par.* 1742.

† Keir's *Macquer's Dictionary*.

‡ Dr Lewis.

§ *Elemens de Chim. Dijon*, t. 3.

may be drawn out into wire. Its density is greater than the mean. It ought to be by calculation 7.6296, but it actually is 8.3958; so that its density is increased by about $\frac{1}{10}$th. When the alloy contains three parts of zinc and four of copper, it assumes a colour nearly the same with gold, but it is not so malleable as brass. It is then called *pinchbeck*, *prince's metal*, or *Prince Rupert's metal*. Brass was known, and very much valued by the ancients. They used an ore of zinc to form it, which they called *cadmia*. Dr Watson has proved that it was to brass which they gave the name of *orichalcum**. Their *æs* was copper, or rather bronze †.

6. It is very difficult to form an alloy of iron and zinc. Wallerius has shewn that iron is capable of combining with a small proportion of zinc; and Malouin has shewn that zinc may be used instead of tin to cover iron plates; a proof that there is an affinity between the two metals ‡.

7. Tin and zinc may be easily combined by fusion. The alloy is much harder than zinc, and scarcely less ductile. This alloy is often the principal ingredient in the compound called *pewter*.

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* *Manchester Transactions*, vol. ii. p. 47.

† The ancients do not seem to have known accurately the difference between copper, brass, and bronze. Hence the confusion observable in their names. They considered brass as only a more valuable kind of copper, and therefore often used the word *æs* indifferently to denote either. It was not till a late period that mineralogists began to make the distinction. They called copper *æs cyprium*, and afterwards only *cyprium*, which in process of time was converted into *cuprum*. When these changes took place is not known accurately. Pliny uses *cyprium*, lib. xxxvi. cap. 26. The word *cuprum* occurs first in Spartian, who lived about the year 290. He says, in his life of Caracalla, *cancelli ex ære vel cupro*.

‡ *Mem. Par.* 1742.

8. The alloy of lead and zinc has been examined by Wallerius, Gellert, Muschenbroeck, and Gmelin. This last chemist succeeded in forming the alloy by fusion. He put some suet into the mixture, and covered the crucible, in order to prevent the evaporation of the zinc. When the zinc exceeded the lead very much, the alloy was malleable, and much harder than lead. A mixture of two parts of zinc and one of lead formed an alloy more ductile and harder than the last. A mixture of equal parts of zinc and lead formed an alloy differing little in ductility and colour from lead; but it was harder, and more susceptible of polish, and much more sonorous. When the mixture contained a smaller quantity of zinc, it still approached nearer the ductility and colour of lead, but it continued harder, more sonorous, and susceptible of polish, till the proportions approached to one of zinc and 16 of lead, when the alloy differed from the last metal only in being somewhat harder*.

9. Zinc does not appear capable of combining with nickel by fusion†.

Affinities.

The affinities of zinc and its oxides are as follows:

ZINC.	OXIDE OF ZINC.
Copper,	Oxalic acid,
Antimony,	Sulphuric,
Tin,	Muriatic,
Mercury,	Mucous,

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* *Ann. de Chim.* ix. 95.

† The Chinese, however, seem to be in possession of some method of combining these metals: For, according to Engestroem, the *pak-fong*, or white copper, is composed of copper, nickel, and zinc. The zinc amounts to seven-sixteenths of the whole, and the proportions of the copper and nickel are to each other as five to thirteen. *Mem. Stock.* 1776.

Silver,
Gold,
Cobalt,
Arsenic,
Platinum,
Bismuth,
Lead,
Nickel,
Iron.

Nitric,
Sebacic,
Tartarous,
Phosphoric,
Citric,
Succinic,
Fluoric,
Arsenic,
Formic,
Lactic,
Acetous,
Boracic,
Prussic,
Carbonic,
Ammonia.

SECT. XI.

OF BISMUTH.

History of bismuth.

THE ancients were acquainted with bismuth, but they confounded it with tin. It is mentioned occasionally by the alchymists and earlier mineralogists; and referred sometimes to tin, sometimes to lead, and sometimes to antimony. The German miners gave it the name of *lectum argenti ;* and appear to have considered it as silver beginning to form, and not yet completed *. It is mentioned as a peculiar metal by Stahl, Dufay, and other chemists who wrote about the beginning of the

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* Konig's *Regnum Minerale*, p. 80.

18th century. But Pott, and Geoffroy junior[*], were the first who examined it with attention, and published an account of its peculiar properties.

Its properties.

Bismuth is of a yellowish or reddish white colour, and almost destitute both of taste and smell. It is composed of broad brilliant plates adhering to each other. The figure of its particles, according to Hauy, is an octahedron, or two four-sided pyramids, applied base to base[†].

Its hardness is 7. Its specific gravity is 9.8227[‡].

When hammered cautiously, its density, as Muschenbroeck ascertained, is considerably increased. It is not therefore very brittle; it breaks, however, when struck smartly by a hammer, and consequently is not malleable. Neither can it be drawn out into wire. Its tenacity has not been ascertained.

When heated to the temperature of 460° [§], it melts; and if the heat be much increased, it evaporates, and may be distilled over in close vessels. When allowed to cool slowly, and when the liquid metal is withdrawn, as soon as the surface congeals it crystallizes in parallelopipeds, which cross each other at right angles.

When exposed to the air, it soon loses its lustre, but scarcely undergoes any other change. It is not altered when kept under water.

Oxides.

When kept melted in an open vessel, its surface is soon covered with a dark blue pellicle; when this is removed, another succeeds, till the whole metal is oxidated. When these pellicles are kept hot and agitated in an open vessel, they are soon converted into a brown-

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[*] *Mem. Par.* 1753, p. 296.

[†] *Jour. de Min.* An. v. p. 582.

[‡] Brisson.

[§] Lewis.

ish powder; known by the name of *brown oxide of bismuth.* This oxide, according to Fourcroy, is composed of 90 parts of bismuth and 10 of oxygen. When bismuth is raised to a strong red heat, it takes fire and burns with a faint blue flame, and emits a yellow smoke. When this is collected, it is a yellow powder, not volatile, and called *yellow oxide of bismuth.*

When bismuth is dissolved in nitric acid, if water be poured into the solution, a white powder precipitates, which was formerly called *magistry of bismuth*; and now *white oxide of bismuth.* It is composed of 80 parts of bismuth and 20 of oxygen*. This oxide is used as a paint under the name of *pearl white.* It is more than probable that the white and the yellow oxides of bismuth are precisely the same, and that the different shade of colour is owing to the different modes of preparing them.

The oxides of bismuth are very easily converted into glass; for that reason bismuth is sometimes used in the process of cupellation instead of lead. It was first proposed for that purpose by Dufay in 1727, and his experiments were afterwards confirmed by Pott.

These oxides are easily reduced when heated along with charcoal or other combustible bodies; for the affinity between bismuth and oxygen is but weak.

Bismuth has not been combined with carbon, hydrogen, nor azot. Neither does it seem capable of combining with phosphorus. Mr Pelletier attempted to produce the phosphuret of bismuth by various methods without success. When he dropped phosphorus, however, into bismuth in fusion, he obtained a substance

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* Bergman.

which did not apparently differ from bismuth, but which, when exposed to the blow-pipe, gave evident signs of containing phosphorus [*]. This substance, according to Pelletier, did not contain above four parts in the hundred of phosphorus, and even this small portion seems only to have been mechanically mixed.

Sulphuret.

Sulphur combines readily with bismuth by fusion. The sulphuret of bismuth is of a bluish grey colour, and crystallizes into beautiful tetrahedral needles. It is composed of 85 parts of bismuth and 15 of sulphur [†]. This sulphuret is much less fusible than bismuth. The sulphur is not disengaged except by a strong and long continued heat.

Bismuth combines with almost all the metals, but few of its alloys are much used.

Alloys.

1. Equal parts of bismuth and gold form a brittle alloy, nearly of the same colour with bismuth [‡]; the specific gravity of which is greater than the mean.

2. The alloy of bismuth and platinum is also very brittle. When exposed to the air, it assumes a purple, violet, or blue colour. The bismuth can scarcely be separated by heat [§].

3. Bismuth combines readily with silver by fusion. The alloy is brittle, lamellar, and nearly of the colour of bismuth. This alloy is sometimes formed in order to purify the silver by the process of cupellation.

4. Mercury combines readily with bismuth, either by triturating the metals together, or by pouring two parts of hot mercury into one part of melted bismuth. This amalgam is at first soft, but it becomes gradually

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[*] *Ann. de Chim.* xiii. 130.

[†] Wenzel, Kirwan's *Miner.* ii. 492.

[‡] Keir, Macquer's *Dictionary*.

[§] Dr Lewis.

hard. When melted and cooled slowly, it crystallizes *. When the quantity of mercury exceeds the bismuth considerably, the amalgam remains fluid, and has the property of dissolving lead and rendering it also fluid †. This triple compound may be filtered through shamoy leather without decomposition. Mercury is sometimes adulterated with these metals; but the imposition may be easily detected, not only by the specific gravity of the mercury, which is too small, but because it *drags a tail*, as the workmen say; that is, when a drop of it is agitated on a plain surface, the drop does not remain spherical, but part of it adheres to the surface, as if it were not completely fluid, or as if it were inclosed in a thin pellicle.

5. Copper forms with bismuth a brittle alloy of a pale red colour, and a specific gravity exactly the mean of that of the two metals alloyed ‡.

6. Bismuth combines but imperfectly with iron §. The alloy is brittle, and attracted by the magnet even when the bismuth amounts to $\frac{3}{4}$ths of the whole ||. The specific gravity of this alloy is less than the mean ¶.

7. Bismuth and tin unite readily. A small portion of bismuth increases the brightness, hardness, and sonorousness of tin: it often enters into the composition of *pewter*, though never in Britain. Equal parts of tin and bismuth form an alloy that melts at 280°: eight parts of tin and one of bismuth melt at 390°: two parts of tin and one of bismuth at 330° **.

8. The alloy of lead and bismuth is of a dark grey

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* Pott.

† Cramer.

‡ Gellert.

§ Muschenbroeck.

|| Henkel.

¶ Gellert.

** Dr Lewis.

colour and close grain *. It is ductile, unless the bismuth exceeds the lead considerably †. Bismuth increases the tenacity of lead prodigiously. Muschenbroeck found, that the tenacity of an alloy composed of three parts of lead and two of bismuth was ten times greater than that of pure lead. The specific gravity of this alloy is greater than the mean ‡.

9. The alloy of bismuth and nickel is brittle, and formed of thin plates §.

10. Bismuth does not combine with zinc.

Affinities.

The affinities of bismuth, and of its oxides, are, according to Bergman, as follows:

Bismuth.	Oxide of Bismuth.
Lead,	Oxalic acid,
Silver,	Arsenic,
Gold,	Tartarous,
Mercury,	Phosphoric,
Antimony,	Sulphuric,
Tin,	Sebacic,
Copper,	Muriatic,
Platinum,	Benzoic ‖ ?
Nickel,	Nitric,
Iron,	Fluoric,
Sulphuret of alkali,	Mucous,
Sulphur,	Succinic,
Phosphorus ?	Citric,
	Formic,
	Lactic,
	Acetous,

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* Wallerius. † Baumé. ‡ Gellert. § Cronstedt.

‖ Muriatic acid decomposes benzoat of bismuth.—Trommsdorf, *Ann. de Chim.* xi. 317.

Prussic,
Carbonic,
Ammonia.

SECT. XII.

OF ANTIMONY.

History of antimony.

The ancients were acquainted with an oxide of antimony to which they gave the names of στιμμι and *stibium*. Pliny* informs us, that it was found in silver ore; and we know that at present there are silver ores† in which it is contained. It was used as an external application to sore eyes; and Pliny gives us the method of preparing it‡. It is probable that a dark bluish grey mineral, of a metallic lustre, was also known to them by the same names. It certainly bore these names as early at least as the 8th century. This mineral is composed of the metal now called *antimony* and sulphur; but it has been known by the name of *antimony* ever since the days of Basil Valentine till very lately. The metal itself, after it was discovered, was denominated *regulus of antimony*. The Asiatic|| and Grecian ladies employed this mineral to paint their eyebrows black. But it does not appear that the ancients considered this substance as containing a metal, or that they knew our antimony in a state of purity§. Who first extracted it from

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[*] Pliny, lib. xxxiii. cap. 6.

[†] Kirwan's *Miner.* ii. 110.

[‡] Pliny, Ibid.

[||] 2 Kings, ix. 30. and Ezek. xxiii. 40.

[§] Mr Roux indeed, who at the request of Count Caylus analysed an its ore we do not know; but Basil Valentine is the first who describes the process. To his *Currus Triumphalis Antimonii,* published towards the end of the 15th century, and to the exertions of those medical alchymists who followed his career, we are indebted for almost all the properties of this substance.

No metal, not even mercury nor iron, has attracted so much of the attention of physicians as antimony. One party extolled it as an infallible specific for every disease; while another decried it as a most virulent poison, which ought to be expunged from the list of medicines. Lemeri, about the end of the 17th century, was the first chemist who attempted a rational account of its properties; and Meuder, in 1738, published the first accurate analysis of its ores*. But the number of writers who have made this metal their particular study is so great, that it would be in vain to attempt even a list of their names. Bergman, Berthollet, and Thenart, are the modern chemists who have thrown the greatest light upon its properties†.

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ancient mirror, found it composed of copper, lead, and antimony. This would go far to convince us that the ancients knew this metal, provided it could be proved that the mirror was *really* an ancient one; but this point appears to be extremely doubtful.

* *Analysis Antimonii Physico-chim. rationalis.*

† The word *alcohol,* which is still employed in chemistry, was, if we believe Hamerus Poppius Thallinus, first applied to this mineral. "Hispanicis mulierculis ejus usus in ciliorum pulchritudine concilianda fuit usitatissimus: pulverem autem vocabant alcohol (quæ vox etiam adhuc in Hermeticorum laboratoriis sonat) unde antimonium crudum et nondum contusum piedra de alcohol nominarunt." It was known among the alchymists by a great variety of absurd names; such as, *Otki, alkofol, alcosol, aries, saturnus philosophorum, magnesia saturni, filius* and *nothus saturni,*

Its properties.

Antimony is of a greyish white colour, and has a good deal of brilliancy. Its texture is laminated, and exhibits plates crossing each other in every direction, and sometimes assuming the appearance of imperfect crystals. Hauy has with great labour ascertained that the primitive form of these crystals is an octahedron, and that the integrant particles of antimony have the figure of tetrahedrons *. When rubbed upon the fingers, it communicates to them a peculiar taste and smell.

Its hardness is $6\frac{1}{2}$. Its specific gravity is, according to Brisson, 6.702; according to Bergman, 6.86.

It is very brittle, and may be easily reduced in a mortar to a very fine powder. Its tenacity has not been tried.

When heated to 809° Fahrenheit, or just to redness, it melts. If after this the heat be increased, the metal evaporates. On cooling, it assumes the form of oblong crystals, perpendicular to the internal surface of the vessel in which it cools. It is to this crystallization that the laminated structure which antimony always assumes is owing.

When exposed to the air, it undergoes no change except the loss of its lustre. Neither is it altered by being kept under water. But when steam is made to pass over red hot antimony, it is decomposed so rapidly that a violent detonation is the consequence †.

When heated in an open vessel, it gradually combines with oxygen, and evaporates in a white vapour. This vapour, when collected, constitutes a white oxide, formerly called *argentine flowers of antimony*. When raised to a white heat, and suddenly agitated, antimony burns, and is converted into the same white oxide.

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* *Jour. de Min.* An. v. 601.

† Fourcroy, v. 228.

Book I.
Oxides.

According to the experiments of Thenart, who has examined the combinations of antimony with more precision than any other chemist, this metal is capable of combining with six different proportions of oxygen, and of forming six oxides; namely, the *black*, the *brown*, the *orange*, the *yellow*, the *white*, and the *acidulous*.

1. The black oxide may be obtained by dissolving antimony in nitro-muriatic acid, and putting into the solution a plate of zinc or iron; a great number of black coloured flakes accumulate round the plate, which are gradually precipitated to the bottom of the vessel. These flakes constitute the *black oxide*, which, according to Thenart, is composed of 98 parts of antimony and 2 of oxygen. When dried by a gentle heat in an open vessel, it takes fire, and is converted into the white oxide of antimony[*].

2. The brown oxide may be obtained by exposing the white oxide of antimony to heat in a close vessel. It gradually loses oxygen, and changes its colour, till at last it becomes of a deep brown. This is the *brown oxide* of antimony. It is composed of 84 parts of antimony and 16 of oxygen[†].

3. The orange oxide may be obtained by the same process, withdrawing the fire whenever the oxide assumes an orange colour. It is composed of 82 parts of antimony and 18 of oxygen[‡].

4. The same process succeeds also for obtaining the yellow oxide, which is usually of a vitreous appearance, and is composed of 81 parts of antimony and 19 of oxygen[§].

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[*] Thenart, *Ann. de Chim.* xxxii. 259.

[†] Ibid.

[‡] Ibid.

[§] Ibid.

5. The fifth oxide may be obtained either by exposing antimony to a red heat, and collecting the white flowers which are sublimed, or by dissolving antimony in nitro-muriatic acid, and pouring water into the solution; a white powder precipitates, which is white oxide[*]. It is composed of 80 parts of antimony and 20 of oxygen[†].

6. The sixth oxide may be obtained by mixing together two parts of nitre and one part of antimony, reduced to a fine powder, and throwing the mixture by little and little into a red hot crucible. It takes fire and burns, or rather *detonates*, with great violence, emitting a very bright white flame. After the combustion there remains in the crucible a white mass, consisting of the oxide of antimony, combined with the potass of the nitre. Water dissolves a part of this compound: when an acid is poured into this solution, a white powder precipitates, which is the *acidulous oxide* of antimony[‡]. It is composed of 68 parts of antimony and 32 of oxygen[§]. This oxide may be procured also by pouring nitric acid upon antimony. The acid acts upon the metal with great violence, and soon converts it into a white powder, which is the acidulous oxide.

All the oxides of antimony are soluble in water except the black. Thenart has observed, that the acidu-

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[*] When obtained by this, or at least by a process very similar, it was called formerly *powder of* Agaroth, from Victor Algarothi, a physician in Verona, who first procured it in that manner from muriat of antimony.

[†] Thenart, *Ann. de Chim.* xxxii. 259.

[‡] As both the 5th and 6th oxides of antimony are of a white colour, some epithet was necessary to distinguish them from each other: I have appropriated the term *white oxide* to the first of these. The second resembles the acids in several of its properties, it may therefore be denominated *acidulous oxide* till some better name be contrived.

[§] Thenart, Ibid.

lous is the least soluble of them all. The first five are easily reduced into the metallic state by heating them in close vessels. The oxygen is driven off, while the pure metal is left behind. The acidulous oxide may be reduced by the same method; but a higher temperature is necessary, unless it be mixed with a little antimony. In that case it parts with its oxygen, and is converted successively into the white, yellow, orange, and brown oxides, and at last is reduced to the state of a pure metal *.

Antimony has never been combined with carbon, hydrogen, nor azot. When its oxides are heated along with charcoal or oils, they are reduced, but imperfectly, unless some body (as potass) be present to favour the fusion of the metal. The greater part remains in the state of black oxide, forming a spongy mass, which often takes fire when exposed to the air. It combines readily with sulphur and with phosphorus.

Sulphuret.

Sulphuret of antimony may be formed by mixing its two component parts together and fusing them in a crucible. It has a dark bluish grey colour, with a lustre approaching the metallic; it is much more fusible than antimony, and may be crystallized by slow cooling. It is composed of 74 parts of antimony and 26 of sulphur †. This substance is found native in great abundance, and indeed is almost the only ore of antimony. It was to this sulphuret that the term *antimony* was applied by the earlier chemists; the pure metal was called *regulus of antimony* ‡.

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* Thenart, *Ann. de Chim.* xxxii. 259.

† Berg. iii. 167.

‡ Sulphuret of antimony is sometimes used to separate the baser metals from gold. When heated along with gold, it carries off all the other metals, while part of the antimony combines with the gold. This is re-

Glass of antimony.

The brown oxide of antimony combines also with about 0.04 of sulphur, and forms a compound which, by the application of a sudden heat, may be fused into a glass of a brown colour, and possessing some degree of transparency. This is the substance commonly sold by apothecaries under the name of *glass of antimony*. It is usually prepared by exposing sulphuret of antimony in powder to a gentle heat for a considerable time in an open vessel. By this process, which is called *roasting*, the greater part of the sulphur is driven off, and the metal is reduced to a brown oxide. In this state it is put into a crucible, and melted by a sudden heat into glass. If the roasting has been carried so far as to drive off the whole of the sulphur, only dark coloured scoriæ are obtained; but on the addition of a little sulphur or sulphuret of antimony, the glass may be easily obtained *.

Glass of antimony contains also a little sulphurated hydrogen, as Bergman has shown †. The glass sold by apothecaries is seldom or never pure, containing almost always, as Vauquelin has demonstrated, about 0.09‡ parts of silica §; derived undoubtedly from the crucibles in which the oxidated sulphuret is fused; for these crucibles contain a very great proportion of siliceous earth.

The brown oxide of antimony, sulphur and sulphurated hydrogen form also another compound, once very celebrated for its virtues as a medicine. It was formerly

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moved by oxidating the gold by means of heat and nitre. This property of sulphuret of antimony induced the alchymists to give it the name of the *wolf*, quia ferocia sua omnia metalla præter leonem, h. e. aurum, absumit. *Hameri Poppii Basilica Antimonii*, c. 1.

* Berg. iii. 166. † Ibid. p. 169. ‡ *Ann. de Chim.* xxxiv. 136.

§ An *earth* which will be described in the next Book.

known by the name of *kermes mineral*, and is now called *red hydro-sulphuret of antimony*. But the description of this compound belongs to a different part of this Work [*].

Phosphuret.

When equal parts of antimony and phosphoric glass are mixed together with a little charcoal powder, and melted in a crucible, phosphuret of antimony is produced. It is of a white colour, brittle, appears laminated when broken, and at the fracture there appear a number of small cubic facettes. When melted it emits a green flame, and the white oxide of antimony sublimes. Phosphuret of antimony may likewise be prepared by fusing equal parts of antimony and phosphoric glass, or by dropping phosphorus into melted antimony [†].

Antimony combines readily with most of the metals; but the greater number of its alloys have not been applied to any use.

Alloys.

1. Antimony and gold may be combined by fusion, and form a brittle compound of a yellow colour. Great attention was paid to this alloy by the alchymists, who affirmed that the quantity of gold might be increased by alloying it with gold and then purifying it [‡].

2. Platinum easily combines with antimony. The alloy is brittle, and much lighter than platinum [§]. The

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[*] See the Chapter on *Hydro-sulphurets* in Book II. In that Chapter also the *yellow hydro-sulphuret of antimony*, formerly called *golden sulphur*, and composed of orange oxide of antimony, sulphur and sulphurated hydrogen will be described.

[†] Pelletier, *Ann. de Chim.* xiii. 132.

[‡] This made them give antimony the name of *balneum regale*. The cause of their mistake is obvious: they did not separate the whole of the antimony from the gold; hence the increase of weight.

[§] Dr Lewis.

antimony cannot afterwards be completely separated by heat.

3. Silver may be alloyed with antimony by fusion. The alloy is brittle, and its specific gravity, as Gellert has observed *, is greater than intermediate between the specific gravities of the two metals which enter into it.

4. Antimony does not amalgamate with mercury while cold. When three parts of mercury are mixed with one part of melted antimony, a soft amalgam is obtained, which very soon decomposes of itself †. Gellert also succeeded in forming this amalgam ‡.

5. Copper combines readily with antimony by fusion. The alloy, when it consists of equal parts of the two metals, is of a beautiful violet colour, and its specific gravity is greater than intermediate §. This alloy was called *regulus of Venus* by the alchymists.

6. Iron combines with antimony by fusion, and forms a brittle hard alloy, the specific gravity of which is less than intermediate. The magnetic quality of iron is much more diminished by being alloyed with antimony than with any other metal ||. This alloy may be obtained also by fusing in a crucible two parts of sulphuret and one of iron. It was formerly called *martial regulus*.

7. The alloy of tin and antimony is white and brittle; its specific gravity is less than intermediate ¶. This alloy is employed for different purposes; particularly for making the plates on which music is engraved **.

8. When equal quantities of lead and antimony are

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* *Metallurgic Chemistry*, p. 136.

† Wallerius.

‡ *Metall. Chim.* p. 141.

§ Gellert, p. 136.

|| Ibid.

¶ Ibid.

** Fourcroy, vi. 25.

fused, the alloy is porous and brittle: three parts of lead and one of antimony form a compact alloy, malleable, and much harder than lead: 12 parts of lead and one of antimony form an alloy very malleable, and a good deal harder than lead: 16 parts of lead and one of antimony form an alloy which does not differ from lead except in hardness[*]. This alloy forms printers types. Its tenacity is very considerable[†], and its specific gravity is greater than the mean[‡].

9. Zinc may be readily combined with antimony by fusion. The alloy is hard and brittle, and has the colour of steel. Its specific gravity is less than intermediate[§].

10. Antimony forms a brittle alloy with bismuth; to manganese it unites but imperfectly[||]: the compounds which it forms with nickel and cobalt have not been examined.

The affinities of antimony, and of its oxides, are, according to Bergman, as follows:

Affinities.

ANTIMONY.	OXIDE OF ANTIMONY.
Iron,	Sebacic acid,
Copper,	Muriatic,
Tin,	Benzoic[¶]?
Lead,	Oxalic,
Nickel,	Sulphuric,
Silver,	Nitric,
Bismuth,	Tartarous,

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[*] Gmelin, *Ann. de Chim.* viii. 319.

[†] Muschenbroeck.

[‡] Gellert, p. 136.

[§] Gellert, ibid.

[||] Gmelin, *Ann. de Chim.* xix. 367.

[¶] Muriatic acid decomposes benzoat of antimony. Trommsdorf, *Ann. de Chim.* xi. 317.

Zinc,
Gold,
Platinum,
Mercury,
Arsenic,
Cobalt,
Sulphuret of arsenic,
Sulphur,
Phosphorus?

Mucous,
Phosphoric,
Citric,
Succinic,
Fluoric,
Arsenic,
Formic,
Lactic,
Acetous,
Boracic,
Prussic,
Carbonic.

SECT. XIII.

OF TELLURIUM.

History of tellurium.

THE mine of Mariahilf, in the mountains of Fatzbay near Zalethna in Transylvania, contains an ore of a bluish white colour and a metallic lustre, concerning the nature of which mineralogists were for a long time doubtful. That it contained a little gold was certain; but by far the greatest part of it consists of a metallic substance, which some supposed to be bismuth, others antimony. Muller of Reichenstein examined it in 1782*, and concluded, from his experiments, that this ore, which had been distinguished by the names of *aurum problematicum*, *aurum paradoxicum*, and *aurum album*,

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* Born, ii. 468.

Book I.

contains a new metal different from every other. Being still dissatisfied with his own conclusions, he sent a specimen of it to Bergman; but the specimen was too small to enable that illustrious chemist to decide the point. He ascertained, however, that the metal in question is not antimony. The experiments of Muller appeared so satisfactory, that they induced Mr Kirwan, in the second edition of his *Mineralogy*, published in 1796, to give this metal a separate place, under the name of *sylvanite*. Klaproth published an analysis of the ore in 1798, and completely confirmed the conclusions of Muller *. To the new metal, which constitutes 0.925 of the ore, he gave the name of *tellurium;* and this name has been generally adopted. Gmelin examined the ore in 1799 †; and his experiments coincide almost exactly with those of Muller and Klaproth. By these philosophers the following properties of tellurium have been ascertained.

Its properties.

Its colour is bluish white, intermediate between that of zinc and lead; its texture is laminated like antimony; and its brilliancy is considerable.

Its hardness has not been ascertained. Its specific gravity, according to Klaproth, is 6.115 ‡.

It is very brittle, and may be easily reduced to powder.

It melts when raised to a temperature somewhat higher than the fusing point of lead. If the heat be increased a little, it boils and evaporates, and attaches itself in brilliant drops to the upper part of the retort in which the experiment is made. It is therefore, next to

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* Crell's *Annals*, 1798, i. 91.

† Ibid. 1799, i. 275. and 365.

‡ Muller found it 6.343; but probably his specimen was not pure.

mercury and arsenic, the most volatile of all the metals. When cooled slowly, it crystallizes.

When exposed to the action of the blow-pipe upon charcoal, it takes fire, and burns with a lively blue flame, the edges of which are green; and is completely volatilized in the form of a white smoke, which, according to Klaproth, has a smell not unlike that of radishes *.

Oxide.

This white smoke is the *oxide of tellurium*, which may be obtained also by dissolving the metal in nitro-muriatic acid, and diluting the solution with a great quantity of water. A white powder falls to the bottom, which is the oxide. It may be procured also by dissolving the metal in nitric acid, and adding potass slowly till the oxide precipitates. This oxide is easily melted by heat into a straw-coloured mass of a radiated texture. When made into a paste with oil, and heated in charcoal, it is reduced to the metallic state so rapidly, that a kind of explosion is produced.

Sulphuret.

Tellurium may be combined with sulphur by fusion. This sulphuret has a leaden grey colour, and a radiated texture: on red hot coals it burns with a blue flame.

Tellurium may be amalgamated with mercury by trituration. Its other properties have not yet been examined.

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* Gmelin could not perceive this smell.

SECT. XIV.

OF ARSENIC.

History of arsenic.

The word *arsenic* (αρσενικον) occurs first in the works of Dioscorides, and of some other authors who wrote about the beginning of the Christian era. It denotes in their works the same substance which Aristotle had called σανδαραχη*, and his disciple Theophrastus αρρενικον, which is a reddish coloured mineral, composed of arsenic and sulphur, used by the ancients in painting, and as a medicine.

The *white oxide of arsenic*, or what is known in commerce by the name of arsenic, is mentioned by Avicenna in the 11th century; but at what period the metal called arsenic was first extracted from that oxide is unknown. Paracelsus seems to have known it; and a process for obtaining it is described by Schroeder in his Pharmacopœia published in 1649†. But it was only in the year 1733 that this metal was examined with chemical precision. This examination, which was performed by Mr Brandt, demonstrated its peculiar nature; and since that time it has been always considered as a distinct metal, to which the term *arsenic* has been appropriated. Its properties were still farther investigated by Macquer in 1746‡, by Monnet in 1773§, and by

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* Pliny seems to make a distinction between sandaracha and arsenic. See lib. xxxiv. cap. 18.

† Bergman, ii. 278.

‡ *Mem. Par.* 1746, p. 223. and 1748, p. 35.

§ *Sur l' Arsenic.*

Bergman in 1777*. To the labours of these philosophers, and to those of Mr Scheele†, we are indebted for almost every thing known about the properties of this metal.

Its properties.

Arsenic has a bluish white colour not unlike that of steel, and a good deal of brilliancy. It has no sensible smell while cold, but when heated it emits a strong odour of garlic, which is very characteristic.

Its hardness scarcely exceeds 5. Its specific gravity is 8.31‡.

It is perhaps the most brittle of all the metals, falling to pieces under a very moderate blow of a hammer, and admitting of being easily reduced to a very fine powder in a mortar.

Its fusing point is not known, because it is the most volatile of the metals, subliming without melting when exposed in close vessels to a heat of 540° §. When sublimed slowly, it crystallizes in tetrahedrons, which Hauy has demonstrated to be the form of its integrant particles.

It may be kept under water without alteration; but when exposed to the open air, it soon loses its lustre, becomes black, and falls into powder.

Oxides.

When exposed to a moderate heat in contact with air, it sublimes in the form of a white powder, and at the same time emits a smell resembling garlic. If the heat be increased, it burns with an obscure bluish flame. Arsenic indeed is one of the most combustible substances known. The substance which sublimes was formerly called *arsenic* or *white arsenic*, and is still

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* *Opusc.* ii. 272.

† Scheele, i. 129.

‡ Bergman, ii. 254.

§ Ibid.

known by these names in the commercial world. It is a combination of arsenic and oxygen ; and is now denominated *white oxide of arsenic*, and by Fourcroy *arsenious acid*, because it possesses several of the properties of an acid. It is seldom prepared by chemists, because it exists native ; and is often procured abundantly during the extraction of the other metals from their ores.

When obtained by these processes, it is a white, brittle, compact substance, of a glassy appearance. It has a sharp acrid taste, which at last leaves an impression of sweetness, and is one of the most virulent poisons known. It has an alliacious smell. It is soluble in 80 parts of water at the temperature of 60°, and in 15 parts of boiling water [*]. This solution has an acrid taste, and reddens vegetable blues. When it is slowly evaporated, the oxide crystallizes in regular tetrahedrons. This oxide sublimes when heated to 283° : if heat be applied in close vessels, it becomes pellucid like glass ; but when exposed to the air, it soon recovers its former appearance. The specific gravity of this glass is 5.000 ; that of the oxide, in its usual state, 3.706 [†]. This oxide is capable of combining with most of the metals, and in general renders them brittle. It seems, from the experiments of Berthollet, to be composed of 93 parts of arsenic and 7 of oxygen [‡].

Arsenic is capable of combining with an additional dose of oxygen, and of forming another compound first discovered by Scheele, known by the name of *arsenic acid*. It is formed by pouring six parts of nitric acid upon one part of white oxide of arsenic in a retort, and

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[*] Bergman, ii. 291.

[†] Ibid. ii. 286.

[‡] Kirwan's *Miner.* ii. 490.

distilling. The nitric acid is decomposed, and the arsenic acid remains behind in the retort. It is composed of 91 parts of arsenic and 9 of oxygen*.

Arsenic does not combine with carbon, azot, nor hydrogen. This last substance, however, when in the gazeous state, dissolves it; for when muriatic acid is boiled over arsenic, that metal is gradually oxidated and dissolved, and at the same time hydrogen gas is emitted, which has the smell and the poisonous qualities of arsenic.

Sulphuret.

Sulphur combines readily with arsenic either by melting them in a crucible, or by subliming them together. There are two compounds containing sulphur and arsenic, both of which are found native, and therefore are seldom formed artificially. The first, called *realgar*, has a scarlet colour, and is often found crystallized in prisms. It is brittle: its specific gravity is 3.225†. This substance is used as a paint. It is composed, according to Westrum, of 80 parts of arsenic and 20 of sulphur‡. It is therefore a *sulphuret of arsenic*.

Sulphurated oxide.

The second, called *orpiment*, has a yellow colour, and is composed of thin flexible plates. Its specific gravity is 5.315. When acids are poured upon realgar, they destroy its red colour, and convert it to yellow; but they produce no change upon the colour of orpiment. They evidently alter the colour of realgar, by oxidating its arsenic. Hence it follows that the arsenic in orpiment is already oxidated §: it is therefore a *sulphurated oxide of arsenic*.

Arsenic combines readily with phosphorus. The

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* Berthollet, Kirwan's *Miner.* ii. 490.

† Berg. ii. 298.

‡ Crell's *Annals*, 1785, i. 299.

§ Berg. ii. 302.

Phosphuret.

phosphuret of arsenic may be formed by distilling equal parts of its ingredients over a moderate fire. It is black and brilliant, and ought to be preserved in water. It may be formed likewise by putting equal parts of phosphorus and arsenic into a sufficient quantity of water, and keeping the mixture moderately hot for some time[*].

Arsenic unites with most metals, and in general renders them more brittle and more fusible.

Alloys.

1. Melted gold takes up $\frac{1}{60}$ of arsenic[†]. The alloy is brittle and pale, and much harder than gold.

2. The alloy of platinum and arsenic is brittle and very fusible. It was first formed by Scheffer. The arsenic may be separated by heat. It is by fusing platinum and the white oxide of arsenic together that this untractable metal is formed into the utensils required. The mixture, after fusion, is hammered at a red heat into bars. The arsenic is gradually driven off, and carries along with it most of the baser metals which happen to be present. The platinum is then sufficiently ductile to be wrought.

3. Melted silver takes up $\frac{1}{14}$ of arsenic[‡]. The alloy is brittle, yellow-coloured, and useless.

4. Mercury may be amalgamated with arsenic by keeping them for some hours over the fire, constantly agitating the mixture. The amalgam is grey-coloured, and composed of five parts of mercury and one of arsenic[§].

5. Copper may be combined with arsenic by fusing them together in a close crucible; while their surface

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[*] Pelletier, *Ann. de Chim.* xiii. 139.

[†] Bergman, Ibid.

[‡] Ibid.

[§] Berg. ii. 281.

is covered with common salt to prevent the action of the air, which would oxidate the arsenic. This alloy is white and brittle, and is used for a variety of purposes; but it is usual to add to it a little tin or bismuth. It is known by the names of *white copper* and *white tombac.* When the quantity of arsenic is small, the alloy is both ductile and malleable.

6. Iron and arsenic may be alloyed by fusion. The alloy is white and brittle, and may be crystallized. It is found native; and is known among mineralogists by the name of *mispickel.* Iron is capable of combining with more than its own weight of arsenic*.

7. Tin and arsenic may be alloyed by fusion. The alloy is white, harder, and more sonorous than tin; and brittle, unless the proportion of arsenic be very small. An alloy, composed of 15 parts of tin and 1 of arsenic, crystallizes in large plates like bismuth: it is more brittle than zinc, and more infusible than tin. The arsenic may be separated by long exposure of the alloy to heat in the open air†.

8. Lead and arsenic may be combined by fusion. The alloy is brittle, dark-coloured, and composed of plates. Lead takes up $\frac{1}{6}$ of its weight of arsenic‡.

9. Zinc may be combined with arsenic by distilling a mixture of it and of white oxide of arsenic§. This alloy, according to Bergman, is composed of four parts of zinc and one of arsenic.

10. Antimony forms with arsenic an alloy which is very brittle, very hard, and very fusible; and compo-

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* Bergman, ii. 281.

† Bayen.

‡ Bergman.

§ Malouin.

sed, according to Bergman, of seven parts of antimony and one part of arsenic.

11. Bismuth may be combined with about $\frac{1}{11}$ of its weight of arsenic*; but the properties of this alloy have not been examined.

The affinities of arsenic, and of its oxides, are placed by Bergman in the following order:

Affinities.

ARSENIC.	OXIDE OF ARSENIC.
Nickel,	Muriatic acid,
Cobalt,	Oxalic,
Copper,	Sulphuric,
Iron,	Nitric,
Silver,	Sebacic,
Tin,	Tartarous,
Gold,	Phosphoric,
Platinum,	Fluoric,
Zinc,	Mucous,
Antimony,	Succinic,
Sulphuret of alkali,	Citric,
Sulphur,	Formic,
Phosphorus.	Lactic,
	Arsenic,
	Acetous,
	Prussic,
	Ammonia,
	Water.

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* Bergman, ii. 281.

SECT. XV.

OF COBALT.

History of cobalt.

A MINERAL called *cobalt**, of a grey colour, and very heavy, has been used in different parts of Europe ſince the 15th century to tinge glass of a blue colour. But the nature of this mineral was altogether unknown till it was examined by Brandt in 1733. This celebrated Swedish chemist obtained from it a new metal, to which

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* The word *cobalt* seems to be derived from *cobalus*, which was the name of a spirit that, according to the superstitious notions of the times, haunted mines, destroyed the labours of the miners, and often gave them a great deal of unnecessary trouble. The miners probably gave this name to the mineral out of joke, because it thwarted them as much as the supposed spirit, by exciting false hopes, and rendering their labour often fruitless; for as it was not known at first to what use the mineral could be applied, it was thrown aside as useless. It was once customary in Germany to introduce into the church-service a prayer that God would preserve miners and their works from *kobalts* and spirits. See Beckmann's *History of Inventions*, ii. 362.

Mathesius, in his tenth sermon, where he speaks of *cadmia fossilis* (probably cobalt ore), says, " Ye miners call it *cobolt;* the Germans call the black devil and the old devil's whores and hags, old and black *kobel*, which by their witchcraft do injury to people and to their cattle."

Lehmann, Paw, Delaval, and several other philosophers, have supposed that *smalt* (oxide of cobalt melted with glass and pounded) was known to the ancients, and used to tinge the beautiful blue glass still visible in some of their works; but we learn from Gmelin, who analysed some of these pieces of glass, that they owe their *blue* colour, not to the presence of *cobalt* but of *iron*.

According to Lehmann, cobalt ore was first used to tinge glass blue by Christopher Schurer, a glassmaker at Platten, about the year 1540.

he gave the name of *cobalt*[*]. Bergman confirmed and extended the discovery of Brandt in different dissertations published in the year 1780[†]. Scarcely any farther addition was made to our knowledge of this metal till 1798, when a paper on it was published by Mr Tassaert[‡]. In the year 1800, a new set of experiments were made upon it by the School of Mines at Paris, in order to procure it perfectly pure, and to ascertain its properties when in that state[§]. These confirm most of the conclusions which had been drawn from the labours of former chemists.

Its properties.

Cobalt is of a grey colour with a shade of red, and by no means brilliant. Its texture varies according to the heat employed in fusing it. Sometimes it is composed of plates, sometimes of grains, and sometimes of small fibres adhering to each other[‖]. It has scarcely any taste or smell.

Its hardness is 6. Its specific gravity, according to Bergman and the School of Mines at Paris, is 7.7; but Tassaert makes it 8.5384.

It is brittle, and easily reduced to powder; but if we believe Leonhardi, it is somewhat malleable when red hot. Its tenacity is unknown.

When heated to the temperature of 130° Wedgewood, it melts; but no heat which we can produce is sufficient to cause it to evaporate. When cooled slowly in a crucible, if the vessel be inclined the moment the

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[*] *Acta Upsal*, 1733 and 1742.

[†] *Opusc.* ii. 444, 501. and iv. 371.

[‡] *Ann. de Chim.* xxviii. 101.

[§] Fourcroy, *Discours Preliminaire*, p. 114.

[‖] *L'Ecole des Mines.*

surface of the metal congeals, it may be obtained crystallized in irregular prisms*.

Like iron, it is attracted by the magnet; and, from the experiments of Wenzel, it appears that it may be converted into a magnet precisely similar in its properties to the common magnetic needle.

When exposed to the air it undergoes no change, neither is it altered when kept under water; its affinity for oxygen is not sufficiently strong to occasion a decomposition of the water.

Oxide.

When kept red hot in an open vessel, it gradually imbibes oxygen, and is converted into a powder at first brown, but which gradually becomes deeper and deeper, till at last it becomes black, or rather of so deep a blue that it appears to the eye black. If the heat be very violent, the cobalt takes fire and burns with a red flame. By this process it is converted into the same oxide.

It has not been ascertained whether cobalt be capable of forming more than one oxide. The blue oxide formed by heat is composed, according to Morveau, of about 71 parts of cobalt and 29 of oxygen. When cobalt, dissolved in acids, is precipitated by an alkali, the precipitate has a reddish brown colour; but, as far as experiments have yet gone, it is composed of precisely the same proportions of oxygen and cobalt as the *blue oxide*.

Sulphuret.

Cobalt does not combine with carbon, hydrogen, nor azot. It cannot be combined with sulphur by fusion. But sulphuret of cobalt may be formed by melting the metal along with sulphur previously combined with potass. It has a yellowish white colour, displays the

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* Fourcroy, v. 137.

rudiments of crystals, and can scarcely be decomposed by heat.

Phosphuret.

Phosphuret of cobalt may be formed by heating the metal red hot, and then gradually dropping in small bits of phosphorus. It contains about $\frac{1}{15}$th of phosphorus. It is white and brittle, and when exposed to the air soon loses its metallic lustre. The phosphorus is separated by heat, and the cobalt is at the same time oxidated. This phosphuret is much more fusible than pure cobalt *.

Cobalt seems capable of combining with most of the metals, but its alloys are very imperfectly known.

Alloys.

1. Cobalt combines with a small portion of gold; but the alloy scarcely differs from pure cobalt in its properties.

2. The alloy of cobalt and platinum has not been examined.

3. When 2 parts of cobalt and 1 of silver are melted together, the two metals are obtained separately after the process; the silver at the bottom of the crucible and the cobalt above it. Each of them, however, has absorbed a small portion of the other metal; for the silver is brittle and dark coloured, while the cobalt is whiter than usual †.

4. Cobalt does not combine with mercury.

5. The alloy of copper and cobalt is scarcely known.

6. The alloy of iron and cobalt is very hard, and not easily broken. Cobalt generally contains some iron, from which it is with great difficulty separated.

7. The alloy of tin and cobalt is of a light violet colour, and formed of small grains.

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* Pelletier, *Ann. de Chim.* xiii. 134.

† Gellert, 137.

Chap. III.

8. It was supposed formerly that cobalt does not combine with lead by fusion; for upon melting equal parts of lead and cobalt together, both metals are found separate, the lead at the bottom and the cobalt above. Indeed when this cobalt is melted with iron, it appears that it had combined with a little lead; for the iron combines with the cobalt and the lead is separated*. But Gmelin has shown that the alloy may be formed. He put cobalt in powder within plates of lead, and covered them with charcoal to exclude the air. He then applied heat to the crucibles containing the mixtures. Equal parts of lead and cobalt produced an alloy, in which the metals appeared pretty uniformly distributed, though in some places the lead predominated. It was brittle, received a better polish than lead, resembled rather cobalt than lead; its specific gravity was 8.12. Two parts of lead and one of cobalt produced an uniform mixture, more like cobalt than lead, very little malleable, and softer than the last. Its specific gravity was 8.28. Four parts of lead and one of cobalt formed an alloy still brittle, and having the fracture of cobalt but the polish of lead. It was harder than lead. Six parts of lead and one of cobalt formed an alloy more malleable, and harder than lead. Its specific gravity was 9.65. Eight parts of lead and one of cobalt was still harder than lead, and it received a better polish. It was as malleable as lead. Its specific gravity was 9.78 †.

9. Cobalt is often found naturally combined with nickel.

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* Gellert, p. 137.

† *Ann. de Chim.* xix. 357.

10. It does not seem capable of combining with bismuth nor with zinc by fusion.

The affinities of cobalt, and its oxide, are, according to Bergman, as follows:

Affinities.

Cobalt.	Oxide of Cobalt.
Iron,	Oxalic acid,
Nickel,	Muriatic,
Arsenic,	Sulphuric,
Copper,	Tartarous,
Gold,	Nitric,
Platinum,	Sebacic,
Tin,	Phosphoric,
Antimony,	Fluoric,
Zinc,	Mucous,
Sulphuret of alkali,	Succinic,
Phosphorus,	Citric,
Sulphur.	Formic,
	Lactic,
	Acetous,
	Arsenic,
	Boracic,
	Prussic,
	Carbonic,
	Ammonia.

SECT. XVI.

OF MANGANESE.

History.

THE dark grey or brown mineral called *manganese*, in Latin *magnesia* (according to Boyle, from its resemblance to the *magnet*), has been long known and used in the manufacture of glass. A mine of it was discovered in England by Boyle. A few experiments were made upon this mineral by Glauber in 1656*, and by Waitz in 1705†; but chemists in general seem to have paid but very little attention to it. The greater number of mineralogists, though much puzzled what to make of it, agreed in placing it among iron ores: but Pott, who published the first chemical examination of this mineral in 1740, having ascertained that it often contains scarcely any iron, Cronstedt, in his *System of Mineralogy*, which appeared in 1758, assigned it a place of its own, on the supposition that it consisted chiefly of a peculiar earth. Rinman examined it anew in 1765‡; and in the year 1770 Kaim published at Vienna a set of experiments, in order to prove that a peculiar metal might be extracted from it§. The same idea had struck Bergman about the same time, and induced him to request of Scheele, in 1771, to undertake an examination of manganese. Scheele's dissertation on it, which appeared in 1774, is a masterpiece of analysis,

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* *Prosperitas Germaniæ.*

† Wiegleb's *Geschichte*, i. 127.

‡ *Mem. Stockholm*, 1765, p. 235.

§ *De Metallis dubiis*, p. 48.

and contains some of the most important discoveries of modern chemistry. Bergman himself published a dissertation on it the same year; in which he demonstrates, that the mineral, then called *manganese*, is a metallic oxide *. He accordingly made several attempts to reduce it, but without success; the whole mass either assuming the form of scoriæ, or yielding only small separate globules attracted by the magnet. This difficulty of fusion led him to suspect that the metal he was in quest of bore a strong analogy to platinum. In the mean time, Dr Gahn, who was making experiments on the same mineral, actually succeeded in reducing it by the following process: He lined a crucible with charcoal powder moistened with water, put into it some of the mineral formed into a ball by means of oil, then filled up the crucible with charcoal powder, luted another crucible over it, and exposed the whole for about an hour to a very intense heat. At the bottom of the crucible was found a metallic button, or rather a number of small metallic globules, equal in weight to one-third of the mineral employed †. It is easy to see by what means this reduction was accomplished. The charcoal attracted the oxygen from the oxide, and the metal remained behind. The metal obtained, which is called *manganese*, was farther examined by Ilseman in 1782, Hielm in 1785, and Bindheim in 1789.

Its properties.

Manganese, when pure, is of a greyish-white colour, and has a good deal of brilliancy. Its texture is granular. It has neither taste nor smell.

Its hardness is 9, or equal to that of iron. Its specific gravity is 7.000 ‡.

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* *Opusc.* ii. 201.

† Bergman, ii. 211.

‡ Hielm.

It is very brittle; of course it can neither be hammered nor drawn out into wire. Its tenacity is unknown.

It requires, according to Morveau, the temperature of 160° Wedgewood to melt it; so that, platinum excepted, it is the most infusible of all the metals.

When reduced to powder, it is attracted by the magnet.

Manganese, when exposed to the air, attracts oxygen more rapidly than any other body, phosphorus excepted. It loses its lustre almost instantly, becomes grey, violet, brown, and at last black. Its affinity for oxygen is greater than that of any other metallic body. These changes take place still more rapidly if the metal be heated in an open vessel.

Oxides.

This metal seems capable of combining with three different proportions of oxygen, and of forming three different oxides, the *white*, the *red*, and the *black*.

The *white* oxide may be obtained by sulphuric or nitric acid, or the black oxide of manganese, and adding a little sugar. The sugar attracts oxygen from the black oxide, and converts it into the white, which is dissolved by the acid. Into the solution pour a quantity of potass; the white oxide precipitates in the form of a white powder. It is composed, according to Bergman, of 80 parts of manganese and 20 of oxygen. When exposed to the air, it soon attracts oxygen, and is converted into the black oxide*.

The *red* oxide may be obtained by dissolving the black oxide in sulphuric acid, without the addition of any combustible substance. When black oxide of man-

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* *Opusc.* ii. 211.

Book I.

ganese, made into a paste with sulphuric acid, is heated in a retort, a great quantity of oxygen gas comes over, while the oxide, thus deprived of part of its oxygen, dissolves in the acid. Distil to dryness, and pour water upon the residuum, and pass it through a filter. A red coloured solution is obtained, consisting of the sulphat of manganese dissolved in the water. On the addition of an alkali, a red powder precipitates, which is the *red oxide of manganese*. According to Bergman, it is composed of 74 parts of manganese and 26 of oxygen*. This oxide likewise attracts oxygen when exposed to the atmosphere, and is converted into the black oxide.

The *black* oxide of manganese exists abundantly in nature; indeed it is almost always in this state that manganese is found. It was to the black oxide that the appellation *manganese* itself was originally applied. It may be formed very soon by exposing the metal to the air. This oxide, according to Fourcroy, is composed of 60 parts of manganese and 40 of oxygen†. When this oxide is heated to redness in an earthen retort, it gives out abundance of oxygen gas, which may be collected in proper vessels. By this operation it is reduced to the state of red, or almost of white oxide. If it be exposed to the air, it soon absorbs a new dose of oxygen; and thus the process may be repeated as often as you please. No oxygen gas can be obtained from the white oxide: a proof that its oxygen is retained by a stronger affinity than the additional dose of oxygen which constitutes the black oxide. Seguin has observed, that in some cases the black oxide of manganese emits, before it becomes red, a quantity of azotic gas.

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* *Opusc.* ii. 215.

† Fourcroy, v. 177.

When long exposed to a strong heat, it assumes a green colour. In that state it is whitened by sulphuric acid, but not dissolved [*]. A very violent heat fuses this oxide, and converts it into a green coloured glass.

Manganese does not combine with hydrogen nor azot. When dissolved in sulphuric acid, a black spongy mass of carburet of iron is left behind. Hence it has been supposed capable of combining with carbon; but it is more probable that the carbon is combined with the iron, which is almost always present in manganese. It seems pretty clear, however, that carburet of iron is capable of combining with this metal, and that it always forms a part of steel.

Sulphurated oxide.

Bergman did not succeed in his attempt to combine manganese with sulphur; but he formed a sulphurated oxide of manganese, by combining eight parts of the black oxide with three parts of sulphur. It is of a green colour, and gives out sulphurated hydrogen gas when acted on by acids [†].

Phosphuret.

Phosphorus may be combined with manganese by melting together equal parts of the metal and of phosphoric glass; or by dropping phosphorus upon red hot manganese. The phosphuret of manganese is of a white colour, brittle, granulated, disposed to crystallize, not altered by exposure to the air, and more fusible than manganese. When heated, the phosphorus burns, and the metal becomes oxidated [‡].

Manganese combines with many of the metals, and forms with them alloys which have been but very imperfectly examined.

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[*] Bergman, ii. 216.

[†] Ibid. p. 221.

[‡] Pelletier, *Ann. de Chim.* xiii. 137.

Alloys. It combines readily with copper. The compound, according to Bergman, is very malleable, its colour is red, and it sometimes becomes green by age. Gmelin made a number of experiments to see whether this alloy could be formed by fusing the black oxide of manganese along with copper. He partly succeeded, and proposed to substitute this alloy instead of the alloy of copper and arsenic, which is used in the arts*.

It combines readily with iron; indeed it has scarcely ever been found quite free from some mixture of that metal. Manganese gives iron a white colour, and renders it brittle. It combines also with tin, but scarcely with zinc†.

It does not combine with mercury nor with bismuth. Gmelin found that lead cannot be alloyed with bismuth without great difficulty; and that it unites to antimony very imperfectly‡. Chemists have not attempted to combine it with gold, platinum, silver, nickel, nor cobalt.

The affinities of manganese, and of its white and red oxides, are, according to Bergman, as follows:

Affinities.

MANGANESE.	OXIDE OF MANGANESE.
Copper,	Oxalic acid,
Iron,	Citric,
Gold,	Phosphoric,
Silver,	Tartarous,
Tin,	Fluoric,
Sulphuret of alkali,	Muriatic,
Phosphorus?	Sulphuric,

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* *Ann. de Chim.* i. 303.

† Bergman, ii. p. 205.

‡ *Ann. de Chim.* xix. 366.

Nitric,
Mucous,
Succinic,
Sebacic,
Tartarous,
Formic,
Lactic,
Acetous,
Prussic,
Carbonic.

The three metals, *cobalt*, *nickel*, and *manganese*, resemble iron in several particulars: Like it, they are magnetic, very hard, and very difficult to fuse: but they differ from it in specific gravity, malleability, and in the properties of all their combinations with other substances; the oxides, for instance, of iron, cobalt, nickel, and manganese, possess very different qualities.

SECT. XVII.

OF TUNGSTEN.

History of tungsten.

THERE is a mineral found in Sweden of an opaque white colour and great weight; from which last circumstance it got the name of *tungsten*, or *ponderous stone*. Some mineralogists considered it as an ore of tin, others supposed that it contained iron. Scheele analysed it in 1781, and found that it was composed of lime and a peculiar earthy-like substance, which he called from its properties *tungstic acid* *. Bergman

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* Scheele, ii. 81.

conjectured that the basis of this acid is a metal[*]; and this conjecture was soon after fully confirmed by the experiments of Messrs D'Elhuyart, who obtained the same substance from a mineral of a brownish black colour, called by the Germans *wolfram*[†], which is sometimes found in tin mines. This mineral they found to contain $\frac{65}{100}$ of tungstic acid; the rest of it consisted of manganese, iron, and tin. This acid substance they mixed with charcoal powder, and heated violently in a crucible. On opening the crucible after it had cooled, they found in it a button of metal, of a dark brown colour, which crumbled to powder between the fingers. On viewing it with a glass, they found it to consist of a congeries of metallic globules, some of which were as large as a pin head. The metal thus obtained is called *tungsten*. The manner in which it was produced is evident: tungstic acid is composed of oxygen and tungsten; the oxygen combined with the carbon, and left the metal in a state of purity[‡].

The experiments of the Elhuyarts were repeated in 1796 by Vauquelin and Hecht, in general with success; but they were unable to procure the metal completely fused, though this had been accomplished by the Spanish chemists[§]. Nor is this to be wondered at, as Dr Pearson[‖] and Mr Klaproth[¶] had made the same attempt before them without succeeding.

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[*] Scheele, ii. 91.

[†] Wolfram had been analysed in 1761 by Lehmann. He imagined it a compound of iron and tin. See his *Probierkunst*, p. 8.

[‡] *Mem. Thoulouse*, ii. 141.

[§] *Jour. de Min.* No. xix. 3.

[‖] *Transl. of the Chem. Nomenclature.*

[¶] *Observ. on the Fossils of Cornwall*, p. 77.

Its properties.

Tungsten, called by the German chemists *scheelium*, is of a greyish-white colour, and has a good deal of brilliancy.

It is one of the hardest of the metals; for Vauquelin and Hecht could scarcely make any impression upon it with a file. It seems also to be brittle. Its specific gravity, according to the D'Elhuyarts, is 17.6; but this must still continue doubtful, as no other person has been able to obtain the metal in a state for ascertaining its specific gravity.

It requires for fusion a temperature at least equal to 170° Wedgewood. It seems to have the property of crystallizing on cooling, like all the other metals; for the imperfect button procured by Vauquelin and Hecht contained a great number of small crystals.

It is not attracted by the magnet.

Oxides.

When heated in an open vessel, it gradually absorbs oxygen, and is converted into an oxide. Tungsten seems capable of combining with two different proportions of oxygen, and of forming two different oxides; the *black* and the *yellow*.

The black oxide, which contains the smallest proportion of oxygen, may be obtained by heating the yellow oxide for some hours in a covered crucible.

The yellow oxide, known also by the name of *tungstic acid* *, is found native in wolfram, and may be obtained from it by boiling three parts of muriatic acid in one part of wolfram. The acid is to be decanted

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* The tungstic acid of Scheele is different from this oxide. It is a white powder of an acid taste, and soluble in water. The D'Elhuyarts have demonstrated that it is a triple salt, composed of the yellow oxide of tungsten, potass, and the acid employed to decompose the mineral from which it is obtained.

off in about half an hour, and allowed to settle. A yellow powder gradually precipitates. This powder is to be dissolved in *ammonia* [*], the solution is to be evaporated to dryness, and the dry mass kept for some time in a red heat. It is then *yellow oxide* in a state of purity. This oxide has no taste. It is insoluble in water, but remains long suspended in that liquid, forming a kind of yellow milk, which has no action on vegetable colours. When heated in a platinum spoon it becomes dark green; but before the blow-pipe on charcoal it acquires a black colour. It is composed of 80 parts of tungsten and 20 of oxygen. Its specific gravity is 6.12.

The sulphuret of tungsten is of a bluish black colour, hard, and capable of crystallizing.

Phosphorus is capable of combining with tungsten [†]; but none of the properties of the phosphuret have been ascertained.

The Elhuyarts alone attempted to combine tungsten with other metals. They mixed 100 grains of the metals to be alloyed with 50 grains of the yellow oxide of tungsten and a quantity of charcoal, and heated the mixture in a crucible. The result of their experiments is as follows:

Alloys.

1. With gold and platinum the tungsten did not combine.

2. With silver it formed a button of a whitish-brown colour, something spongy, which with a few strokes of a hammer extended itself easily, but on continuing them it split in pieces. This button weighed 142 grains.

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[*] An alkali which will be afterwards described.

[†] Pelletier, *Ann. de Chim.* xiii. 137.

3. With copper it gave a button of a copperish red, which approached to a dark brown, was spongy, and pretty ductile, and weighed 133 grains.

4. With crude or cast-iron, of a white quality, it gave a perfect button, the fracture of which was compact and of a whitish brown colour: it was hard, harsh, and weighed 137 grains.

5. With lead it formed a button of a dull dark brown, with very little lustre, spongy, very ductile, and splitting into leaves when hammered: it weighed 127 grains.

6. The button formed with tin was of a lighter brown than the last, very spongy, somewhat ductile, and weighed 138 grains.

7. That with antimony was of a dark-brown colour, shining, something spongy, harsh, and broke in pieces easily: it weighed 108 grains.

8. That of bismuth presented a fracture, which when seen in one light, was of a dark brown colour, with the lustre of a metal, and in another appeared like earth, without any lustre; but in both cases one could distinguish an infinity of little holes over the whole mass. This button was pretty hard, harsh, and weighed 68 grains.

9. With manganese it gave a button of a dark bluish-brown colour and earthy aspect; and, on examining the internal part of it with a lens, it resembled impure dross of iron: it weighed 107 grains.

SECT. XVIII.

OF MOLYBDENUM.

History of molybdenum.

THE Greek word μολυβδαινα, and its Latin translation *plumbago*, seem to have been employed by the ancients to denote various oxides of lead; but by the moderns they were applied indiscriminately to all substances possessed of the following properties: Light, friable, and soft, of a dark colour and greasy feel, and which leave a stain upon the fingers. Scheele first examined these minerals with attention. He found that two very different substances had been confounded together. To one of these, which is composed of carbon and iron, and which has been already described, he appropriated the word *plumbago;* the other he called *molybdena.*

Molybdena is composed of scaly particles adhering slightly to each other. Its colour is bluish, very much resembling that of lead. Scheele analysed it in 1778, and obtained sulphur and a whitish powder, which possessed the properties of an acid, and which, therefore, he called *acid of molybdena*[*]. Bergman suspected this acid, from its properties, to be a metallic oxide; and, at his request, Hielm, in 1782, undertook the laborious course of experiments by which he succeeded in obtaining a metal from this acid. His method was to form it into a paste with linseed oil, and then to apply a very strong heat. This process he repeated several times successively[†]. To the metal which he obtained

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[*] Scheele, i. 236.

[†] Bergman's *Sciagraphia*, p. 19. Engl. Transl.

he gave the name of *molybdenum*[*]. The experiments of Scheele were afterwards repeated by Pelletier[†], Ilseman[‡], and Heyer[§]; and not only fully confirmed, but many new facts discovered, and the metallic nature of molybdic acid was put beyond a doubt: though, in consequence of the very violent heat necessary to fuse molybdenum, only very minute grains of it have been hitherto obtained in the state of a metal. Still more lately Mr Hatchett has published a very valuable set of experiments, which throw still greater light upon the nature of this metal[¶].

Its properties.

Molybdenum is externally of a whitish yellow colour, but its fracture is a whitish grey.

Hitherto it has only been procured in small grains, agglutinated together in brittle masses.

Its specific gravity is 7.500. It is almost infusible in our fires.

When exposed to heat in an open vessel, it gradually combines with oxygen, and is converted into a white oxide, which is volatilized in small brilliant needle-form crystals. This oxide, having the properties of an acid, is known by the name of *molybdic acid.*

Oxides.

From the experiments of Mr Hatchett, it follows that molybdenum is capable of combining with four different proportions of oxygen, and of forming four oxides; namely, 1. The black; 2. The blue; 3. The green, to which Mr Hatchett has given the name of *molybdous acid;* and, 4. The *yellow* or *white*, or the molybdic acid[||].

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[*] Crell's *Annals*, 1790, i. 39, &c.

[†] *Jour. de Phys.* 1795, Decembre.

[‡] Crell's *Annals*, 1787, i. 407.

[§] Ibid. 1787. ii. 21. and 124.

[¶] *Phil. Trans.* 1795, p. 323.

[||] Ibid. 1786, 323.

The black oxide may be obtained by mixing molybdic acid with charcoal powder in a crucible, and applying heat. A black mass remains, which is the black oxide. It seems to contain only a very minute quantity of oxygen.

The blue oxide may be obtained by the same process not carried so far: it is formed also whenever a plate of tin is plunged into a solution of molybdic acid.

The white oxide, or molybdic acid, is obtained by distilling six parts of diluted nitric acid repeatedly off native molybdena in powder. A white mass is left behind, composed of sulphuric and molybdic acids. A little pure water washes away the sulphuric acid, and molybdic acid remains behind. This acid has at first a white colour; but when melted and sublimed, it becomes yellow.

Sulphuret. Molybdenum combines readily with sulphur; and the compound has exactly the properties of molybdena, the substance which Scheele decompounded[*]. Molybdena is therefore *sulphuret of molybdenum.* The reason that Scheele obtained from it molybdic acid was, that the metal combined with oxygen during his process. Sulphuret of molybdenum may be formed also by distilling together one part of molybdic acid and five parts of sulphur.

Molybdenum is also capable of combining with phosphorus[†].

Alloys. Few of the alloys of this metal have been hitherto examined.

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[*] Pelletier, *Journ. de Phys.* 1785.

[†] Pelletier, *Ann. de Chim.* xiii. 137.

It seems capable of uniting with gold. The alloy is probably of a white colour[*].

It combines readily with platinum while in the state of an oxide. The compound is fusible. Its specific gravity is 20.00[†].

The alloys of molybdenum with silver, iron, and copper, are metallic and friable; those with lead and tin are powders which cannot be fused[‡]. Several other combinations have been made both by Hielm and Richter; but as the metals which they tried were alloyed not with molybdenum, but with molybdic acid, they cannot be considered as by any means the same with the alloys formed by molybdenum itself.

SECT. XIX.

OF URANIUM.

History of uranium.

THERE is a mineral found in the George Wagsfort mine at Johann-Georgenstadt in Saxony, partly in a pure or unmixed state, and partly stratified with other kinds of stones and earths. The first variety is of a blackish colour inclining to a dark iron grey, of a moderate splendor, a close texture, and when broken presents a somewhat uneven, and, in the smallest particles, a conchoidal surface. It is quite opaque, tolerably hard, and on being pounded yields a black powder. Its specific gravity is about 7.500. The second sort is di-

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[*] Ruprecht, *Ann. de Chim.* viii. 8.

[†] Hielm, *Ann. de Chim.* iv. 17.

[‡] Pelletier, *Journ. de Phys.* Dec. 1785.

stinguished by a finer black colour, with here and there a reddish cast; by a stronger lustre, not unlike that of pitcoal; by an inferior hardness; and by a shade of green, which tinges its black colour when it is reduced to powder*.

This fossil was called *pechblende;* and mineralogists, misled by the name †, had taken it for an ore of zinc, till the celebrated Werner, convinced from its texture, hardness, and specific gravity, that it was not a *blende*, placed it among the ores of iron. Afterwards he suspected that it contained *tungsten;* and this conjecture was seemingly confirmed by the experiments of some German mineralogists, published in the Miners Journal ‡. But Klaproth, the most celebrated analyst in Europe, examined this ore in 1789, and found that it consists chiefly of sulphur combined with a peculiar metal, to which he gave the name of *uranium* ||.

Uranium is of a dark grey colour; internally it is somewhat inclined to brown §.

Its properties.

Its malleability is unknown. Its hardness is about 6. It requires a stronger heat for fusion than manganese. Indeed Klaproth only obtained it in very small conglutinated metallic grains, forming altogether a porous and spongy mass. Its specific gravity is 6.440¶.

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[*] Klaproth, Crell's *Journal*, Eng. Transl. i. 126.

[†] *Blende* is the name given to ores of zinc.

[‡] Ibid.

[||] From *Uranus* (Ουρανος), the name given by Mr Bode to the new planet discovered by Herschel; which name the German astronomers have adopted. Mr Klaproth called the metal at first *uranite;* but he afterwards changed that name for *uranium.*

[§] Ibid. 233.

[¶] Ibid.

When exposed for some time to a red heat, it suffers no change. By means of nitric acid, however, it may be converted into a yellow powder. This is the *yellow oxide of uranium*, which seems to be composed of about 56 parts of uranium and 44 of oxygen. This oxide is found native mixed with the mineral above described.

Uranium is capable of combining with sulphur. The mineral from which Mr Klaproth first obtained it is a native sulphuret of uranium.

Nothing is known concerning the alloys or affinities of uranium.

SECT. XX.

OF TITANIUM.

History of titanium.

In the valley of Menachan, in Cornwall, there is found a black sand, bearing a strong resemblance to gunpowder. It was examined in 1791 by Mr Gregor, who found it composed almost entirely of iron, and the oxide of a new metal, to which he gave the name of *menachine**. He attempted in vain to reduce this oxide to the metallic state; but his experiments were sufficient to demonstrate the metallic nature of the substance, and that it contained a metal till then absolutely unknown. This curious and ingenious analysis seems to have excited but little attention, since nobody thought of repeating it, or of verifying the conclusions of Mr Gregor.

But in 1795 Klaproth published the analysis of a brownish red mineral, known to mineralogists by the

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* *Jour. de Phys.* xxxix. 72. and 152.

name of *red shorl.* He found it entirely composed of the oxide of a peculiar metal, to which he gave the name of *titanium* *. He failed indeed in his attempts to reduce this oxide, but his experiments left no doubt of its metallic nature. On examining in 1797 the black mineral analysed by Mr Gregor, he found it a compound of the oxides of iron and titanium †. Consequently the analysis of Mr Gregor was accurate, and his *menachine* is the same with the *titanium*, of which he was undoubtedly the original discoverer. The term *titanium* has been preferred by chemists, on account of the great celebrity and authority of the illustrious philosopher who imposed it. Klaproth's experiments were repeated, confirmed, and extended, by Vauquelin and Hecht in 1796, who succeeded in reducing a very minute portion of the oxide of titanium to the metallic state ‡. They were repeated also and confirmed by Lowitz of Petersburgh in 1798 §. By these philosophers the following properties of titanium have been ascertained.

Its properties.

Its colour is orange-red, and it has a good deal of lustre.

As it has been only obtained in very small agglutinated grains, neither its hardness, specific gravity, nor malleability, have been ascertained.

It is one of the most infusible of metals, requiring a greater heat to melt it than can be produced by any method at present known.

When heated in the open air, it combines readily with oxygen, and seems capable of forming three dif-

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[*] Beitrage, i. 233.

[†] Ibid. ii. 226.

[‡] *Jour. de Min.* No. xv. 10.

[§] Crell's *Annals*, 1799. i. 183.

ferent oxides; namely, the *blue* or *purple*, the *red*, and the *white*.

The blue or purple oxide is formed, when titanium is exposed hot to the open air, evidently in consequence of the absorption of oxygen.

The red oxide is found native. It is often crystallized in four-sided prisms; its specific gravity is about 4.2; and it is hard enough to scratch glass. When heated it becomes brown, and when urged by a very very violent fire some of it is volatilized. When heated along with charcoal it is reduced to the metallic state.

The white oxide may be obtained by fusing the red oxide in a crucible with four times its weight of potass, and dissolving the whole in water. A white powder soon precipitates, which is the white oxide of titanium. Vauquelin and Hecht have shown that it is composed of 89 parts of red oxide and 11 parts of oxygen.

Titanium does not seem to be capable of combining with sulphur *.

Phosphuret of titanium has been formed by Mr Chenevix by the following process: He put a mixture of charcoal, phosphat of titanium (phosphoric acid combined with oxide of titanium), and a little borax, into a double crucible, well luted, and exposed it to the heat of a forge. A gentle heat was first applied, which was gradually raised for three quarters of an hour, and maintained for half an hour as high as possible. The phosphuret of titanium was found in the crucible in the form of a metallic button. It is of a pale white colour, brittle, and granular; and does not melt before the blowpipe †.

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* Gregor.

† Nicholson's *Journal*, v. 134.

Book I.

Vauquelin and Hecht attempted to combine it with silver, copper, lead, and arsenic, but without success. But they combined it with iron, and formed an alloy of a grey colour, interspersed with yellow coloured brilliant particles. This alloy they were not able to fuse.

The affinities of the oxides of titanium are, according to Professor Lampadius, as follows *:

Gallic acid,
Phosphoric,
Arsenic,
Oxalic,
Sulphuric,
Muriatic,
Nitric,
Acetous.

SECT. XXI.

OF CHROMUM.

History of chromum.

In the year 1766, Lehmann, in a letter to Buffon, published the first description of a beautiful red mineral with a shade of yellow, crystallized in four-sided prisms, which is found in the mine of Beresof, near Ekaterimbourg in Siberia. This mineral, known by the name of *red lead ore of Siberia*, was used as a paint, and is now become exceedingly scarce and dear. It was examined soon after by Pallas, who considered it as a compound of lead, arsenic, and sulphur. Macquart, who in 1783 was sent upon a mineralogical expedition to the north of Europe, having brought a quantity of it to

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* *Ann. de Chim.* xxvi. 91.

Paris, analysed it in 1789 in company with Mr Vauquelin. These gentlemen concluded, from their analysis, that it is a compound of the oxides of lead and of iron. On the other hand, Mr Bindheim of Moscow concluded, from an analysis of his own, that its ingredients are lead, molybdie acid and nickel. These discordant analyses destroyed each other, and prevented mineralogists from putting any confidence in either. This induced Vauquelin, who had now made himself a consummate master of the art of analysing minerals, to examine it again in 1797*. He found it a combination of the oxide of lead, and an acid with a metallic basis never before examined. By exposing this acid to a violent heat along with charcoal powder, he reduced it to the metallic state; and to the metal thus obtained he gave the name of *chromum*†. The experiments of Vauquelin have been since repeated, and verified by Klaproth‡, Gmelin §, and Moussin Pouschkin ||.

Its properties.

Only a very few of the properties of this metal have been ascertained. Its colour is white with a shade of yellow. It is very brittle, and requires a very high temperature for fusion. It is but little altered by exposure to heat, and probably would be affected neither by the action of air nor of water. Acids act upon it

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* *Ann. de Chim.* xxv. 21. and 194.

† From χρωμα, because it possesses the property of giving colour to other bodies in a remarkable degree.

‡ Crell's *Annals*, 1798, i. 80. Mr Klaproth had examined the *red lead ore* in consequence of the analysis of Bindheim. His experiments led him to conclude, that the metallic acid, combined with the lead, was not the molybdic, but the acid of some new unknown metal: But his specimen was too small to enable him to decide the point. In the mean time, Vauquelin's experiments were published.

§ Ibid. 1799, i. 275.

|| Ibid. 1798, i. 355, &c.

Book I.

but slowly; nitric acid gradually converts it into an oxide by communicating oxygen.

Chromum seems capable of combining with three different proportions of oxygen, and of forming three oxides; namely, the *green*, the *brown*, and the *yellow* or *chromic acid.*

The *green* oxide may be obtained by exposing chromic acid to heat in close vessels; oxygen gas passes over, and the green oxide remains behind.

The *brown* oxide is intermediate between the green oxide and chromic acid. Moussin Pouschkin, who first described this oxide, compares it to the brown oxide of iron. He has not given an account of the method by which he obtained it*.

Chromic acid is found native in the *red lead ore.* It is a red or orange yellow powder, soluble in water, and composed of 33 parts of chromum and 67 of oxygen.

The remaining properties of chromum have not been examined.

SECT. XXII.

GENERAL REMARKS.

THE object of the preceding Sections has been to describe the properties of the different metals, and to examine the compounds which they form with oxygen, with simple combustibles, and with each other.

1. The following TABLE exhibits in one view the principal properties of the metals.

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* Crell's *Annals*, 1798, ii. 445.

Metals.	Colour.	Hardness.	Specific Gravity.	Fusing Point.	Malleability.	Tenacity.
Gold	Yellow	6½	19.300	32 W. 1298 F.	282000	272
Platinum	White	8	23.000	170+W.		497
Silver	White	7	10.510	28 W. 1044 F.	160000	337
Mercury	White		13.568	—39 F.		
Copper	Red	7½	8.870	27 W.		546
Iron	Blue-grey	9	7.788	158 W.		995
Tin	White	6	7.299	410 F.	2000	31
Lead	Blue-white	5½	11.352	540 F.		18.4
Nickel	White	8½	9.000	150 W.		
Zinc	White	6½	7.190	700 F.		
Bismuth	White	7	9.822	460 F.	0	
Antimony	Grey	6½	6.860	809 F.	0	
Tellurium	White		6.115	540+F.	0	
Arsenic	White	5	8.310	400? F.	0	
Cobalt	White	6	8.150	130 W.	0	
Manganese	White	9	7.000	160 W.	0	
Tungsten	Grey	10	17.600	170+W.	0	
Molybdenum	Grey		7.500		0	
Uranium	Grey	6	6.440		0	
Titanium	Red	9	4.180		0	
Chromum	White				0	

W. Wedgewood's pyrometer. F. Fahrenheit's thermometer.

Oxides

2. All the metals are capable of combining with oxygen, and of course belong to the class of combustible substances. The affinity of each for oxygen is different; for some metals are capable of absorbing oxygen from others, and of decomposing their oxides. The order of the affinity of each metal for oxygen, as far as it has been ascertained, may be seen by inspecting the table of the affinities of oxygen at the end of the first Chapter of this Book.

It is by no means the metal which has the strongest affinity for oxygen which is most combustible. Arsenic, for instance, is the most combustible of all the metals; yet its affinity for oxygen is not so strong as the affinity of tin, which may be exposed to the air for years without undergoing any considerable oxidation. We would err, therefore, very much, if we were to determine the affinity of metals for oxygen by their combustibility, as some chemists have done.

Some metals are capable of combining with only one proportion of oxygen, and consequently of forming one oxide; but the greater number combine with two, three, four, or even six different doses, and form a variety of oxides which are easily distinguished from each other by their colour. These doses are different for different metals, and for different oxides; but the same proportion of oxygen is always necessary to form the same oxide. In short, every oxide is composed of certain determinate proportions of metal and oxygen, as has been demonstrated by Mr Proust and other chemical philosophers. Hence it follows that metals are not capable of indefinite degrees of oxidation, but only of a certain number; and that every particular oxide consists of a determinate quantity of the metal and of oxygen chemically combined. Iron, for instance, is not ca-

Chap. III.

pable, as has been supposed, of uniting with oxygen in all the intermediate degrees between 0.27 and 0.48, and consequently of forming 20 or 30 different oxides: it can only combine with precisely 0.27 parts, or 0.48 parts, and with no other proportions; and therefore is only capable of forming two oxides, the *green* and the *brown.* In like manner every other metal combines with certain proportions of oxygen, and forms either two oxides or more according to its nature. To talk therefore of oxidating a metal indefinitely is not accurate, except it be intended to signify the combining of part of it with oxygen, while the rest remains in its natural state. If iron be oxidated at all, it must be combined with 0.27 of oxygen; if it be oxidated more than this, it must be combined with 0.48 of oxygen.

Contain different doses of oxygen,

When metals are capable of forming more than one oxide, it is only the first oxide, or that which contains a minimum of oxygen, which is formed by the direct combination of oxygen and the metal; for oxygen is capable of uniting with metals, or with any other substance for which it has an affinity, only in *one* determinate proportion. Iron, for instance, and oxygen can only combine in the proportion of 73 parts of iron and 27 of oxygen. These two quantities saturate each other, and form a compound which is incapable of receiving into it any more oxygen or iron: this compound is the *black oxide of iron.* How comes it then, it will be asked, that there is another oxide of iron, the *brown oxide,* which contains 52 parts of iron and 48 of oxygen, proportions certainly very different from 73 and 27? Because there is an affinity between the green oxide of iron and oxygen. They are capable of combining together, and of saturating each other in the

Book I.

proportion of about 71.5 parts of green oxide and 28.5 of oxygen; and the compound which they form is the *brown oxide*, which of course contains 52 parts of iron and 48 of oxygen: But then it is not formed by the combination of these two substances directly, but by the combination of the black oxide and oxygen. In like manner, the arsenic acid is not composed of arsenic and oxygen combined directly, but of white oxide of arsenic combined with oxygen. To give another example: Lead and oxygen combined form grey oxide of lead; grey oxide of lead and oxygen combined form white oxide; white oxide of lead and oxygen combined form red oxide; which last oxide, when combined with oxygen, forms the brown oxide of lead.

That this is the case, cannot be doubted, if we consider that, in general, every one of these successive doses of oxygen is retained by a weaker affinity than the dose which precedes it. Thus the brown oxide of iron is composed of iron and two doses of oxygen. The first dose amounts to 0.37, the second to 0.56 of the iron. Consequently,

Iron. Oxygen. Black oxide.

$1 + 0.37 = 1.37$ Oxygen. Brown oxide.

$1.37 + 0.56 = 1.93$

Retained by different affinities.

If the second dose of oxygen be abstracted, there will remain behind 1.37 of black oxide. If both doses be abstracted, there will remain behind 1 of pure iron. If both these doses adhere to the iron with the same force, it is obvious that every substance which is capable of abstracting one of these doses must be capable also of abstracting both, provided it be employed in sufficient quantity. But it is a fact that many substances are capable of abstracting the second dose of oxygen, which

Chap. III.

are incapable of abstracting the first dose. If hydrogen gas, for instance, be made to pass through brown oxide of iron, heated to redness in a porcelain tube, it converts it into black oxide of iron, and consequently deprives the iron of its second dose of oxygen. But it produces no change upon the black oxide in the same circumstances. Consequently hydrogen gas is capable of depriving iron of its second dose of oxygen, but not of its first dose. If iron be kept under water at the temperature of 80°, or if steam be made to pass over red hot iron, the water is decomposed, its hydrogen is liberated, and its oxygen combines and converts iron to a black oxide. Iron then has a stronger affinity for its first dose of oxygen than hydrogen has, but it has a weaker affinity for its second dose; or, to speak with more precision, iron has a stronger affinity for oxygen than hydrogen has; but the black oxide of iron has a weaker affinity. Accordingly the black oxide produces no change whatever upon water.

These observations apply equally to the oxides of the other metals: Every oxide that contains more than one dose of oxygen is a compound of oxygen with the oxide which immediately precedes it; and every successive dose adheres to the compound with a weaker affinity than the dose which immediately goes before it. Consequently, in a table of the affinities of oxygen, not only the metals ought to enter, but all the metallic oxides also, except those which contain a maximum of oxygen. But it is impossible to draw up such a table at present, because the affinities of these different oxides have not been examined with sufficient attention. The subject, however, is of the highest importance, and must be investigated before the action of the metals and their oxides upon each other can be understood. Thus when equal parts of iron and red oxide of iron are heated together, the whole is converted into black oxide. This ought to be the case, because iron has a stronger affinity for oxygen than black oxide has. It deprives the oxide of its second dose of oxygen, and consequently both the iron and the red oxide are reduced to the state of black oxide. Let us suppose 193 parts of red oxide and 193 parts of iron to be heated together: 193 parts of red oxide are composed of 137 black oxide + 56 oxygen: 193 parts of iron, to be converted into black oxide, require 71 parts of oxygen; but the second dose, which they can alone attract, consists of only 56 parts, consequently 15 parts of oxygen are wanting. This small portion must either be supplied by the atmosphere, or 55 parts of the iron must remain uncombined with oxygen *.

The following Table exhibits the number of metallic oxides, and the quantity of oxygen contained in one part of each, as far as this difficult subject has been investigated.

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* This is a proof that the proportions of oxygen in the oxides are not yet accurately ascertained. Indeed, from the very nature of the experiments, nothing but approximations can be expected.

Metals.	Oxides.	Proportion of Oxygen.
Gold	1. Purple	
	2. Yellow	0.10
Platinum	Yellow	0.07
Silver	1. Grey	0.10
	2. White	
Mercury	1. Black	0.04
	2. Yellow	
	3. Red	0.10
Copper	1. Orange	0.115
	2. Brown	0.20
Iron	1. Black	0.27
	2. Brown	0.48
Tin	1. Yellow	0.20
	2. White	0.28
Lead	1. Grey	
	2. White	0.07
	3. Red	0.09
	4. Brown	0.21
Nickel	Green	0.33
Zinc	White	0.20
Bismuth	1. Brown	
	2. White	0.20
Antimony	1. Black	0.02

Metals.	Oxides.	Proportion of Oxygen.
Antimony	2. Brown 3. Orange 4. Yellow 5. White 6. Acidulous	0.16 0.18 0.19 0.20 0.32
Tellurium	White	
Arsenic	1. White 2. Acid	0.248 0.346
Cobalt	Blue	0.29
Manganese	1. White 2. Red 3. Black	0.20 0.26 0.40
Tungsten	1. Black 2. Yellow	0.20
Molybdenum	1. Black 2. Blue 3. Green 4. White	
Uranium	Yellow	0.44
Titanium	1. Blue 2. Red 3. White	
Chromum	1. Green 2. Brown 3. Red	0.67

3. Two of the simple combustibles are considered at present as incapable of combining with metals; these are hydrogen and azot. Hydrogen gas indeed, in certain circumstances, dissolves a minute portion of iron, zinc, arsenic, or their oxides, and perhaps also of tin; but these solutions are not permanent. Carbon can only be combined with one metal, namely, iron. It is found indeed sometimes in zinc and in manganese, but always combined with iron.

Sulphurets.

Sulphur combines with all the metals, except gold, mercury, zinc, manganese, and titanium*. Two of these metals when oxidated, I mean mercury and zinc, combine with sulphur, and form sulphurated oxides. The metallic sulphurets are all brittle; and most of them are dark-coloured, and destitute of the metallic lustre. Scarcely any of them have been applied to any use, but some of the sulphurated oxides, as those of mercury and tin, are employed as paints.

Phosphurets.

All the metals hitherto tried are capable of combining with phosphorus except bismuth and mercury; and this last metal combines with phosphorus when in the state of black oxide. The metallic phosphurets have been applied to no use: Most of them have the metallic lustre, and all of them are brittle except those of tin, lead and zinc. In general, both sulphur and phosphorus may be separated from metals by heat.

Alloys.

4. Almost all the metals are capable of combining with each other, and of forming alloys, many of which are of the greatest utility in the arts. This property

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* Proust has proved that platinum is capable of combining with sulphur, and that sulphuret of antimony is found native.—*Ann. de Chim.* xxxviii. 149.

was long reckoned peculiar to metals, and is at present one of the best criterions for determining the metallic nature of any substance. Much is wanting to render the chemistry of alloys complete. Many of them have never been examined; and the proportions of almost all of them are unknown. Neither has any accurate method been yet discovered of determining the affinities of metals for each other. The order of affinities which has been given for each metal was determined by Bergman; but he acknowledges himself that he wanted the proper data to ensure accuracy. These alloys are much better known to artists and manufacturers than to chemists: But an examination of them, guided by the lights which chemistry is now able to furnish, would undoubtedly contribute essentially to the improvement of some of the most important branches of human industry.

CHAP. IV.

OF LIGHT.

Peculiarity of light and heat.

THE substances described in the three preceding Chapters are of such a nature that they can be collected together in quantities, and retained and confined in proper vessels, in order to be subjected to the test of experiment, and examined with accuracy. But *light* and *heat*, the substances which are now to occupy our attention, are very different. We have no method of collecting and retaining them till we submit them to our examination. They are of too subtile a nature to be confined in our vessels, and have too strong an affinity for other bodies to remain a moment in a separate state. These peculiarities have rendered the investigation of heat and light particularly intricate, and have given birth to a great many theories and hypotheses concerning them, which have been supported with much ingenuity and address by several distinguished philosophers. Their intimate connection with *combustion*, the most important problem in chemistry, has procured them the highest attention, and rendered the investigation of their properties the most interesting part of chemistry. Let us begin with the consideration of *light*, because its nature has been more completely examined than that of heat, and its properties ascertained with greater precision.

Nature of light.

EVERY person is acquainted with the light of the sun, the light of a candle, and other burning bodies; and every one knows that it is by means of light that bodies are rendered visible.

Concerning the nature of *this light*, two different theories have been advanced by philosophers. Huygens considered it as a subtile fluid filling space, and rendering bodies visible by the undulations into which it is thrown. According to his theory, when the sun rises it agitates this fluid, the undulations gradually extend themselves, and at last striking against our eye, we see the sun. This opinion of Huygens was adopted also by Euler, who exhausted the whole of his consummate mathematical skill in its defence.

The rest of philosophers, with Newton at their head, consider light as a substance consisting of small particles, constantly separating from luminous bodies, moving in straight lines, and rendering bodies luminous by passing from them and entering the eye. Newton established this theory on the firm basis of mathematical demonstration; by showing that all the phenomena of light may be mathematically deduced from it. Huygens and Euler, on the contrary, attempted to support their hypothesis rather by starting objections to the theory of Newton, than by bringing forward direct proofs. Their objections, even if valid, instead of establishing their own opinions, would prove only that the phenomena of light are not completely understood; a truth which no man will refuse to acknowledge, whatever side of the question he adopts. Newton and his disciples, on the contrary, have shewn, that the known phenomena of light are *inconsistent* with the undulations of a fluid, and that on such a supposition there can be no such thing as darkness at all. They have also brought forward a great number of direct arguments, which it has been impossible to answer, in support of their theory. The Newtonian theory therefore is much more probable than the other. Taking it for granted, then, that light is constantly moving in straight lines from luminous bodies, let us proceed to examine its properties.

Its velocity.

1. It was first demonstrated by Roemer *, a Danish philosopher, that light takes about eight minutes in moving across one half of the earth's orbit; consequently it moves at the rate of nearly 200,000 miles in a second. The discovery of Roemer has been still farther confirmed and elucidated by Dr Bradley's very ingenious theory of the aberration of the light of the fixed stars †.

Size.

2. From this astonishing velocity we are enabled to form some notion of the size of the particles of light. Mechanical philosophers have demonstrated, that the force with which a body strikes another depends upon its size and the velocity with which it moves. A 24 pound ball, if thrown from the hand, makes no impression upon a common wall; but, when discharged from a cannon, with the velocity of 1300 feet in a second, it will shatter the wall to pieces. The greater the velocity, therefore, with which a body moves, the greater the effect which it is capable of producing. Consequently to produce any effect whatever by a body,

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* *Phil. Trans.* xii. 83.

† Ibid. xxxv. 637. and xlv. 1.

however small, we have only to increase its velocity sufficiently; and in order to prevent a body from producing a given effect, its quantity must be diminished in proportion as its velocity is increased. Now the velocity of light is so great, that if each of its particles weighed the 1000th part of a grain, its force would be greater than that of a bullet discharged from a musket. Were it even the millionth part of a grain in weight, it would destroy every thing against which it struck. If it even weighed the millionth part of that, it would still have a very sensible force. But how much less must be the weight of a particle of light, which makes no sensible impression upon so delicate an organ as the eye? We are certain then that no particle of light weighs $\frac{1}{1,000,000,000,000}$th of a grain; but were we even to suppose it of that size, the addition of 9000 millions of particles to any body, or their abstraction, would make no difference of weight capable of being detected by the most sensible balance. Every attempt then to ascertain the accumulation of light in bodies by changes in their weight must be hopeless.

Refraction.

3. While a ray of light is passing through the same medium, or when it passes perpendicularly from one medium to another, it continues to move without changing its direction; but when it passes obliquely from one medium to another of a different density, it always bends a little from its old direction, and assumes a new one. It is then said to be *refracted.* When it passes into a denser medium, it is refracted *towards* the perpendicular; but when it passes into a rarer medium, it is refracted *from* the perpendicular. In general the quantity of refraction is proportional to the density of the medium; but if the medium be combustible, the

refraction is greater than it otherwise would be *. In the same medium the sines of the angles of incidence and of refraction have always the same ratio to each other.

Reflection.

4. When a ray of light enters a transparent medium, as a plate of glass with a certain obliquity, it continues to move on till it comes to the opposite surface of the glass; but then, instead of passing through the glass, it bends, and passes out again at the same surface at which it entered; just as a ball would do if made to strike obliquely against the floor. The ray is then said to be *reflected.* The angle of reflection is always equal to the angle of incidence. When the surface of a medium is polished, as glass or mirrors, oblique rays do not enter them at all, but are *reflected* when they approach the surface of the body. All surfaces are capable of reflecting a greater or smaller number of oblique rays. Rays are only reflected at surfaces.

Inflection.

5. When a ray of light passes within a certain distance of a body parallel to which it is moving, it is bent *towards* it. Thus if a ray of light be let into a dark room through a small hole in the window-shutter, and received upon paper, it will form a round luminous spot. If two penknives, with their edges towards each other, be placed on opposite sides of the hole, and made to approach each other, the luminous spot will gradually dilate itself on the side of the knives, indicating that those rays which pass nearest the knives have been drawn from their former direction towards

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* It was the knowledge of this law that led Newton to suspect the diamond to be combustible, and water to contain a combustible ingredient.—*Optics*, p. 270.

the knives. This property of light is called *inflection*.

Deflection.

6. The ray, when its distance from the body parallel to which it moves is somewhat greater, is bent *from* it. It is then said to be *deflected*.

Newton has demonstrated, that these phenomena are owing to the attraction between light and the medium through which it is moving, the medium towards which it is approaching, or the bodies in its neighbourhood.

Opacity and transparency

7. Some substances, as water, are *transparent*, or allow light to pass freely through them; others, as iron, are *opaque*, or allow no light to pass through them. Now, it can scarcely be doubted that the component particles of all bodies are far enough distant from each other to allow the free transmission of light; consequently opacity and transparency must depend, not upon the distance of the particles of bodies, but upon something else. Newton has shown, that transparency can only be explained by supposing the particles of transparent bodies uniformly arranged and of equal density. When a ray of light enters such a body, being attracted equally in every direction, it is in the same state as if it were not attracted at all, and therefore passes through the body without obstruction. In opaque bodies, on the contrary, the particles are either not uniformly arranged, or they are of unequal density. Hence the ray is unequally attracted, obliged constantly to change its direction, and cannot therefore make its way through the body.

Composed of seven coloured rays.

8. When a ray of light is made to pass through a triangular prism, and received upon a sheet of white paper, the image, or *spectrum* as it is called, instead of being circular, is oblong, and terminated by semicircular arches. In this case the refraction of the light is

increased considerably by the figure of the prism. Consequently if light consists of a congeries of rays differing in refrangibility, they will be separated from each other: the least refrangible occupying the luminous circle which the ray would have formed had it not been for the prismatic form of the glass; the others going to a greater or smaller distance from this circle, according to their refrangibility. The oblong figure of the spectrum is a proof that light consists of rays differently refrangible; and as the spectrum exhibits seven colours, these rays have been reduced under seven classes. The colours are in the following order: RED, ORANGE, YELLOW, GREEN, BLUE, INDIGO, VIOLET. The red is the most refrangible, the violet the least; the others are refrangible in the order in which they have been named. Newton ascertained, by actual measurement, that if the whole of the spectrum be divided into 360 parts, then

The red will occupy 45 of these parts

orange	27
yellow	48
green	60
blue	60
indigo	40
violet	80

But they have been since observed to differ somewhat in their relative lengths in the spectrum, according to the refracting medium.

9. These coloured rays differ from each other in reflexibility and inflexibility, precisely as they do in refrangibility: the red rays being least reflexible and inflexible, the violet most, and the rest according to their order in the prismatic spectrum.

10. Every one of these coloured rays is permanent; not being affected nor altered by any number of refractions or reflections.

The properties of light now enumerated constitute the object of the science called Optics. They prove, in the most decisive manner, that light is attracted by other bodies; and not only attracted, but attracted unequally. For combustible bodies, provided all other things be equal, refract light more powerfully than other bodies, and consequently attract light more powerfully. But it is *variation*, in point of strength, which constitutes the characteristic mark of chemical affinity. Hence it follows that the attraction which subsists between light and other bodies does not differ from chemical affinity. The importance of this remark will be seen hereafter.

Illuminating power of each.

11. The rays of light differ in their power of illuminating objects: For if an equal portion of each of these rays, one after another, be made to illuminate a minute object, a printed page for instance, it will not be seen distinctly at the same distance when illuminated by each. We must stand nearest the object when it is illuminated by the violet: we see distinctly at a somewhat greater distance when the object is illuminated by the indigo ray; at a greater, when by the blue; at a still greater, when by the deep green; and at the greatest of all, when by the lightest green or deepest yellow: we must stand nearer when the object is enlightened by the orange-ray, and still nearer when by the red. Thus it appears that the rays towards the middle of the spectrum possess the greatest illuminating power, and those at the extremity the least; and that the illuminating power of the rays gradually diminishes from

the middle of the spectrum towards its extremities. For these facts we are indebted to the experiments of Dr Herschel [*].

Light enters bodies,

12. Light is capable of entering into bodies and remaining in them, and of being afterwards extricated without any alteration. Father Beccaria, and several other philosophers, have shown us, by their experiments, that there are a great many substances which become luminous after being exposed to the light [†]. This property was discovered by carrying them instantly from the light into a dark place, or by darkening the chamber in which they were exposed. Most of these substances, indeed, lose this property in a very short time, but they recover it again on being exposed to the light; and this may be repeated as often as we please. We are indebted to Mr Canton for some very interesting experiments on this subject, and for discovering a composition which possesses this property in a remarkable degree [‡]. He calcined some common oyster shells in a good coal fire for half an hour, and then pounded and sifted the purest part of them. Three parts of this powder were mixed with one part of the 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 phial well stopped. 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 being again exposed to the

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[*] *Phil. Trans.* 1800, p. 255.

[†] Ibid. lxi. 212.

[‡] Ibid. lviii. 337.

light. Light then is not only acted upon by other bodies, but it is capable of uniting with them, and afterwards leaving them without any change.

It is well known that light is emitted during combustion; and it has been objected to this conclusion, that these bodies are luminous only from a slow and imperceptible combustion. But surely combustion cannot be suspected in many of Father Beccaria's experiments, when we reflect that one of the bodies on which they were made was his own hand, and that many of the others were altogether incombustible; and the phenomena observed by Mr Canton are also incompatible with the notion of combustion. His pyrophorus shone only in consequence of being exposed to light, and lost that property by being kept in the dark. It is not exposure to light which causes substances capable of combustion at the temperature of the atmosphere to become luminous, but exposure to air. If the same temperature continues, they do not cease to shine till they are consumed; and if they cease, it is not the application of light, but of caloric, which renders them again luminous: but Canton's pyrophorus, on the contrary, when it had lost its property of shining, did not recover it by the application of heat, except it was accompanied by light. The only effect which heat had was to increase the separation of light from the pyrophorus, and of course to shorten the duration of its luminousness. Two glass globes, hermetically sealed, containing each some of this pyrophorus, were exposed to the light and carried into a dark room. One of them, on being immersed in a bason of boiling water, became much brighter than the other, but in ten minutes it ceased to give out light; the other remained visible for more than two hours. After having been kept in the dark for two days, they were both plunged into a bason of hot water; the pyrophorus which had been in the water formerly did not shine, but the other became luminous, and continued to give out light for a considerable time. Neither of them afterwards shone by the application of hot water; but when brought near to an iron heated so as scarcely to be visible in the dark, they suddenly gave out their remaining light, and never shone more by the same treatment: but when exposed a second time to the light, they exibited over again precisely the same phenomena; even a lighted candle and electricity communicated some light to them. Surely these facts are altogether incompatible with combustion, and fully sufficient to convince us that light alone was the agent, and that it had actually entered into the luminous bodies.

It has been questioned, indeed, whether the light emitted by pyrophori be the same with that to which they are exposed. Mr Wilson has proved, that in many cases at least it is different, and in particular that on many pyrophori the blue rays have a greater effect than any other, and that they cause an extrication of red light. Mr de Grosser has shown the same thing with regard to the diamond, which is a natural pyrophorus *. Still, however, it cannot be questioned that the luminousness of these bodies is owing to exposure to light, and that the phenomenon is not connected with combustion.

And combines with them.

13. But light does not only enter into bodies, it also combines with them, and constitutes one of their

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* *Jour. de Phys.* xx. 270.

component parts. That this is the case, has been rendered very evident by a set of experiments made long ago by Mr Canton *, and lately repeated and carried a great deal farther by Dr Hulme †. It has been long known that different kinds of meat and fish, just when they are beginning to putrify, become luminous in the dark, and of course give out light. This is the case in particular with the whiting, the herring, and the mackerell. When four drams of either of these are put into a phial containing two ounces of sea water, or of pure water, holding in solution $\frac{1}{2}$ dram of common salt, or two drams of sulphat of magnesia, if the phial be put into a dark place a luminous ring appears on the surface of the liquid within three days, and the whole liquid, when agitated, becomes luminous, and continues in that state for some time. When these liquids are frozen, the light disappears, but it is again emitted as soon as they are thawed. A moderate heat increases the luminousness, but a boiling heat extinguishes it altogether. The light is extinguished also by water, lime water, water impregnated with carbonic acid gas, or sulphurated hydrogen gas, fermented liquors, spirituous liquors, acids, alkalies, and water saturated with a variety of salts, as sal-ammoniac, common salt, sulphat of magnesia; but the light appears again when these solutions are diluted with water. This light produces no sensible effect on the thermometer ‡. After these experiments, it can scarcely be denied that light constitutes a component part of these substances, and that it is the first of its con-

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* *Phil. Trans.* lix. 446.

† Ibid. 1800. p. 161.

‡ Hulme.

stituent parts which makes its escape when the substance containing it is beginning to be decomposed.

Cause of colour.

14. Almost all bodies have the property of absorbing light, though they do not all emit it again like the pyrophori and animal bodies. But they by no means absorb all the rays indiscriminately; some absorb one coloured ray, others another, while they reflect the rest. This is the cause of the different colours of bodies. A red body, for instance, reflects the red rays, while it absorbs the rest; a green reflects the green rays, and perhaps also the blue and the yellow, and absorbs the rest. A white body reflects all the rays, and absorbs none; while a black body, on the contrary, absorbs all the rays, and reflects none. The different colours of bodies, then, depend upon the affinity of each for particular rays, and its want of affinity for the others.

Light produces changes in bodies.

15. The absorption of light by bodies produces very sensible changes in them. Plants, for instance, may be made to vegetate tolerably well in the dark; but in that case their colour is always white, they have scarcely any taste, and contain but a very small proportion of combustible matter. In a very short time, however, after their exposure to light, their colour becomes green, their taste is rendered much more intense, and the quantity of combustible matter is considerably increased. These changes are very obvious, and they depend incontestibly upon the agency of light. Another very remarkable instance of the agency of light is the reduction of the metallic oxide. The red oxide of mercury and of lead become much lighter when exposed to the sun; and the white oxide of silver, in the same situation, soon becomes black and is reduced. The oxide of gold may be reduced in the same manner. Light,

then, has the property of separating oxygen from several of the oxides. Scheele, who first attended accurately to these facts, observed also, that the violet ray reduces the oxide of silver sooner than any of the other rays *; and Senebier has ascertained, that the same ray has the greatest effect in producing the green colour of plants †. Berthollet observed, that during the reduction of the oxides, a quantity of oxygen gas makes its escape.

Such are the properties of light as far as they have been examined. They are sufficient to convince us that it is a body, and that it possesses many qualities in common with other bodies. It is attracted by them, and combines with them precisely as other bodies do.

Possesses three peculiar properties.

But it is distinguished from all the substances hitherto described, by possessing three peculiar properties, of which they are destitute. The first of these properties is the power which it has of exciting in us the sensation of vision, by moving from the object seen, and entering the eye. The phenomena of colours, and the prismatic spectrum, indicate the existence of seven different species of light; but to what the difference of these species is owing, has not been ascertained. We are altogether ignorant of the component parts of every one of these species.

The second peculiar property of light, is the prodigious velocity with which it moves whenever it is separated from any body with which it was formerly combined. This velocity, which is but little less than 200,000 miles in a second, it acquires in a moment;

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* On *Fire*, p. 78. and 98.

† *Mem. Physico-chim.* ii. 72.

and it seems to acquire it too in all cases, whatever the body be from which it separates.

The third, and not the least singular of its peculiar properties, is, that its particles are never found cohering together, so as to form masses of any sensible magnitude. This difference between light and other bodies can only be accounted for by supposing that its particles repel each other. This seems to constitute the grand distinction between light and the bodies hitherto described. Its particles *repel* each other, while the particles of the other bodies attract each other; and accordingly are found cohering together in masses of more or less magnitude.

Sources of light.

16. It now only remains to consider the different methods by which light may be procured; or, to speak more precisely, the different sources from which light is emitted in a visible form. These sources are four: 1. The sun and stars; 2. Combustion; 3. Heat; and, 4. Percussion.

1. The sun.

The light emitted by the sun is familiarly known by the names of *sunshine* and *light of day*. The light of the stars, as has been ascertained, possesses precisely the same properties. With respect to the cause why the sun and stars are constantly emitting light, the question will probably for ever baffle the human understanding; at any rate, it is not considered as connected with the science of chemistry.

2. Combustion.

17. Light is emitted in every case of *combustion*. Now combustion, as far at least as regards simple combustibles and metals, is merely the act of combination of the combustible with oxygen. Consequently the light which is emitted during combustion must have existed previously combined either with the combus-

tible or with the oxygen; but with which of the two, the present state of chemistry is insufficient to determine. But this subject will be resumed in the next Chapter, where the nature of combustion will be particularly considered.

3. Heat.

18. If heat be applied to bodies, and continually increased, there is a certain temperature at which, when they arrive, they become luminous. No fact is more familiar than this; so well known indeed is it, that little attention has been paid to it. When a body becomes luminous by being heated in a fire, it is said in common language to be *red hot.* As far as experiments have been made upon this subject, it appears, that all bodies which are capable of enduring the requisite degree of heat without decomposition or volatilization begin to emit light at precisely the same temperature. The first person who examined this subject with attention was Sir Isaac Newton. He ascertained, by a very ingenious set of experiments, first published in 1701, that iron is just visible in the dark when heated to 635°; that it shines strongly in the dark when raised to the temperature of 752°; that it is luminous in the twilight just after sunset when heated to 884°; and that when it shines, even in broad day-light, its temperature is above 1000°. From the experiments of Muschenbroeck and others, it appears, that what in common language is called a *red heat*, commences about the temperature of 800°.

A red hot body continues to shine for some time after it has been taken from the fire and put into a dark place. The constant accession, then, either of light or heat, is not necessary for the shining of bodies: but if a red hot body be blown upon by a strong current of air, it immediately ceases to shine *. Consequently the moment the temperature of a body is diminished by a certain number of degrees, it ceases to be luminous.

Whenever a body reaches the proper temperature, it becomes luminous, independent of any contact of air; for a piece of iron wire becomes red hot while immersed in melted lead †.

To this general law there is one remarkable exception: It does not appear that the gases become luminous even at a much higher temperature. The following ingenious experiment of Mr T. Wedgewood seems to set the truth of this exception in a very clear point of view. He took an earthen ware tube B (fig. 7.), bent so in the middle that it could be sunk, and make several turns in the large crucible C, which was filled with sand. To one end of this tube was fixed the pair of bellows A; at the other end was the globular vessel D, in which was the passage F, furnished with a valve to allow air to pass out, but none to enter. There was another opening in this 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 E was hung at that part of the vessel where the earthen ware tube entered, it became faintly luminous. A proof, that though the air was not luminous, it had been hot enough to raise other bodies to the shining temperature.

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* T. Wedgewood, *Phil. Trans.* 1792.

† Id. Ibid.

4. Percussion.

19. The last of the sources of light is *percussion*. It is well known, that when flint and steel are smartly struck against each other, a spark always makes its appearance, which is capable of setting fire to tinder or to gunpowder. The spark in this case, as was long ago ascertained by Dr Hooke, is a small particle of the iron, which is driven off, and catches fire during its passage through the air. This, therefore, and all similar cases, belong to the class of combustion. But light often makes its appearance when two bodies are struck against each other, when we are certain that no such thing as combustion can happen, because both the bodies are incombustible. Thus, for instance, sparks are emitted, when two quartz stones are struck smartly against each other, and light is emitted when they are rubbed against each other. The experiment succeeds equally well under water. Many other hard stones also emit sparks in the same circumstances.

If they be often made to emit sparks above a sheet of white paper, there are found upon it a number of small black bodies, not very unlike the eggs of flies. These bodies are hard but friable, and when rubbed on the paper leave a black stain. When viewed with a microscope, they seem to have been melted. Muriatic acid changes their colour to a green, as it does that of lavas*. These substances evidently produced the sparks by being heated red hot. Lamanon supposes that they are particles of quartz combined with oxygen. Were that the case, the phenomenon would be precisely similar to that which is produced by the collision of flint and steel. That they are particles of quartz cannot be

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* Lamanon, *Jour. de Phys.* 1785.

Chap. IV.

doubted; but to suppose them combined with oxygen is contrary to all experience: for these stones never shew any disposition to combine with oxygen even when exposed to the most violent heat. La Metherie made experiments on purpose to see whether Lamanon's opinion was well founded; but they all turned out unfavourable to it. And Monge ascertained, that the particles described by Lamanon were pure crystal unaltered, with a quantity of black powder adhering to them. He concludes accordingly, that these fragments had been raised to so high a temperature during their passage through the air, that they set fire to all the minute bodies that came in their way *. The emission of the light is accompanied by a very peculiar smell, having some analogy to that of burning sulphur, or more nearly to burning gunpowder.

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* *Ann. de Chim.* xvi. 206.

CHAP. V.

OF CALORIC.

Nothing is more familiar to us than *heat;* to attempt therefore to define it is unnecessary. When we say that *a person feels heat*, that *a stone is hot*, the expressions are understood without difficulty; yet in each of these propositions the word *heat* has a distinct meaning. In the one, it signifies the *sensation of heat;* in the other, the *cause* of that sensation. This ambiguity, though of little consequence in common life, leads unavoidably in philosophical discussions to confusion and perplexity. It was to prevent this that the word *caloric* has been chosen to signify the *cause of heat*. When I put my hand on a hot stone, I experience a certain sensation, which I call the *sensation of heat;* the cause of this sensation is *caloric.*

As the phenomena in which caloric is concerned are the most intricate and interesting in chemistry; as the study of them has contributed in a very particular manner to the advancement of the science; as they involve some of those parts of it which are still exceedingly obscure, and which have given occasion to the most important disputes in which chemists have been engaged—they naturally lay claim to a very particular attention. I shall divide this Chapter into twelve Sections: The first will be occupied with the nature of

Chap. V.

caloric, and with those of its properties in which it resembles light; the six succeeding Sections will be employed in examining the phenomena produced by its action on other bodies; the eighth Section will treat of cold; and the ninth, tenth, eleventh, and twelfth, of the sources from which caloric is produced.

SECT. I.

NATURE OF CALORIC.

CONCERNING the nature of caloric, there are two opinions which have divided philosophers ever since they turned their attention to the subject. Some suppose that caloric, like gravity, is merely a property of matter, and that it consists, some how or other, in a peculiar vibration of its particles; others, on the contrary, think that it is a distinct substance. Each of these opinions has been supported by the greatest philosophers; and till lately the obscurity of the subject has been such, that both sides have been able to produce exceedingly plausible and forcible arguments. The recent improvements, however, in this branch of chemistry, have gradually rendered the latter opinion much more probable than the former: And a recent discovery, made by Dr Herschell, has at last put an end to the dispute, by demonstrating, that caloric is not a property, but a peculiar substance.

Discovery of rays of caloric.

1. Dr Herschell had been employed in making observations on the sun by means of telescopes. To prevent the inconvenience arising from the heat, he used colour-

ed glasses; but these glasses, when they were deep enough coloured to intercept the light, very soon cracked and broke in pieces. This circumstance induced him to examine the heating power of the different coloured rays. He made each of them in its turn fall upon the bulb of a thermometer, near which two other thermometers were placed to serve as a standard. The number of degrees, which the thermometer exposed to the coloured ray rose above the other two thermometers, indicated the heating power of that ray. He found that the most refrangible rays have the least heating power; and that the heating power gradually increases as the refrangibility diminishes. The violet ray therefore has the smallest heating power, and the red ray the greatest. Dr Herschell found that the heating power of the violet, green, and red rays are to each other as the following numbers:

Violet = 16
Green = 22.4
Red = 55

It struck Dr Herschell as remarkable, that the illuminating power and the heating power of the rays follow such different laws. The first exists in greatest perfection in the middle of the spectrum, and diminishes as we approach either extremity; but the second increases constantly from the violet end, and is greatest at the red end. This led him to suspect that perhaps the heating power does not stop at the end of the visible spectrum, but is continued beyond it. He placed the thermometer completely beyond the boundary of the red ray, but still in the line of the spectrum; and it rose still higher than it had done when exposed to the red ray. On shifting the thermometer still farther, it continued to rise; and the rise did not reach its maximum till the thermometer was half an inch beyond the utmost extremity of the red ray. When shifted still farther, it sunk a little; but the power of heating was sensible at the distance of 1½ inch from the red ray.

From these experiments it follows, that there are rays emitted from the sun, which produce heat, but have not the power of illuminating; and that these are the rays which produce the greatest quantity of heat. Consequently *caloric* is emitted from the sun in rays, and the rays of caloric are not the same with the rays of light.

On examining the other extremity of the spectrum, Dr Herschell ascertained that no rays of caloric can be traced beyond the violet ray. He had found, however, as Sennebier had done before him, that all the coloured rays of the spectrum have the power of heating: it may be questioned therefore whether there be any rays which do not *warm*. The coloured rays must either have the property of exciting heat as rays of light, or they must derive that property from a mixture of rays of caloric. If the first of these suppositions were true, light ought to excite heat in all cases; but it has been long known to philosophers that the *light* of the *moon* does not produce the least sensible heat, even when concentrated so strongly as to surpass, in point of illumination, the brightest candles or lamps, and yet these produce a very sensible heat. Here then are rays of light which do not produce heat: rays, too, composed of all the seven prismatic coloured rays. We must conclude, from this well-known fact, that rays of light do not excite heat; and consequently that the coloured rays from the sun and combustible bodies, since they excite heat, must consist of a mixture of rays of light and rays of caloric. That this is the case was demonstrated long ago by Scheele, who separated the two species from each other by a very simple method. If a glass mirror be held before a fire, it reflects the rays of light, but not the rays of caloric; a metallic mirror, on the other hand, reflects both. The glass mirror becomes hot; the metallic mirror does not alter its temperature. If a plate of glass be suddenly interposed between a glowing fire and the face, it intercepts completely the warming power of the fire, without causing any sensible diminution of its brilliancy; consequently it intercepts the rays of caloric, but allows the rays of light to pass. If the glass be allowed to remain in its station till its temperature has reached its maximum, in that situation it ceases to intercept the rays of caloric, but allows them to pass as freely as the rays of light. This curious fact, which shews us that glass only intercepts the rays of caloric till it be saturated with them, was discovered long ago by Dr Robison, professor of natural philosophy in the university of Edinburgh. These facts are sufficient to convince us that the rays of light and of caloric are different, and that the coloured rays derive their heating power from the rays of caloric which they contain.

Refracted.

2. The rays of caloric are refracted by transparent bodies just as the rays of light. We see too, that, like rays of light, they differ in their refrangibility; that some of them are as refrangible as the violet rays, but that the greater number of them are less refrangible than the red rays. Whether they are transmitted through all transparent bodies has not been ascertained; neither has the difference of their refraction in diffe-

rent mediums been examined. We are certain, however, that they are transmitted and refracted by all transparent bodies which have been employed as burning-glasses. Dr Herschell has also proved, by experiment, that it is not only the caloric emitted by the sun which is refrangible, but likewise the rays emitted by common ſires, by candles, by hot iron, and even by hot water.

Reflected.

3. The rays of caloric are reflected by polished surfaces in the same manner as the rays of light. This was lately proved by Herschell; but it had been demonstrated long before by Scheele, who had even ascertained that the angle of their reflection is equal to the angle of their incidence. Mr Pictet also had made a set of very ingenious experiments on this subject, about the year 1790, which led to the same conclusion. He placed two concave mirrors of tin, of nine inches focus, at the distance of twelve feet two inches from one another. In the focus of one of them he placed a ball of iron two inches in diameter, heated so as not to be visible in the dark; in the other was placed the bulb of a thermometer. In six minutes the thermometer rose 22°. A lighted candle, which was substituted for the ball of iron, produced nearly the same effect. In this case both light and heat appeared to act. In order to separate them, he interposed between the two mirrors a plate of clear glass. The thermometer sunk in nine minutes 14°; and when the glass was again removed, it rose in seven minutes about 12°; yet the light which fell on the thermometer did not seem at all diminished by the glass. Mr Pictet therefore concluded, that the caloric had been reflected by the mirror, and that it had been the cause of the rise of the thermometer. In

another experiment, a glass matrass was substituted for the iron ball, nearly of the same diameter with it, and containing 2044 grains of boiling water. Two minutes after a thick screen of silk, which had been interposed between the two mirrors, was removed, the thermometer rose from 47° to $50\frac{1}{8}$, and descended again the moment the matrass was removed from the focus.

The mirrors of tin were now placed at the distance of 90 inches from each other; the matrass with the boiling water in one of the foci, and a very sensible air thermometer in the other, every degree of which was equal to about $\frac{1}{11}$th of a degree of Fahrenheit. Exactly in the middle space between the two mirrors there was placed a very thin common glass mirror, suspended in such a manner that either side could be turned towards the matrass. When the polished side of this mirror was turned to the matrass, the thermometer rose only 0.5°; but when the side covered with tinfoil, and which had been blackened with ink and smoke, was turned towards the matrass, the thermometer rose to 3.5°. In another experiment, when the polished side of the mirror was turned to the matrass, the thermometer rose 3°, when the other side 9.2°. On rubbing off the tinfoil, and repeating the experiment, the thermometer rose 18°. On substituting for the glass mirror a piece of thin white pasteboard of the same dimensions with it, the thermometer rose 10° *.

Their velocity.

4. As the rays of light and of caloric emitted by the sun accompany each other, it cannot be doubted that they move with the same velocity. The rays of caloric, therefore, move at the rate of almost 200,000 miles

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* Pictet, *sur le Feu*, chap. iii.

in a second. This is confirmed by an experiment of Mr Pictet. He placed two concave mirrors at the distance of 69 feet from each other; the one of tin as before, the other of plaster gilt, and 18 inches in diameter. Into the focus of this last mirror he put an air thermometer, and a hot bullet of iron into that of the other. A few inches from the face of the tin mirror there was placed a thick screen, which was removed as soon as the bullet reached the focus. The thermometer rose the instant the screen was removed without any perceptible interval; consequently the time which caloric takes in moving 69 feet is too minute to be measured*. We see at once that this must be the case when we recollect that caloric moves at the rate of 200,000 miles in a second.

Size.

5. The velocity of caloric being equal to that of light, its particles must be equally minute. Therefore neither the addition of caloric nor its abstraction can sensibly affect the weight of bodies. As this follows necessarily as a consequence from Dr Herschell's experiments, were it possible to prove by experiment that caloric affects the weight of bodies, the theory founded on Dr Herschell's discoveries would be overturned: But such deductions have been drawn from the experiments of De Luc†, Fordyce‡, Morveau§, and Chaussier‖. According to these philosophers, bodies become absolutely lighter by being heated. The experiment of Fordyce, which seems to have been made with the greatest care, was conducted in the following manner:

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* Pictet, *sur le Feu*, chap. iii.

† *Sur les Modif. de l'Atmosph.*

‡ *Phil. Trans.* 1785, part ii.

§ *Jour. de Phys.* 1785, Oct.

‖ *Jour. de Sçavans*, 1785, p. 493.

He took a glass globe three inches in diameter, with a short neck, and weighing 451 grains; poured into it 1700 grains of water from the New River, London, and then sealed it hermetically. The whole weighed 2150$\frac{11}{12}$ grains at the temperature of 32°. It was put for twenty minutes into a freezing mixture of snow and salt till some of it was frozen; it was then, after being wiped first with a dry linen cloth, next with clean washed dry leather, immediately weighed, and found to be $\frac{1}{60}$th of a grain heavier than before. This was repeated exactly in the same manner five different times. At each, more of the water was frozen and more weight gained. When the whole water was frozen, it was $\frac{3}{16}$ths of a grain heavier than it had been when fluid. A thermometer applied to the globe stood at 10°. When allowed to remain till the thermometer rose to 32°, it weighed $\frac{2}{16}$ths of a grain more than it did at the same temperature when fluid. It will be seen afterwards that ice contains less caloric than water of the same temperature with it. The balance used was nice enough to mark $\frac{1}{1000}$th part of a grain.

This subject had attracted the attention of Lavoisier, a philosopher distinguished by the uncommon accuracy of his researches. His experiments, which were published in the Memoirs of the French Academy for 1783, led him to conclude that the weight of bodies is not altered by heating or cooling them, and consequently that caloric produces no sensible change on the weight of bodies. Count Rumford's experiments on the same subject, which were made about the year 1787, are perfectly decisive. He repeated the experiment of Dr Fordyce with the most scrupulous caution; and, by a number of the most ingenious contrivances, demonstrated, that neither the addition nor the abstraction of caloric makes any sensible alteration in the weight of bodies*.

6. Caloric not only possesses the velocity of light, but agrees with it also in another property no less peculiar. Its particles are never found cohering together in masses; and whenever they are forcibly accumulated, they fly off in all directions, and separate from each other with inconceivable rapidity. This property necessarily supposes the existence of a mutual repulsion between the particles of caloric.

Thus it appears that caloric and light resemble each other in a great number of properties. Both are emitted from the sun in rays, with the velocity of 200,000 miles in a second; both of them are refracted by transparent bodies, and reflected by polished surfaces; both of them consist of particles which mutually repel each other, and which produce no sensible effect upon the weight of other bodies. They differ, however, in this particular: light produces in us the sensation of vision; caloric, on the contrary, the sensation of heat.

SECT. II.

OF THE EXPANSION BY CALORIC.

THE properties of caloric, enumerated in the last Section, demonstrate, that it is attracted by other bodies, and consequently that it attracts them in its turn. This mutual attraction or affinity causes it to

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* *Phil. Trans.* 1799, p. 179.

Action of caloric on bodies.

enter into other bodies, to combine with them, and to occasion changes in them. The result of these mutual actions are some of the most important phenomena which ever engaged the attention of philosophers: phenomena which pervade nature, and which seem to constitute, as it were, the secret springs by which the whole machinery of this terrestrial world is regulated. These phenomena, such of them at least as have been attended to by philosophers, may be arranged, not inconveniently, under the six following heads:

1. Expansion produced by caloric.
2. Equal distribution of temperature.
3. Motion of caloric through bodies.
4. Specific caloric.
5. Caloric of fluidity.
6. Quantity of caloric in bodies.

The consideration of these topics will occupy this and the five following Sections.

Expansion.

When bodies become hot, or, which is the same thing, when caloric enters into them, they expand or increase in bulk in every direction; and this expansion is proportional to the accumulation of caloric. Caloric does not expand all substances equally, and we are still ignorant of the law which it follows. All that can be done, therefore, is to collect facts till this law be discovered. A number of these may be seen in the following Tables:

I. EXPANSION OF GASES *.

Temperature.	Hydrogen gas.	Nitrous gas.	Carbonic acid gas.	Air.	Oxygen gas.	Ammoniacal gas.	Azotic.
32°	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
41	1.01746	1.01042	1.01734	1.01109	1.00492	1.03633	1.00326
50	1.03552	1.02202	1.03679	1.02415	1.01146	1.07944	1.00779
59	1.05420	1.03492	1.05861	1.03952	1.02017	1.13059	1.01408
68	1.07352	1.04927	1.08307	1.05760	1.03177	1.19128	1.02284
77	1.09350	1.06523	1.11051	1.07890	1.04720	1.26330	1.03500
86	1.11417	1.08299	1.14129	1.10397	1.06775	1.34876	1.05192
95	1.13554	1.10695	1.17580	1.13347	1.09510	1.45017	1.07010
104	1.15764	1.12471	1.21452	1.17585	1.13151	1.57050	1.10814
113	1.18050	1.14915	1.25793	1.20908	1.17998	1.71328	1.15360
122	1.20414	1.17634	1.30663	1.25720	1.24450	1.82270	1.21680
131	1.22860	1.20659	1.36125	1.31385	1.33039	2.08384	1.30468
140	1.25389	1.24023	1.42250	1.38052	1.44473	2.32230	1.42685
149	1.28004	1.27766	1.49121	1.45901	1.59692	2.60536	1.59669
158	1.30709	1.31929	1.56826	1.55139	1.79953	2.94125	1.83283
167	1.33507	1.36560	1.65468	1.66014	2.06923	3.33982	2.16113
176	1.36401	1.41712	1.75161	1.78814	2.42825	3.81275	2.61656
185	1.39793	1.47443	1.86032	1.93882	2.90619	4.37393	3.25214
194	1.42488	1.53818	1.98224	2.11618	3.54238	5.03983	4.13438
203	1.45689	1.60909	2.11899	2.32495	4.38928	5.82999	5.36095
212	1.49000	1.68798	2.27236	2.57069	5.51666	6.76759	7.06623

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* Du Vernois, *Encyc. Method.* art. *Air.*—Prony, *Journal de l'Ecole Polytechnique*, I. ii. 24.

II. Expansion of Liquids.

Temperature.	Water *.	Mercury.	Linseed oil †.	Alcohol ‡.	Sulphuric acid §.	Nitric acid ‖.	Glass ¶.
30°	—	—	—	100000	—	—	—
32	—	100000.0	100000	—	—	—	100000
35	100000	100030.0	—	100267	—	—	—
40	99997	100081.0	—	100539	—	—	—
45	100005	100131.9	—	101818	—	100005	—
50	100023	100182.8	—	101105	100149	100149	—
55	100053	100253.7	—	101401	100263	101074	100006
60	100091	100304.6	—	101688	100382	101389	—
65	100141	100355.5	—	101984	100615	101767	—
70	100197	100406.4	—	102281	100751	102096	—
75	100261	100457.3	—	102583	—	—	100014
80	100332	100508.2	—	102890	—	—	—
85	100411	100559.1	—	103202	—	—	—
90	100694	100610.0	—	103517	—	—	—
95	100790	100660.9	102560	103840	—	—	—
100	100908	100711.8	—	104162	—	—	100023
105	—	100762.7	—	—	—	—	—
110	—	100813.6	—	—	—	—	—
120	101404	100915.4	—	—	—	—	—
122	—	—	—	—	—	—	100033
130	—	101017.2	—	—	—	—	—
140	—	101119.0	—	—	—	—	—
150	102017	101220.8	—	—	—	—	100044
160	—	101322.6	—	—	—	—	—
167	102753	—	—	—	—	—	100056
170	—	101424.4	—	—	—	—	—
180	—	101526.2	—	—	—	—	—
190	103617	101628.0	—	—	—	—	100069
200	—	101729.8	—	—	—	—	—
212	104577	101835.0	107250	—	—	—	100083
408	—	—	115160	—	—	—	—

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* Blagden. † Newton. ‡ Blagden. § Kirwan. ‖ Id. ¶ De Luc.

III. EXPANSION OF SOLIDS.

Temperature.	Platinum †.	Antimony.	Steel.	Iron.	Cast Iron.	Bismuth.
32°	120000	120000	120000	120000	120000	120000
212	120104	120130	120147	120151		120167
White heat *			123428	121500	122571	

	Copper.	Cast Brass.	Brass Wire.	Tin.	Lead.	Zinc.
32°	120000	120000	120000	120000	120000	120000
212	120204	120225	120232	120298	120344	120355

	Hammered zinc.	Zinc 8 Tin 1	Lead 2 Tin 1	Brass 2 Zinc 1	Pewter.	Copper 3 Tin ‡ 1
32°	120000	120000	120000	120000	120000	120000
212	120373	120323	120301	120247	120274	120218

From these Tables it appears that gaseous bodies expand most when heated to a given temperature, liquids next, and solids least of all. The most expansible of the gases is azotic gas: the other gases succeed it in the following order:

1. Ammoniacal.
2. Oxygen.
3. Air.
4. Carbonic.
5. Nitrous.
6. Hydrogen.

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[*] Rinman.

[†] Borda.

[‡] The metal whose expansion is here given was an alloy composed of three parts of copper and one of tin. The figures in some of the preceding columns are to be understood in the same manner. Thus in the last column but two, the metal consisted of two parts of brass alloyed with one of zinc.

The different temperatures at which their increments of bulk are the same, may be seen from the following TABLE:

BULK.	1	1½	2	3	4	5	6	7
Hydrogen gas	32°	212°						
Nitrous gas	32	190						
Carb. acid gas	32	150	195°					
Air	32	153	187					
Oxygen gas	32	143	164	186°	198°	208°		
Ammoniac. gas	32	99	128	159	178	194	204°	
Azotic gas	32	144	163	182	193	200	207	212°

Their diminution in bulk, when cooled down to —22°, as calculated by Prony, is as follows:

Ammoniacal gas	0.12494
Hydrogen gas	0.09328
Carbonic acid gas	0.07098
Nitrous gas	0.04380
Air	0.03908
Oxygen gas	0.01217
Azotic gas	0.00718[*]

Nitric acid is the most expansible of the liquid bodies which have been examined. The others observe the following order:

1. Nitric acid.
2. Linseed oil.
3. Sulphuric acid.
4. Alcohol.
5. Water.
6. Mercury.

Zinc is the most expansible of solid bodies. The expansion of the other solids contained in the Table is as follows:

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[*] Prony, *Jour. de l'Ecole Polytechn.* I. ii. 69.

1. Zinc.
2. Lead.
3. Tin.
4. Pewter.
5. Brass.
6. Copper.
7. Bismuth.
8. Iron.
9. Steel.
10. Antimony.
11. Platinum.
12. Glass.

We see too, from the Table, that the expansion is often not *equable;* that is to say, equal increments of temperature do not produce equal increments of expansion. Thus if we take two portions of water, each 100,000 cubic inches in bulk, one of them of the temperature of 50°, the other of 90°, and increase the temperature of each 5°; it follows, from the experiments of Sir Charles Blagden and Mr Gilpin, that the coldest portion will expand to the bulk of 100,030 cubic inches, the warmest portion to the bulk of 100,096. Here the increments are 30 and 96, which are manifestly unequal.

None of the gaseous bodies expand equably; the expansion of hydrogen gas is the most equable; that of azotic gas the least equable.

Of liquids, mercury alone expands equably; as has been ascertained by the experiments, of Dr Brooke Taylor[*], Mr De Luc, and Dr Black. The acids expand least equably: the expansion of alcohol is much more equable than that of water.

Solid bodies have not been examined with sufficient attention; but it has been concluded, from the experiments which have been made, that their expansion is pretty nearly equable[†].

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[*] *Phil. Trans.* xxxii. 291.

[†] On the supposition that metals expand equably, the expansion of a

Exception to expansion.

From the general law of the expansion of bodies by caloric there is one remarkable exception. Water, at the temperature of 30°, instead of being dilated by heat, suffers a remarkable contraction; and this contraction continues from the temperature of 30° to that of 40°, as is evident from the following Table of its bulk for every degree between 30° and 40°.

	Bulk.
30° . . .	100074
31 . . .	100070
32 . . .	100066
33 . . .	100063
34 . . .	100060
35 . . .	100058
36 . . .	100056
37 . . .	100055
38 . . .	100054
39 . . .	100054
40 . . .	100054*

From 40° it expands, like other substances, on being heated †.

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mass of mètal, by being heated a given number of degrees, is as follows: Let $a =$ the expansion of the mass in length for 1°, which must be found by experiment; $b =$ the number of degrees whose expansion is required; $s =$ the solid contents of the metallic mass; $x =$ the expansion sought; then $x = 3bas$.

* Blagden.

† There was a curious fact concerning dilatation observed by Mr De Luc. A brass rod which he used as a thermometer became in summer *habitually* longer; that is to say, that after being for some time lengthened by heat, it did not contract by the application of cold to its old length, but continued somewhat longer. In winter the contrary phenomenon took place. After being contracted for some time by cold, it did not return to its old length on the application of heat, but kept somewhat shorter. A leaden rod shewed these effects in a greater degree. Glass

Chap. V.

Nature of the thermometer.

The property which bodies possess of expanding, when heat is applied to them, has furnished us with an instrument for measuring the relative temperatures of bodies. This instrument is the *thermometer*. A thermometer is merely a hollow tube of glass, hermetically sealed, and blown at one end into a hollow globe or *bulb*. The bulb and part of the tube are filled with mercury. When the bulb is plunged into a hot body, the mercury expands, and of course *rises* in the tube; but when it is plunged into a cold body, the mercury contracts, and of course *falls* in the tube. The rising of the mercury indicates an increase of heat; its falling a diminution of it; and the quantity which it rises and falls indicates the proportion of increase or diminution. To facilitate observation, the tube is divided into a a number of equal parts called degrees.

The thermometer, to which we are indebted for almost all the knowledge respecting caloric which we possess, was invented about the beginning of the 17th century; and seems to have been first thought of by Sanctorio, the celebrated founder of statical medicine. The first rude thermometer was improved by the Florentine academicians, and by Mr Boyle; but it was Sir Isaac Newton who first rendered it really useful, by pointing out the method of constructing thermometers capable of being compared together.

If we plunge a thermometer ever so often into melting snow, it will always stand at the same point. Hence we learn, that snow always begins to melt at the

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has not this quality. De Luc suspects that this property is inversely as the elasticity of bodies. Glass is perfectly elastic, and lead is less elastic than brass.—*Jour. de Phys.* xviii. 369.

same temperature. Dr Hooke observed also, that if we plunge a thermometer ever so often into boiling water, it always stands at the same point, provided the pressure of the atmosphere be the same; consequently water (other things being the same) always boils at the same temperature. If therefore we plunge a new made thermometer into melting snow, and mark the point at which the mercury stands in the tube; then plunge it into boiling water, and mark the new point at which the mercury stands; then divide the portion of the tube between the two marks into any number of equal parts; suppose 100, calling the freezing point 0, and the boiling point 100; every other thermometer constructed in a similar manner will stand at the same degree with the first thermometer, when both are applied to a body of the same temperature. All such thermometers therefore may be compared together, and the scale may be extended to any length both above the boiling point and below the freezing point.

Newton first pointed out the method of making comparable thermometers*; but the practical part of the art was greatly simplified by Mr Fahrenheit of Amsterdam and Dr Martine of St Andrew's †. Mercury is the liquid which answers best for thermometers, because its expansion is equable. There are four different thermometers used at present in Europe, differing from one another in the number of degrees into which the space between the freezing and boiling points is divided. These are Fahrenheit's, Celsius's, Reaumur's and Delisle's.

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* *Phil. Trans.* Abr. iv. 1.

† On the Construction and Graduation of Thermometers.

Different thermometers.

Fahrenheit's thermometer is used in Britain. The space between the boiling and freezing points is divided into 180°; but the scale begins at the temperature produced by mixing together snow and common salt, which is 32° below the freezing point; of course the freezing point is marked 32°, and the boiling point 212° *.

The thermometer of Celsius is used in Sweden; it has been used also in France since the Revolution under the name of the *thermometre centigradè*. In it the space between the freezing and boiling points is divided into 100°. The freezing point is marked 0, the boiling point 100° †.

The thermometer known by the name of Reaumur, which was in fact constructed by De Luc, was used in France before the Revolution, and is still used in Italy and Spain. In it the space between the boiling and freezing points is divided into 80°. The freezing point is marked 0, the boiling point 80° ‡.

Delisle's thermometer is used in Russia. The space between the boiling and freezing points is divided into 150°, but the graduation begins at the boiling point, and increases towards the freezing point. The boiling point is marked 0, the freezing point 150° §.

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* This is the thermometer always used throughout this Work, unless when some other is particularly mentioned.

† Consequently the degrees of Fahrenheit are to those of Celsius, as 180 : 100 = 18 : 10 = 9 : 5. That is, 9° of Fahrenheit are equal to 5° of Celsius. Therefore, to reduce the degrees of Celsius to those of Fahrenheit, we have $F = \frac{9\,C}{5} + 32$.

‡ Consequently 180 F = 80 R, or 18 F = 8 R, or 9 F = 4 R; therefore $F = \frac{9\,R}{4} + 32$.

§ Hence 180 F = 150 D, or 6 F = 5 D. To reduce the degrees of

SECT. III.

OF THE EQUAL DISTRIBUTION OF TEMPERATURE.

Contiguous bodies assume the same temperature.

We can easily increase the temperature of bodies, whenever we choose, by exposing them to the action of our artificial fires. Thus a bar of iron may be made red hot by keeping it a sufficient time in a common fire: but if we take it from the fire, and expose it to the open air, it does not retain the heat which it had received; but becomes gradually colder and colder, till it arrives at the temperature of the bodies in its neighbourhood. On the other hand, if we cool down the iron bar, by keeping it for some time covered with snow, and then carry it into a warm room, it does not retain its low temperature, but becomes gradually hotter, till it acquires the temperature of the room. Thus it appears that no body can retain its high temperature while surrounded by colder bodies, nor its low temperature while it is surrounded by hotter bodies. The caloric, however, combined at first, gradually distributes itself in such a manner, that all contiguous bodies, when examined by the thermometer, indicate the same temperature. These changes occupy a longer or a shorter time, according to the size or the nature of the body; but they always take place at last.

Delisle's thermometer under the boiling point to those of Fahrenheit, we have $F=212-\frac{6D}{5}$; to reduce those above the boiling point, $F=212+\frac{6D}{5}$.

Chap. V.

This law is familiar to every person: when we wish to heat any thing, we carry it towards the fire; when we wish to cool it, we surround it by cold bodies. The caloric in this last case is not lost, it is merely distributed equally through the bodies. When a number of substances are mixed together, some of them cold and some of them hot, they all acquire the same temperature; and this new temperature is a mean of all the first temperatures of the substances. Those which were hot become colder, and those which were cold become hotter. This property of caloric has been called by philosophers the *equilibrium of caloric;* but it might, with greater propriety, be denominated, the *equal distribution of temperature.*

Attempts to explain why.

This property, so familiar in common life, was long before it attracted the attention of philosophers; but after they did begin to examine the subject, they found it by no means an easy task to account for it in a satisfactory manner. De Mairan, and other writers in the earlier part of the 18th century, explained it by supposing that caloric is a fluid which pervades all space, and that bodies merely float in it as a sponge does in water, without having any affinity for it whatever. The consequence of all this was a constant tendency to an equality of density. Of course, if too much caloric is accumulated in one body, it must flow out; if two little, it must flow in till the equality of density be restored.

This hypothesis is inconsistent with the phenomena which it is intended to explain. Were it true, all bodies ought to heat and to cool with the same facility; and the heat ought to continue as long in the focus of a burning glass as in a globe of gold of the same diameter. It

Book I.

is equally inconsistent with the nature of caloric; which has been shewn in the first Section of this Chapter to be a body very different from the hypothetical fluid of De Mairan.

Another explanation of the equal distribution of temperature, and a much more ingenious one, was proposed by Mr Pictet. According to this philosopher, when caloric is accumulated in any body, the repulsion between its particles is increased, because the distance between them is diminished. Accordingly they repel each other; and this causes them to fly off in every direction, and to continue to separate till they are opposed by caloric in other bodies of the same relative density with themselves, which, by repelling them in its turn, compels them to continue where they are. The equal distribution of temperature therefore depends on the balancing of two opposite forces: the repulsion between the particles of caloric in the body, which tends to diminish the temperature; and the repulsion between the caloric of the body and the surrounding caloric, which tends to raise the temperature. When the first force is greater than the second, as is the case when the temperature of a body is higher than that of the surrounding bodies, the caloric flies off, and the body becomes colder. When the last force is stronger than the first, as is the case when a body is colder than those which are around it, the particles of its caloric are obliged to approach nearer each other, new caloric enters to occupy the space which they had left, and the body becomes hotter. When the two forces are equal, the bodies are said to be of the same temperature, and no change takes place *.

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* See Pictet, *sur le Feu*, chap. i.

But this theory, notwithstanding its ingenuity, is inconsistent with the phenomena of the heating and cooling of bodies, and cannot therefore be admitted. Were it true, a hot body would cool much more rapidly when hung up in a vacuum than when exposed to the open air; because the repulsive force of the surrounding caloric, which retards the cooling process, is removed. For it cannot be supposed that the repulsion between the particles of caloric acts sensibly at a distance which exceeds the 800th or 1000th part of an inch; since two bladders filled with air, and lying close together, exhibits no marks of repulsion, though heated ever so much. And this holds how thin or how light soever the bladders are; it even holds with two soap bubbles. But undoubtedly the bladders or the soap bubbles would separate from each other if the sphere of the repulsion of caloric exceeded the thickness of their respective coats. Now Count Rumford* has demonstrated, that hot bodies cool more slowly when suspended in a torricellian vacuum than when surrounded by air; and Mr Pictet † himself has ascertained, that the same thing holds in the exhausted receiver of an air pump. The equal distribution of temperature, then, is owing to the balancing of more complicated forces than this theory supposes.

As caloric moves at the rate of 200,000 miles in a second, it never could be accumulated in any body were it not retarded by its affinity for that body; but for this retarding force, it would pass through the body with the rapidity of lightning, and leave no trace behind it. There must therefore be an affinity between caloric and every body which is capable of being heated.

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[*] *Phil. Trans.* 1786, part i.

[†] *Sur le Feu*, chap. i.

Now as almost all bodies are capable of being heated, we are certain that there is an affinity between almost all bodies and caloric.

Owing to the balancing of three forces.

It follows from this, that whenever caloric is accumulated in any body, it is acted upon at once by three different forces: 1. The affinity between it and the body in which it is accumulated. 2. The affinity between it and the surrounding bodies. 3. The repulsion between its particles. The first of these tends to preserve the temperature of the hot body, the other two to diminish its temperature. It is upon these three forces that the equal distribution of temperature depends. When the temperature of two neighbouring bodies is the same, the affinity of each for caloric must be the same; for if not, the body which has the strongest affinity for caloric would absorb it from the other, and thus destroy the equality. When the temperature of a body continues unchanged, its affinity for the caloric combined with it must precisely counterbalance the repulsion between the particles of that caloric. When a number of bodies, situated near each other, continue of the same temperature, the affinity of each for the caloric combined with it must counterbalance the mutual repulsion between the particles of that caloric and the affinity between it and the surrounding bodies. If an additional dose of caloric be thrown into one of these bodies, it cannot remain there, because the balance between the opposite forces is now destroyed; the repulsion between the particles of the caloric being increased, and the affinity of the colder bodies for caloric being greater than that of the hot body.

A hot body cools more slowly in a vacuum, because the affinity of the surrounding bodies for caloric is in a great measure removed. It cools more rapidly when exposed to a blast of cold air; because new bodies are constantly applied, whose affinity for caloric is greater than the body. A very hot body cools much more rapidly than one which is only moderately warm; because both the cooling forces are much stronger in the first case than in the last. The rapidity of cooling is proportional to the surface of the hot body, because the action of the surrounding bodies is proportional to that surface.

When a thermometer, plunged into a body, remains unchanged, it indicates merely, that the temperature of the body, and of the thermometer, are the same; and consequently that each of them is combined with such a proportion of caloric, that the affinity of each for new portions of it is the same. The thermometer does not inform us of the absolute quantity of coloric in the body to which we apply it; but merely, whether that body or the thermometer have the strongest affinity for caloric. But as this affinity depends upon the quantity of caloric in the body, we can conclude from it, whether the caloric in the body be greater or less than usual, and in what proportion.

To this explanation of the equal distribution of temperature it may be objected, that there is no resemblance between chemical combinations and the combinations of bodies with caloric. In chemical combinations, the substances unite always in certain proportions, and mutually saturate each other; but caloric unites to bodies in any proportion, and no such thing as saturation takes place. Thus water is a chemical compound of 85 parts of oxygen and 15 of hydrogen, and the ingredients cannot combine in any other proportion. But iron may be cooled down

Book I.

to —68°, and afterwards heated to whiteness. Between these two extremes there is a vast interval; yet every dose of caloric is combined with the iron; for if the heating cause be removed at any stage of the heating process, the iron does not cool down instantly, and consequently the caloric is retained by the body. It would appear from this, that iron either cannot be saturated with caloric, or that after saturation it is still capable of combining with more caloric; both of which seem different from chemical affinity.

But this difference is merely apparent: for many other bodies are capable of combining with others in various proportions, even when the combinations into which they enter are undoubtedly chemical. Water, for instance, combines with sulphuric acid and alcohol in any proportion whatever. Even oxygen unites in various doses to all the simple combustibles except hydrogen, and to almost all the metals. Allowing, therefore, that it were impossible to explain why bodies are capable of combining with caloric indefinitely, this could be no objection to the theory that it unites only chemically with bodies, because the same phenomenon is exhibited by other bodies which, it cannot be doubted, combine only by means of affinity.

I have already, in my remarks on the metallic oxides *, endeavoured to give a general explanation of the manner in which various doses of one body combine with another. The first dose combines directly with the base, and forms a compound which we shall call A; the second dose combines directly with A, and forms a compound which we shall call B; the third dose combines

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* Book I. Chap. iii. Sect. 22.

directly with B, and forms a compound which we shall call C; and so on. It is in this manner that caloric unites with bodies. Let us suppose, for instance, that caloric is presented to ice; that they combine together in a certain proportion, and saturate each other. The product of this combination is water; a substance possessed of properties very different from those of caloric or ice in a concrete state: it is incapable of being decomposed by any method merely mechanical, and exhibits all the appearances of a simple substance. Let us therefore consider this compound for a moment as a simple substance. May it not still have an affinity for caloric? and will it not, in that case, unite with it? Water and caloric have an affinity for each other; accordingly, when presented to one another, they combine in a certain proportion, and form a new compound, differing from water at 32° in specific gravity, and several other particulars. The affinity, however, between water and caloric is much feebler than between ice and caloric; and accordingly the new compound is easily broken, and the caloric absorbed by many other substances. We can even conceive this new compound still to have an affinity for caloric, to unite with it, and to form another compound, the affinity between the ingredients of which is still feebler. And in this manner may the indefinite increase of temperature be accounted for.

But one difficulty still remains to be accounted for: How comes it that bodies cool each other reciprocally? for it is well known that there is no substance whatever which may not be cooled indefinitely merely by surrounding it with bodies which are colder than itself. Put a bit of hot iron, for instance, in cold water, it is

Book I.

very soon cooled down to the temperature of that liquid. This seems plain enough; the attraction of water for caloric is greater than that of iron: but reverse the experiment; put hot water within cold iron, and the water is cooled in its turn down to the temperature of the iron: so that the iron also has a greater affinity for caloric, as well as the water; which is absurd.

But this seeming absurdity vanishes altogether upon a closer inspection. It was mentioned formerly as a general law, that when a body is capable of combining with several different doses of another body, every additional dose is retained by an affinity weaker than the dose which precedes it. This holds in all the metallic oxides which contain more than one dose of oxygen. Now as caloric may be combined indefinitely with all bodies, all bodies may contain an indefinite number of doses of it. But, according to the general law, every one of these doses must be retained by a weaker affinity than the dose which precedes it; consequently the greater number of doses with which a body is combined, the weaker is the affinity by which the last of them are retained. This shews us why bodies cool down each other reciprocally. A hot body is combined with a greater number of doses of caloric than a cold body; consequently it is reasonable to expect that its affinity for some of these doses will be less than the affinity of the cold body for caloric. The cold body therefore separates these doses, and combines with them itself; that is to say, it cools down the body to its own temperature. For we mean nothing more when we say that two bodies are of the same temperature, than that both of them affect the thermometer in the same manner; which must always be the case when they are allowed to act upon each other for a sufficient time: Both of them must have combined with such a number of dozes of caloric, that the affinity between each of them and the last dose with which it has combined is the same. But this may happen, even though the one has combined in reality with twice the quantity of caloric which the other contains. The equal distribution of temperature, then, is nothing more than an equality in point of affinity between all contiguous bodies and the caloric with which they are combined.

It is necessary for all organized bodies, and probably for all bodies, that they contain a certain portion of caloric; and it has been wisely ordered by the Author of Nature, that the portion of caloric indicated, when we speak in common language of the temperature of bodies, has so weak an affinity for the bodies with which it is combined, that it may be easily separated from them; and thus the proper quantity of caloric be secured without difficulty by those bodies which require its influence.

SECT. IV.

OF THE MOTION OF CALORIC.

When caloric is at perfect liberty, it moves at the rate of 200,000 miles in a second. Such is its velocity when it is emitted from the sun or from burning bodies. But it is capable not only of moving through free space, but also of making its way through all terrestrial bodies whatever. In this respect it differs from all other substances, even from light, which, as far as we know, cannot make its way through all bodies.

Motion of caloric through bodies of two kinds:

The motion of caloric through bodies is of two kinds: Through some bodies it moves with the same rapidity as through free space, or at least its velocity suffers no sensible diminution during its passage. In this way it moves through air, and through several other transparent bodies: Through other bodies it moves with a remarkably slow motion. Thus if we put the point of a bar of iron, twenty inches in length, into a common fire, while a thermometer is attached to the other extremity; four minutes elapse before the thermometer begins to ascend, and 15 minutes by the time it has risen 15°; consequently caloric takes 4′ to pass through a bar of iron 20 inches long. The difference between this rate and that of 200,000 miles in a second is enormous. The motions must therefore be different in kind.

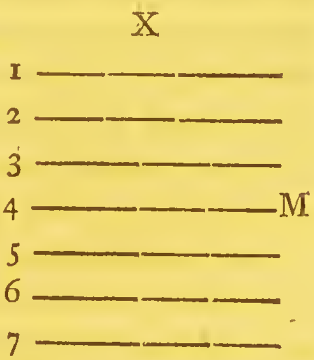
1. Transmitted;
2. Conducted.

When caloric passes through a body with undiminished velocity, we say that it is *transmitted* through it: on the other hand, when its velocity is prodigiously diminished, as in the case of the iron bar, we say that it is *conducted* through it. It cannot be doubted that caloric is *transmitted* through bodies, and *conducted* through them in quite a different manner.

Air, and all the transparent bodies hitherto examined, have the property of transmitting caloric through them; though some of them, as glass, do not transmit it till after they have combined with a certain proportion of it: and probably no body transmits it unless a greater quantity enter than is capable of combining with it in the state in which the body is placed. The phenomena of the transmission of caloric are exactly similar to the transmission of light, and admit of precisely the same explanation. What Scheele and several other chemists have called *radiant heat*, is nothing else than transmitted caloric.

Conducting power explained.

As the velocity of caloric, when it is *conducted* thro' bodies, is excessively retarded, it is clear that it does not move through them without restraint. It must be detained for some time by the particles of the conducting body, and consequently must be attracted by them. Hence it follows that there is an affinity or attraction between *caloric* and every *conductor*. It is in consequence of this affinity that it is conducted through the body. This perhaps will be better understood by the following illustration:



Let M be a body (a mass of iron, for instance) composed of an indefinite number of particles, arranged in the strata 1, 2, 3, 4, 5, 6, 7, &c. Let caloric be communicated to it in the direction X. The first stratum of particles 1 combines with a dose of caloric, and forms a compound which we shall call A. This compound cannot be decomposed by the second stratum, because all the strata before the application of the heat were at the same temperature; consequently the affinity of all for caloric must have been equal. Now it would be absurd to suppose a compound destroyed by an affinity no greater than that which produced it If therefore only one dose of caloric combined with stratum 1, no caloric could pass beyond that stratum. But the compound A has still an affinity for caloric; it therefore combines with an-

Book I.

other dose of it, and forms a new compound, which we shall call B.

This stratum is now combined with two doses of caloric; the second of which, according to the general law already explained, is retained by a weaker affinity than the first. Stratum 2, therefore, is capable of abstracting this second dose. Accordingly it combines with it, and forms the compound A. Here are two strata combined each with a dose of caloric, and consequently constituting compound A. The third stratum is unable to decompose the second, for the same reason that the second was unable to decompose the first while only combined with one dose. Stratum 1 again combines with a dose of caloric, and forms compound B. Stratum 2 is unable to decompose this compound, because being already combined with one dose, its affinity for the second dose cannot be greater than that of stratum 1 for the same second dose.

But stratum 1 combines with a third dose of caloric, and forms a new compound which we shall call C. The affinity of this third dose being inferior to that of the second, stratum 2 abstracts it and forms compound B. This second dose is abstracted from stratum 2 by stratum 3, which now forms compound A. Stratum 1 again forms compound C, to be again decomposed by stratum 2, which stratum forms anew compound B. Compound C is a third time formed by stratum 1. Three strata are now heated. Stratum 1 is combined with three doses, stratum 2 with two doses, and stratum 3 with one dose. The caloric can pass no farther: for stratum 4 cannot decompose compound A, nor stratum 3 compound B, nor stratum 2 compound C. But stratum 1 combines with a fourth dose of caloric, and forms a new compound which we shall call D. This new dose is abstracted by stratum 2, which forms compound C. It is again abstracted from stratum 2 by stratum 3, which forms compound B. From stratum 3 it is abstracted by stratum 4, which forms compound A. Stratum 1 again combines with a new dose, and forms compound D; which is abstracted first by stratum 2, and then by stratum 3, which last stratum forms compound B. Stratum 1 a third time forms compound D; but the dose is immediately abstracted by stratum 2, which forms with it compound C. Compound D is a fourth time formed by stratum 1, and is not decomposed any more. Here are four strata combined with caloric; stratum 1 with four doses, stratum 2 with three doses, stratum 3 with two doses, and stratum 4 with one dose. In this manner may the heating process go on till any number of strata whatever are combined with caloric.

Bodies then conduct caloric in consequence of their affinity for it, and the property which they have of combining indefinitely with additional doses of it. Hence the reason of the slowness of the process, or, which is the same thing, of the long time necessary to heat or to cool a body. The process consists in an almost infinite number of repeated compositions and decompositions.

We see, too, that when heat is applied to one extremity of a body, the temperature of the strata of that body must diminish equably, according to their distance from the source of heat. Every person must have observed that this is always the case. If, for instance, we pass our hand along an iron rod, one end of which is held in the fire, we shall perceive its temperature gradually diminishing from the end in the fire, which is hottest, to the other extremity, which is coldest.

Has a limit.

The passage of caloric through a body, by its conducting power, must have a limit; and that limit depends upon the number of doses of caloric with which the stratum of the body nearest the source of heat is capable of combining. If the length of a body be so great that the strata of which it is composed exceed the number of doses of caloric with which a stratum is capable of combining, it is clear that caloric cannot possibly be conducted through the body; that is to say, the strata farthest distant from the source of heat cannot receive any increase of temperature. This limit depends, in all cases, upon the quantity of caloric with which a body is capable of combining before it changes its state. All bodies, as far as we know at present, are capable of combining indefinitely with caloric; but the greater number, after the addition of a certain number of doses, change their state. Thus ice, after combining with a certain quantity of caloric, is changed into water, which is converted in its turn to steam by the addition of more caloric. Metals also, when heated to a certain degree, melt, are volatilized, and oxidated: wood and most other combustibles catch fire, and are dissipated. Now whenever as much caloric has combined with the first stratum of a body as it can receive without changing its state, it is evident that no more caloric can enter the body; because the next dose will dissipate the first stratum.

The distance therefore to which a body is capable of conducting caloric is always proportional to the temperature to which that body can be raised before it changes its state. Therefore antimony is capable of conducting caloric farther than wood, and iron farther than antimony, and perhaps stones are capable of conducting it even farther than iron.

As bodies conduct caloric in consequence of their affinity for it, and as all bodies have an affinity for caloric, it follows as a consequence, that all bodies must be conductors, unless their conducting power be counteracted by some other property. If a body, for instance, were of such a nature that a single dose of caloric sufficed to produce a change in its state, it is evident that it could not conduct caloric; because every row of particles, as soon as it had combined with a dose of caloric, would change its place, and could not therefore communicate caloric to the strata behind it.

All solids conductors.

All *solids* are conductors; because all solids are capable of combining with various doses of caloric before they change their state. This is the case in a very remarkable degree with all earthy and stony bodies; it is the case also with metals, with vegetables, and with animal matters. This, however, must be understood with certain limitations. All bodies are indeed conductors; but they are not conductors in all situations. Most solids are conductors at the common temperature of the atmosphere; but when heated to the temperature at which they change their state, they are no longer conductors. Thus at the temperature of 60° sulphur is a conductor; but when heated to 185°, or the point at which it melts or is volatilized, it is no longer a conductor. In the same manner ice conducts caloric when at the temperature of 20°, or any other degree below the freezing point; but ice at 32° is not a conductor, because the addition of caloric causes it to change its state.

With respect to liquids and gaseous bodies, it would appear at first sight that they also are all conductors; for they can be heated as well as solids, and heated too considerably without sensibly changing their state. But fluids differ from solids in one essential particular; their particles are at full liberty to move among themselves, and they obey the smallest impulse: while the particles of solids, from the very nature of these bodies, are fixed and stationary. One of the changes which caloric produces on bodies is expansion, or increase of bulk; and this increase is attended with a proportional diminution of specific gravity. Therefore whenever caloric combines with a stratum of particles, the whole stratum becomes specifically lighter than the other particles. This produces no change of situation in solids; but in fluids, if the heated stratum happens to be below the other strata, it is pressed upwards by them, and being at liberty to move, it changes its place, and is buoyed up to the surface of the fluid.

Fluids carry caloric,

In fluids, then, it makes a very great difference to what part of the body the source of heat is applied. If it be applied to the highest stratum of all, or to the surface of the liquid, the caloric can only makes its way downwards, as through solids, by the conducting power of the fluid; but if it be applied to the lowest stratum, it makes its way upwards, independent of that conducting power, in consequence of the fluidity of the body and the expansion of the heated particles. The lowest stratum, as soon as it combines with a dose of caloric, becomes specifically lighter, and ascends. New particles approach the source of heat, combine with caloric in their turn, and are displaced. In this manner all the particles come, one after another, to the source of heat; of course the whole of them are heated in a very short time, and the caloric is carried almost at once to much greater distances in fluids than in any solid whatever. Fluids therefore have the property of *carrying* or *transporting* caloric; in consequence of which they acquire heat independent altogether of any conducting power.

The *carrying* power of fluids was first accurately examined by Count Rumford. This ingenious philosopher was so struck with it the first time he observed it, that he was led to conclude that it is by means of it alone that fluids acquire heat, and that they are altogether destitute of the property of conducting caloric. In a set of experiments on the communication of heat, he made use of thermometers of an uncommon size. Having exposed one of these (the bulb of which was near four inches in diameter) filled with alcohol to as great a heat as it could support, he placed it in a window to cool where the sun happened to be shining. Some particles of dust had by accident been mixed with the alcohol: these being illuminated by the sun, became perfectly visible, and discovered that the whole liquid in the tube of the thermometer was in a most rapid motion, running swiftly in opposite directions upwards and downwards at the same time. The *ascending* current occupied the axis, the *descending* current the sides of the tube. When the sides of the tube were cooled by means of ice, the velocity of both currents was accelerated. It diminished as the liquid cooled; and when it had acquired the temperature of the room, the motion ceased altogether. This experiment was repeated with linseed oil, and the result was precisely the same. These currents were evidently produced by the particles of the liquid going individually to the sides of the tube, and giving out their caloric. The moment they did so, their specific gravity being increased, they fell to the bottom, and of course pushed up the warmer part of the fluid, which was thus forced to ascend along the axis of the tube. Having reached the top of the tube, the particles gave out part of their caloric, became specifically heavier, and tumbled in their turn to the bottom.

As these internal motions of fluids can only be discovered by mixing with them bodies of the same specific gravity with themselves, and as there is hardly any substance of the same specific gravity with water which is not soluble in it, Count Rumford had recourse to the following ingenious method of ascertaining whether that fluid also followed the same law. The specific gravity of water is increased considerably by dissolving any salt in it; he added, therefore, potass to water till its specific gravity was exactly equal to that of amber, a substance but very little heavier than pure water. A number of small pieces of amber were then mixed with this solution, and the whole put into a glass globe with a long neck, which, on being heated and exposed to cool, exhibited exactly the same phenomena with the other fluids. A change of temperature, amounting only to a very few degrees, was sufficient to set the currents a-flowing; and a motion might at any time be produced by applying a hot or a cold body to any part of the vessel. When a hot body was applied, that part of the fluid nearest it ascended; but it descended on the application of a cold body.

These observations naturally led Count Rumford to examine, whether the heating and cooling of fluids be not very much retarded by every thing which diminishes the fluidity of these bodies. He took a large linseed-oil thermometer with a copper bulb and glass tube: the bulb was placed exactly in the centre of a brass cylinder; so that there was a void space between them all around 0.25175 of an inch thick. The thermometer was kept in its place by means of four wooden pins projecting from the sides and bottom of the cylinder, and by the tube of it passing through the cork stopper of the cylinder. This cylinder was filled with pure water, then held in melting snow till the thermometer fell to 32°, and immediately plunged into a vessel of boiling water. The thermometer rose from 32° to 200° in 597″. It is obvious that all the caloric which served to raise the thermometer must have made its way through the water in the cylinder. The experiment was repeated exactly in the same manner; but the water in the cylinder, which amounted to 2276 gr. had 192 gr. of starch boiled in it, which rendered it much less fluid. The thermometer now took 1109″ to rise from 32° to 200°. The same experiment was again repeated with the same quantity of pure water, having 192 gr. of eiderdown mixed with it, which would merely tend to embarrass the motion of the particles. A quantity of stewed apples were also in another experiment put into the cylinder. The following TABLES exhibit the result of all these experiments.

Time the Caloric was in passing into the Thermometer.

Temperature.	Through the Water and Starch.	Through the Water and Eiderdown.	Through stewed Apples.	Through pure Water.
	Seconds.	Seconds.	Seconds.	Seconds.
Therm. rose from 32° to 200° in	1109	949	1096½	597
Therm. rose 80°, *viz.* from 80° to 160°, in	341	269	335	172

Time the Caloric was in passing out of the Thermometer.

Temperature.	Through the Water and Starch.	Through the Water and Eiderdown.	Through stewed Apples.	Through pure Water.
	Seconds.	Seconds.	Seconds.	Seconds.
Therm. fell from 200° to 40° in	1548	1541	1749½	1032
Therm. fell 80°, *viz.* from 160° to 80°, in	468	460	520	277

Now the starch and eiderdown diminished the fluidity of the water. It follows from these experiments, that "the more completely the internal motions of a liquid are impeded, the longer is that liquid before it acquires a given temperature." Therefore, when heat is applied to liquids, they acquire the greatest part of their temperature, in common cases, by their carrying power.

If liquids then be conductors, their conducting power is but small when compared with their carrying power.

And conduct it.

All liquids, however, are capable of conducting caloric; for when the sourse of heat is applied to their surface, the caloric gradually makes its way downwards, and the temperature of every stratum gradually diminishes from the surface to the bottom of the liquid. The increase of temperature in this case is not owing to the carrying power of the liquid. By that power caloric may indeed make its way upwards through liquids, but certainly not downwards. Liquids, then, are conductors of caloric.

Count Rumford, indeed, has drawn a different conclusion from his experiments. He fixed a cake of ice in the bottom of a glass jar, covered $\frac{1}{4}$ inch thick with cold water. Over this was poured gently a considerable quantity of boiling water. Now, if water were a non-conductor, no caloric would pass through the cold water, and consequently none of the ice would be melted. The melting of the ice, then, was to determine whether water be a conductor or not. In two hours about half of the ice was melted. This one would think, at first sight, a decisive proof that water is a conductor. But the Count has fallen upon a very ingenious method of acccunting for the melting of the ice, "without being under the necessity (as he tells us) of renouncing his theory that fluids are non-conductors."

It is well known that the specific gravity of water at 40° is a maximum: if it be either heated above 40°, or cooled down below 40°, its density diminishes. Therefore, whenever a particle of water arrives at the temperature of 40°, it will sink to the bottom of the vessel. Now as the water next the ice was at 32°, it is evident that whenever any part of the hot water was cooled down to 40°, it would sink, displace the water at 32°, come into contact with the ice, and of course melt it. The Count's ingenuity, never without resources, enabled him to prove completely that the ice employed in his experiment was actually melted in that manner: for when he covered the ice partially with slips of wood, that part which was shaded by the wood was not melted; and when he covered the whole of the ice with a thin plate of tin, having a circular hole in the middle, only the part exactly under the hole was melted. From these facts it certainly may be concluded that the ice was melted by descending currents of water.

But the point to be proved is not whether there were descending currents, but whether water be a conductor or not. Now if water be a non-conductor, I ask, How the hot water was cooled down to 40°? Not at the surface; for the Count himself tells us, that there the temperature was never under 108°: not by the sides of the vessel; for the descending current in one experiment was exactly in the axis: and it follows irresistibly, from the experiment with the slips of wood, that these descending currents fell equally upon every part of the surface of the ice; which would have been impossible if these currents had been cooled by the side of the vessel. The hot water, then, must have been cooled down to 40° by the cold water below it; consequently it must have imparted caloric to this cold water. If so, one particle of water is capable of absorbing caloric from another; that is, water is a *conductor of caloric*. After the hot water had stood an hour over the ice, its temperature was as follows:

At the surface of the ice	40°
One inch above the ice	80
Two inches	118
Three inches	128
Four inches	130
Seven inches	131

How is it possible to account for this gradual diminution of heat as we approach the ice if water be a non-conductor? The water, it may be said, gives out caloric at its surface, falls down, and arranges itself according to its specific gravity. If so, how comes it that there is only one degree of difference between the temperature at 4 and at 7 inches above the ice? Thus it appears that the Count's experiment, instead of demonstrating that water is a non-conductor, rather favours the supposition that it is a conductor.

The Count tried whether oil and mercury be conductors in the following manner: When water is frozen in a glass jar by means of a freezing mixture, he observed, that the ice first begins to be formed at the sides, and gradually increases in thickness; and that the water on the axis of the vessel, which retains its fluidity longest, being compressed by the expansion of the ice, is forced upwards, and when completely frozen forms a pointed projection or nipple, which is sometimes half an inch higher than the rest of the ice. Upon ice frozen in this manner he poured olive oil, previously cooled down to 32°, till it stood at the height of three inches above the ice. The vessel was surrounded as high as the ice with a mixture of pounded ice and water. A solid cylinder of wrought iron, 1.25 inch in diameter, and 12 inches long, provided with a hollow cylindrical sheath of thick paper, was heated to the

Book I.

temperature of 210° in boiling water; and being suddenly introduced into its sheath, was suspended from the ceiling of the room, and very gradually let down into the oil, until the middle of the flat surface of the hot iron, which was directly above the point of conical projection of the ice, was distant from it only $\frac{2}{10}$ of an inch. The end of the sheath descended $\frac{1}{10}$ of an inch lower than the end of the hot metallic cylinder. Now it is evident, that if olive oil be a conductor, caloric must pass down through it from the iron and melt the ice. None of the ice, however, was melted; and when mercury was substituted for oil, the result was just the same *.

From this experiment the Count concluded, that neither oil nor mercury are capable of conducting caloric. But it is by no means sufficiently delicate to decide the point. If a thermometer be substituted instead of the nipple of ice, it always rises several degrees, as I have ascertained by experiment; consequently caloric passes downwards even in this case. The experiment, then, is in fact favourable to the supposition that these fluids are conductors.

Count Rumford's experiments then do not prove his position, that fluids are non-conductors, but rather the contrary. That they are all in fact conductors of caloric, I ascertained in the following manner: The liquid whose conducting power was to be examined was poured into a glass vessel till it filled it about half way; then a hot liquid of a less specific gravity was poured over it. Thermometers were placed at the surface, in the centre, and at the bottom of the cold liquid; if these

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* Rumford, Essay vii. Part ii. chap. 1.

rose, it followed that the liquid was a conductor, because the caloric made its way downwards. For instance, to examine the conducting power of mercury, a glass jar was half filled with that liquid metal, and boiling water then poured over it. The thermometer at the surface began immediately to rise, then the thermometer at the centre, and lastly that at the bottom. The first rose to 118°, the second to 90°, the third to 86° : the first reached its maximum in 1′, the second in 15′, the third in 25′. The conducting power of water was tried in the same manner, only hot oil was poured over it. A variety of precautions were necessary to ensure accuracy ; but for these I refer to the experiments themselves, which are detailed in Nicholson's Journal *.

Fluids, then, as far as experiments have been made, are conductors of caloric as well as solids. Hence it follows that all bodies with which we are acquainted are capable of conducting caloric.

Relative conducting powers of bodies.

If we take a bar of iron and a piece of stone of equal dimensions, and putting one end of each into the fire, apply either thermometers or our hands to the other, we shall find the extremity of the iron sensibly hot long before that of the stone. Caloric therefore is not conducted through all bodies with the same celerity and ease. Those that allow it to pass with facility, are called *good conductors;* those through which it passes with difficulty, are called *bad conductors.*

The experiments hitherto made on this subject are too few to enable us to determine with precision the rate at which different bodies conduct caloric. The

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* Nicholson's *Journal*, iv. 529.

subject, however, is of the highest importance, and deserves a thorough investigation.

Metals are the best conductors of caloric of all the solids hitherto examined. The conducting powers of all, however, are not equal. Dr Ingenhousz procured cylinders of several metals exactly of the same size, and having coated them with wax, he plunged their ends into hot water, and judged of the conducting power of each by the length of wax-coating melted. From these experiments he concluded, that the conducting powers of the metals which he examined were in the following order *:

Silver,
Gold,
Copper, } nearly equal,
Tin, }
Platinum, }
Iron, }
Steel, } much inferior to the others.
Lead, }

Next to metals stones seem to be the best conductors; but this property varies considerably in different stones. Bricks are much worse conductors than most stones.

Glass seems not to differ much from stones in its conducting power. Like them, it is a bad conductor. This is the reason that it is so apt to crack on being suddenly heated or cooled. One part of it, receiving or parting with its caloric before the rest, expands or contracts, and destroys the cohesion.

Next to these come dried woods. Mr Meyer † has made a set of experiments on the conducting power of

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* *Jour. de Phys.* 1789, p. 68.

† *Ann. de Chim.* xxx. 32.

a considerable number of woods. The result may be seen in the following Table, in which the conducting power of water is supposed = 1.

Bodies.	Conducting Power.
Water	= 1.00
Diaspyrus ebenum	= 2.17
Pyrus malus	= 2.74
Fraxinus excelsior	= 3.08
Fagus sylvatica	= 3.21
Carpinus betulus	= 3.23
Prunus domestica	= 3.25
Ulmus	= 3.25
Quercus robur pedunculata	= 3.26
Pyrus communis	= 3.32
Betula alba	= 3.41
Quercus robur sessilis	= 3.63
Pinus picea	= 3.75
Betula alnus	= 3.84
Pinus sylvestris	= 3.86
Pinus abies	= 3.89
Tilea Europæa	= 3.90

Charcoal is also a bad conductor: According to the experiments of Morveau, its conducting power is to that of fine sand : : 2 : 3 *. Feathers, silk, wool, and hair, are still worse conductors than any of the substances yet mentioned. This is the reason that they answer well for articles of clothing. They do not allow the heat of the body to be carried off by the cold external air. Count Rumford has made a very ingenious set of experiments on the conducting power of these

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* *Ann. de Chim.* xxvi. 225.

substances *. He ascertained that their conducting power is inversely as the fineness of their texture.

The conducting power of liquid bodies has not been examined with any degree of precision. I find, by experiment, that the relative conducting powers of mercury, water, and linseed oil, are as follows :

I. EQUAL BULKS.

Water . . . . = 1
Mercury . . . . . . = 2
Linseed oil . . . . = 1.111

II. EQUAL WEIGHTS.

Water . . . . = 1
Mercury . . . . . . = 4.8
Linseed oil . . . . . = 1.085

As bodies conduct caloric in consequence of their affinity for it, the inequality of their conducting power is a demonstration that their affinities for caloric are also unequal. It is probable that their affinity for caloric is in all cases the inverse of their conducting power. If therefore we were in possession of the relative conducting powers of bodies, the inverse of that would give us the affinities in absolute numbers. Thus the affinity of

Water is . . . . $= 1$ . . . $= 1$
Mercury . . . . $= \frac{1}{4.8}$ . . $= 0.208$
Linseed oil . . . $= \frac{1}{1.085}$. $= 0.921$

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* *Phil. Trans.* 1792.

SECT. V.

OF SPECIFIC CALORIC.

Bodies require different proportions of caloric for the same temperature.

If equal weights of water and mercury, at different temperatures, be mixed together and agitated, it is natural to expect that the mixture would acquire the mean temperature. Suppose, for instance, that the temperature of the water were 100°, and that of the mercury 50°, it is reasonable to suppose that the water would be cooled 25°, and the mercury heated 25°, and that the temperature after mixture would be 75°. But when the experiment is tried, the result is very far from answering this apparently reasonable expectation: for the temperature after mixture is 88°; consequently the water has only lost 12°, while the mercury has gained 38°. On the other hand, if we mix together equal weights of water at 50°, and mercury at 100°, the temperature, after agitation, will be only 62°; so that the mercury has given out 38°, and the water has received only 12°. This experiment demonstrates, that the same quantity of caloric is not required to raise mercury a given number of degrees which is necessary to raise water the same number. The quantity of caloric which raises mercury 38°, raises water only 12°; consequently the caloric which raises the temperature of water 1°, will raise that of the same weight of mercury 3.16°.

If other substances be tried in the same manner, it will be found that they all differ from each other in the quantity of caloric which is necessary to heat each of them to a given temperature; some requiring more than the same weight of water would do, others less; but every one requires a quantity peculiar to itself. Now the quantity of caloric which a body requires, in order to be heated to a certain temperature (one degree for instance), is called the *specific caloric* of that body. We do not indeed know the absolute quantity of caloric which is required to produce a certain degree of heat in any body; but if the unknown quantity necessary to heat water (1° for instance) be made = 1, we can determine, by experiment, how much more, or how much less caloric other bodies require to be heated the same number of degrees. Thus if we find by trial that the quantity of caloric which heats water 1°, heats the same weight of mercury 3.16°, it follows, that the specific caloric of water is 3.16 times greater than that of mercury; therefore if the specific caloric of water = 1, that of mercury must be = 0.31. In this manner may the specific caloric of all bodies be found.

That the specific caloric of bodies is different, was first pointed out by Dr Black. Dr Irvine afterwards investigated the subject, and Dr Crawford published a great number of experiments on it in his *Treatise on Heat*. These three philosophers denoted this property by the phrase *capacity of bodies for heat*. But Professor Wilcke of Stockholm, who published the first set of experiments on the subject, introduced the term *specific caloric*, which has been generally adopted, because the phrase *capacity for caloric* is liable to a great deal of ambiguity, and has introduced confusion into this subject*.

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* The term *specific caloric* has been employed in a different sense by Seguin. He used it for the *whole caloric* which a body contains.

Method of ascertaining this difference.

The experiments of Mr Wilcke were first published in the Stockholm Transactions for 1781, but had been made long before. The manner in which they were conducted is exceedingly ingenious, and they furnish us with the specific caloric of many of the metals. The metal on which the experiment was to be made was first weighed accurately (generally one pound was taken), and then being suspended by a thread, was plunged into a large vessel of tinplate, filled with boiling water, and kept there till it acquired a certain temperature, which was ascertained by a thermometer. Into another small box of tinplate exactly as much water at 32° was put as equalled the weight of the metal. Into this vessel the metal was plunged, and suspended in it so as not to touch its sides or bottom; and the degree of heat, the moment the metal and water were reduced to the same temperature, was marked by a very accurate thermometer. He then calculated what the temperature would have been if a quantity of water, equal in *weight* to the metal, and of the same temperature with it, had been added to the ice-cold water instead of the metal.

Let M be a quantity of water at the temperature C, m another quantity at the temperature c, and let their common temperature after mixture be x; according to a rule demonstrated long ago by Richman, $x = \frac{MC + mc}{M + m}$. In the present case the quantities of water are equal, therefore M and m are each $= 1$; C, the temperature of the ice-cold water, $= 32$: therefore $\frac{MC + mc}{M + m} = \frac{32 + c}{2}$. Now c is the temperature of the metal. There-

Book I. fore if 32 be added to the temperature of the metal, and the whole be divided by 2, the quotient will express the temperature of the mixture, if an equal weight of water with the metal, and of the same temperature with it, had been added to the ice-cold water instead of the metal.

He then calculated what the temperature of the mixture would have been, if, instead of the metal, a quantity of water of the same temperature with it, and equal to the metal in *bulk*, had been added to the ice-cold water. As the weights of the ice-cold water and the metal are equal, their volumes are inversely as their specific gravities. Therefore the volume of ice-cold water is to a a quantity of hot water equal in volume to the metal, as the specific gravity of the metal to that of the water. Let $M =$ volume of cold water, $m =$ volume of hot water, $g =$ specific gravity of the metal, $1 =$ specific gravity of water; then $m : M :: 1 : g$; hence $m = \frac{M}{g} =$ (M being made $= 1$) $\frac{1}{g}$. Substituting this value of m in the formula, $\frac{MC + mc}{M + m} = x$, in which $M = 1$ and $C = 32$, x will be $= \frac{32g + c}{g + 1}$. Therefore if the specific gravity of the metal be multiplied by 32, and the temperature of the metal be added, and the sum be divided by the specific gravity of the metal + 1, the quotient will express the temperature to which the ice-cold water would be raised by adding to it a volume of water equal to that of the metal, and of the same temperature with it.

He then calculated how much water at the temperature of the metal it would take to raise the ice-cold water the same number of degrees which the metal had raised it. Let the temperature to which the metal had raised the ice-cold water be = N, if in the formula $\frac{MC + mc}{M + m} = x$, x be made = N, M = 1, C = 32, m will be $= \frac{N - 32}{c - N}$. Therefore if from the temperature to which the ice-cold water was raised by the metal 32 be subtracted, and if from the temperature of the metal be subtracted the temperature to which it raised the water, and the first remainder be divided by the last, the quotient will express the quantity of water of the temperature of the metal which would have raised the ice-cold water the same number of degrees that the metal did.

Now $\frac{N - 32}{c - N}$ expresses the specific caloric of the metal, that of water being = 1. For (neglecting the small difference occasioned by the difference of temperature) the weight and volume of the ice-cold water are to the weight and volume of the hot water as 1 to $\frac{N - 32}{c - N}$, and the number of particles of water in each are in the same proportion. But the metal is equal in weight to the ice-cold water; it must therefore contain as many particles of matter; therefore the quantity of matter in the metal must be to that in the hot water as 1 to $\frac{N - 32}{c - N}$. But they gave out the same quantity of caloric; which, being divided equally among their particles, gives to each particle a quantity of caloric inversely as the bulks of the metal and water; that is,

Book I.

the specific caloric of the water is to that of the metal as 1 to $\frac{N-32}{c-N}$*.

It will now be proper to give a specimen or two of his experiments, and the calculations founded on them, as above described.

GOLD. *Specific Gravity* 19.040.

Number of experiments.	Temperature of the metal.	Temperature to which the metal raised the water at 32°	Temper. to which it would have been raised by a quantity of water equal in weight and heat to the metal.	Temperature to which it would have been raised by water equal in bulk and temperature to the metal.	Denominator of the fraction $\frac{N-32}{c-N}=\frac{1}{\frac{c-N}{N-32}}$, the numerator being 1.
1	163·4°	38·3°	97·7°	38·555°	19·857
2	144·5	37·4	88.25	37·58	19·833
3	127·4	36.5	79·7	36.68	20.500
4	118.4	36.05	75·2	36.15	20·333
5	103·1	35·6	65·75	35·42	18.750
6	95	34·45	63·5	35·06	19.000

Mean 19·712

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* All these formulas have been altered to make them correspond with Fahrenheit's thermometer. They are a good deal simpler when the experiments are made with Celsius's thermometer, as Mr Wilcke did. In it the freezing point is zero; and consequently instead of 32 in the formula, 0 is always substituted.

LEAD. *Specific Gravity* 11.456.

Number of experiments.	Temperature of the metal.	Temperature to which the metal raised the water at 32°.	Temperature to which the water would have been raised by a quantity of water equal in weight and heat to the metal.	Temperature to which the water would have been raised by water equal in bulk and temperature to the metal.	Denominator of the fraction $\frac{1}{\frac{c-N}{N-32}}$
1	186.8	38.3	109.4	44.425	23.571
2	181.40	37.85	106.7	43.473	24.538
3	165.2	37.4	98.6	42.692	23.666
4	163.4	37.4	97.7	42.548	23.333
5	136.4	36.5	84.2	40.344	22.200
6	131	36.05	81.5	39.947	24.700
7	126.5	36.05	79.25	39.585	22.333
8	107.6	35.15	69.8	38.339	23.000
9	94.1	34.7	63.05	36.985	22.000

Mean 23.515

It is needless to add, that the last column marks the denominator of the specific caloric of the metal; the numerator being always 1, and the specific caloric of water being 1. Thus the specific caloric of gold is $\frac{1}{19.712}$. In exactly the same manner, and by taking a mean of a number of experiments at different temperatures, did Mr Wilcke ascertain the specific caloric of a number of other bodies. He ascertained at the same time, that the specific caloric of a body does not vary with the temperature, but continues always the same. This will appear evident from the experiments on gold and lead above exhibited.

Next, in point of time, and not inferior in ingenious contrivances to ensure accuracy, were the experiments of Dr Crawford made, by mixing together bodies of different temperatures. These were published in his *Treatise on Heat*.

Several experiments on the specific caloric of bodies were made also by Lavoisier and De la Place, which, from the well-known accuracy of these philosophers, cannot but be very valuable.

Their method was exceedingly simple and ingenious; it was first suggested by De la Place. An instrument was contrived, to which Lavoisier gave the name of *calorimeter*. It consists of three circular vessels nearly inscribed into each other, so as to form three different apartments, one within the other. These three we shall call the *interior*, *middle*, and *external cavities*. The interior cavity *f f f f* (see section of the instrument fig. 8.) into which the substances submitted to experiment are put, is composed of a grating or cage of iron wire, supported by several iron bars. Its opening or mouth LM is covered by the lid HG, which is composed of the same materials. The middle cavity *b b b b* is filled with ice. This ice is supported by the grate *m m*, and under the grate is placed a sieve. The external cavity *a a a a* is also filled with ice. We have remarked already, that no caloric can pass through ice at 32°. It can enter ice, indeed, but it remains in it, and is employed in melting it. The quantity of ice melted, then, is a measure of the caloric which has entered into the ice. The exterior and middle cavities being filled with ice, all the water is allowed to drain away, and the temperature of the interior cavity to come down to 32°. Then the substance, the specific caloric of which is to be ascertained, is heated a certain number of degrees, suppose to 212°, and then put into the interior cavity inclosed in a thin vessel. As it cools, it melts the ice in the middle cavity. In proportion as it melts, the water runs through the grate and sieve, and falls through the conical funnel *c c d* and the tube *x y* into a vessel placed below to receive it. The external cavity is filled with ice, in order to prevent the external air from approaching the ice in the middle cavity and melting part of it. The water produced from it is carried off through the pipe ST. The external air ought never to be below 32°, nor above 41°. In the first case, the ice in the middle cavity might be cooled too low; in the last, a current of air flows through the machine, and carries off some of the caloric. By putting various substances at the same temperature into this machine, and observing how much ice each of them melted in cooling down to 32°, it was easy to ascertain the specific caloric of each. Thus if water, in cooling from 212° to 32°, melted one pound of ice, and mercury 0.31 of a pound; the specific caloric of water was one, and that of mercury 0.31. This appears by far the simplest method of making experiments on this subject; and must also be the most accurate, provided we can be certain that all the melted snow falls into the receiver. But from an experiment of Mr Wedgewood, one would be apt to conclude that this does not happen. He found that the melted ice, so far from flowing out, actually *froze* again, and choaked up the passage.

A Table of the specific caloric of various bodies was likewise drawn up by Mr Kirwan, and published by Magellan in his Treatise on Heat. Mr Meyer has lately published a set of experiments on the specific caloric of dried woods.

The result of all these investigations is exhibited in one view in the following TABLE, which contains the specific caloric of those bodies on which experiments have hitherto been made.

I have added to it a column, expressing the specific caloric of equal bulks of the same bodies; which is the only way of considering this subject in which the phrase *capacity for caloric* is intelligible. This column was formed by multiplying the specific caloric of equal weights of the various substances into their respective specific gravities.

TABLE *of the Specific Caloric of various Bodies, that of Water being* = 1.0000 ††.

Bodies.	Specific Gravity.	Specific Caloric of equal Weight.	of equal Volumes.
I. GASES *.			
Hydrogen gas	0.000094	21.4000	0.00214
Oxygen gas	0.0034	4.7490	0.006411
Common air	0.00122	1.7900	0.002183
Carbonic acid gas	0.00183	1.0459	0.001930
Steam		1.5500	
Azotic gas	0.00120	0.7036	0.000952
II. LIQUIDS.			
Water	1.0000	1.0000	1.0000
Carbonat of ammonia †		1.851	
Arterial blood *		1.030	
Cows milk *	1.0324	0.9999	1.0322
Sulphuret of ammonia †	0.818	0.9940	0.8130
Venous blood *		0.8928	
Solution of brown sugar †		0.8600	
Nitric acid ‡		0.844	
Sulphat of magnesia 1 Water . . . . 8 } †		0.844	
Common salt 1 Water . . . . 8 } † . .		0.832	
Nitre 1 Water 8 } ‡		0.8167	
Muriat of ammonia 1 Water . . . . . . 1.5 } †		0.779	

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†† The specific caloric of the substances marked * was ascertained by Dr Crawford, those marked † by Mr Kirwan, ‡ by Lavoisier and La Place, ** by Wilcke, ‖ by Count Rumford. § Is the mean of Crawford, Kirwan, and Lavoisier; ¶ mean of Lavoisier and Kirwan; (*c*) mean of Crawford and Lavoisier; (*d*) mean of Wilcke and Crawford; (*e*) mean of Wilcke, Crawford, and Kirwan; (*f*) Meyer.

TABLE *continued.*

Bodies.	Specific Gravity.	Specific Caloric of equal Weight.	of equal Volumes.
Tartar 1 Water 237.3 } †		0.765	
Solution of potass †	1.346	0.759	1.2216
Sulphat of iron 1 Water 2.5 } †		0.734	
Sulphat of soda 1 Water 2.9 } †		0.728	
Oil of olives †	0.9153	0.710	0.6498
Ammonia †	0.997	0.7080	0.7041
Muriatic acid †	1.122	0.6800	0.763
Sulphuric acid 4 Water 5 } ‡		0.6631	
Alum 1 Water 4.45 } †		0.649	
Nitric acid $9\frac{1}{3}$ Lime 1 } ‡		0.6181	
Nitre 1 Water 3 } †		0.646	
Alcohol *	0.8371	0.6021	0.4993
Sulphuric acid §	1.840	0.5968	1.120
Nitrous acid †	1.355	0.576	0.780
Linseed oil †	0.9403	0.528	0.4964
Spermaceti oil *		0.5000	
Oil of turpentine †	0.9910	0.472	0.4132
Vinegar †		0.3870	0.3966
Lime 9 Water 16 } ‡		0.3346	
Mercury ¶	13.568	0.3100	4.123
Distilled vinegar †		0.1030	0.1039
III. SOLIDS.			
Ice †		0.9000	
Ox-hide with the hair *		0.787	
Lungs of a sheep *		0.769	
Lean of ox-beef *		0.7400	

TABLE *continued.*

Bodies.	Specific Gravity.	Specific Caloric	
		of equal Weight.	of equal Volumes.
Pinus sylvestris (*f*) . .	0.408	0.65	0.265
Pinus abies (*f*)	0.447	0.60	0.268
Tilea Europæa (*f*) . .	0.408	0.62	0.252
Pinus picea (*f*)	0.495	0.58	0.287
Pyrus malus (*f*) . . .	0.639	0.57	0.364
Betula alnus (*f*) . . .	0.484	0.53	0.256
Quercus robur sessilis (*f*)	0.531	0.51	0.270
Fraxinus excelsior (*f*)	0.631	0.51	0.321
Pyrus communis (*f*) .	0.603	0.50	0.301
Rice *		0.5050	
Horse beans *		0.5020	
Dust of the pine tree *		0.5000	
Pease *		0.4920	
Fagus sylvatica (*f*) . .	0.692	0.49	0.358
Carpinus betulus (*f*) .	0.690	0.48	0.331
Betula alba (*f*)	0.608	0.48	0.291
Wheat *		0.4770	
Elm (*f*)	0.646	0.47	0.321
Quercus robur pedunculata (*f*)	0.668	0.45	0.300
Prunus domestica (*f*) .	0.687	0.44	0.302
Diaspyrus ebenum (*f*)	1.054	0.43	0.453
Barley *		0.4210	
Oats *		0.4160	
Pitcoal *		0.2777	
Charcoal *		0.2631	
Chalk *		0.2564	
Rust of iron *		0.2500	
White oxide of antimony washed *		0.2270	
Oxide of copper nearly freed from air * . . .		0.2272	
Quicklime (*c*)		0.2199	
Stoneware †		0.195	
Agate **	2.648	0.195	0.517

TABLE *continued.*

Bodies.	Specific Gravity.	Specific Caloric	
		of equal Weight.	of equal Volumes.
Crystal ‡	3.189?	0.1929	0.6151
Cinders *		0.1923	
Swedish glass **	2.386	0.187	0.448
Ashes of cinders *		0.1885	
Sulphur †	1.99	0.183	0.3680
Flint glass †	3.3293	0.174	0.5792
Rust of iron nearly freed from air *		0.1666	
White oxide of antimony ditto *		0.1666	
Ashes of the elm *		0.1402	
Oxide of zinc nearly free from air *		0.1369	
Iron (*d*)	7.876	0.1264	0.993
Brass (*d*)	8.358	0.1141	0.971
Copper (*d*)	8.784	0.1121	1.027
Sheet iron ‡		0.1099	
Oxide of lead and tin *		0.102	
Gun-metal ‖		0.1100	
White oxide of tin nearly free from air *		0.0990	
Zinc (*d*)	7.154	0.0981	0.735
Ashes of charcoal *		0.0909	
Silver **	10.001	0.082	0.833
Yellow oxide of lead nearly freed from air *		0.0680	
Tin (*e*)	7.380	0.0661	0.444
Antimony (*d*)	6.107	0.0637	0.390
Gold **	19.040	0.050	0.966
Lead (*e*)	11.456	0.0424	0.487
Bismuth **	9.861	0.043	0.427

The difference in the specific caloric of bodies is perfectly analogous to all other chemical combinations.

Scarcely any two metals, for instance, when converted into oxides, combine with precisely the same quantity of oxygen. It depends therefore upon the affinity which exists between bodies and caloric. In all probability, indeed, the specific caloric of bodies is always proportional to their affinity for caloric; that is to say, the greater their affinity, the greater their specific caloric. For it is reasonable to suppose, that the greater the affinity between a body and caloric, the greater quantity of caloric will combine with it before it be in a disposition to part with caloric to other bodies; consequently the greater quantity of caloric will be necessary, in order to raise it to a given temperature.

If this reasoning be conclusive, it follows, that the specific caloric of bodies is always inversely as their conducting power. For it was shewn, in the last Section, that the conducting power is inversely as the affinity of bodies for caloric. This conclusion is of considerable importance; not only because it simplifies the theory of the combinations of caloric with bodies, but because it enables us (if it be accurate) to determine the conducting power of bodies from their specific caloric, or the contrary. A set of experiments on purpose would be necessary to establish it completely. In the small number of bodies whose conducting powers I have ascertained, the numbers are more nearly the inverse of the specific calorics of these bodies, as determined in the Table, than could have been expected in experiments of so delicate a nature. That this is the case, is evident from the following Table:

Bodies.	Specific Caloric.	Conducting Power by Theory.	Conducting Power by Exper.	Difference.
Water	1	1	1	0
Mercury . . .	0.31	3.22	4.600	+ 1.38
Linseed oil . .	0.9403	1.06	1.085	+ 0.02

It is probable, then, that the conducting power of bodies is always inversely as their specific caloric. This will enable us to form a pretty accurate notion of the relative conducting power of bodies, by inspecting the Table of their specific caloric.

SECT. VI.

OF THE CALORIC OF FLUIDITY.

THE important part which caloric acts in the operations of nature was first perceived in its full extent by Dr Black. To this illustrious philosopher we are indebted for the discovery and explanation of the most important properties of that singular body. Before his time nothing was established, the most absurd hypotheses were admitted, and philosophers seem to have been of opinion that only vague conjectures could be advanced upon the subject. But Dr Black demonstrated the truth of all his positions by accurate experiments; while the consequences which he drew followed so obviously from his premises, that every person, when he heard them for the first time, could not avoid wondering how he himself could have missed them. It was this admirable simplicity, the surest characteristic of a great mind, which distinguished Dr Black: no man ever excelled him in clearness and perspicuity, and in the art of proving the truth of his opinions by simple, obvious, and conclusive experiments. His two grand discoveries may be considered as the foundation of every thing which has been done in chemistry since, and as the first great cause of all the modern improvements in the science.

His knowledge of caloric was remarkably correct and extensive. He first pointed out, that substances differ in their conducting power. He was well acquainted with the carrying power of fluids, and always described minutely how they are heated. He knew equally well the difference of the specific caloric of bodies, and first pointed out the method of ascertaining that difference. But his grand discovery was the discovery of the *cause of fluidity*.

Solids rendered fluid by combining with caloric.

The greater number of solid bodies may, by the application of heat, be converted into fluids. Thus ice may be converted into water; sulphur, phosphorus, and the metals, may be melted; and this is the case also with many stony bodies. Now whenever a solid is converted into a fluid, it combines with a certain dose of caloric, without any augmentation of its temperature; and it is this dose of caloric which occasions the change of the solid into a fluid. When the fluid is converted again into a solid, the dose of caloric leaves it, without any diminution of its temperature; and it is this abstraction which occasions the change. Thus the combination of a certain dose of caloric with ice causes it to become water, and the abstraction of a certain dose of caloric from water causes it to become ice. Water, then, is a compound of ice and caloric; and in general all fluids are combinations of the solid, to which they may be converted by cold, and a certain dose of caloric. Dr

Black gave this dose of caloric, which produces fluidity, the name of *latent heat*, because its presence is not indicated by the thermometer; but I shall rather employ the phrase *caloric of fluidity*, proposed by Mr Pictet, because it is plainer, and less apt to mislead.

Such is the opinion concerning the cause of fluidity taught by Dr Black as early as 1757. Its truth was established by the following experiments:

1. If a lump of ice, at the temperature of 22°, be brought into a warm room, in a very short time it is heated to 32 , the freezing point. It then begins to melt; but the process goes on very slowly, and several hours elapse before the whole ice is melted. During the whole of that time its temperature continues at 32°; yet as it is constantly surrounded by warm air, we have reason to believe that caloric is constantly entering into it. Now as none of this caloric is indicated by the thermometer, what becomes of it, unless it has combined with that portion of the ice which is converted into water, and unless it is the cause of the melting of the ice?

2. If, when the thermometer is at 22°, we expose a vessel full of water at 52° to the open air, and beside it another vessel full of brine at the same temperature, with thermometers in each; we shall find, that both of them gradually lose caloric, and are cooled down to 32°. After this the brine (which does not freeze till cooled down to 0°) continues to cool without interruption, and gradually reaches 22°, the temperature of the air; but the pure water remains stationary at 32°. It freezes indeed, but very slowly; and during the whole process its temperature is 32°. Now, why should the one liquid refuse all of a sudden to give out caloric and not the other? Is it not much more probable that the water, as it freezes, gradually gives out

Chap. V.

its caloric of fluidity; and that this evolution maintains the temperature of the water at 32°, notwithstanding what it parts with to the air during the whole process?

3. If when the air is at 22°, we expose to it a quantity of water in a tall beer glass, with a thermometer in it and covered, the water gradually cools down to 22° without freezing. It is therefore 10° below the freezing point. Things being in this situation, if the water be shaken, part of it instantly freezes into a spongy mass, and the temperature of the whole instantly rises to the freezing point; so that the water has acquired ten degrees of caloric in an instant. Now whence came these ten degrees? Is it not evident that it must have come from that part of the water which was frozen, and consequently that water in the act of freezing gives out caloric? Water therefore must be ice combined with caloric.

4. Take any quantity of ice, or (which is the same thing) snow at 32°, and mix it with an equal weight of water at 172°, the snow instantly melts, and the temperature of the mixture is only 32°. Here the water is cooled 140°, while the temperature of the snow is not increased at all; so that 140° of caloric have disappeared. They must have combined with the snow; but they have only melted it without increasing its temperature. Hence it follows irresistibly, that ice, when it is converted into water, absorbs and combines with 140° of caloric.

Water, then, after being cooled down to 32°, cannot freeze till it has parted with 140° of caloric, and ice, after being heated to 32°, cannot melt till it has absorbed 140° of caloric. This is the cause of the extreme slowness of these operations. With regard to water, then, there can be no doubt that it owes its fluidity to the caloric which it contains, and that its *caloric of fluidity* is equal to 140°.

Dr Black ascertained also, by experiment, that the fluidity of melted wax, tallow, spermaceti, metals, is owing to the same cause. Landriani proved, that this is the case with sulphur, alum, nitre, and several of the metals* ; and it has been found to be the case with every substance hitherto examined. We may consider it therefore as a general law, that whenever a solid is converted into a fluid, it combines with caloric, and that this is the cause of its fluidity.

Objection

An objection to this explanation of fluidity was started by Dr Irvine of Glasgow. According to him, the phenomena may be explained without having recourse to the caloric of fluidity at all. For the specific caloric of water being greater than that of ice, a greater quantity of caloric is necessary to raise water to a given temperature than is necessary to raise ice to the same temperature. The instant therefore that ice is converted into water, its temperature would sink considerably, if it did not absorb an additional dose of caloric. The caloric, therefore, which is absorbed during the melting of ice, does not combine with the ice and convert it into water, but after the ice has been melted it is absorbed by the water generated. This theory was zealously adopted by Dr Crawford.

Refuted.

Dr Black observed, very justly, that it does not account for the production of fluidity at all. The specific caloric of water is indeed greater than that of ice ; but how is the ice converted into water ? This is an ob-

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* *Jour. de Phys.* xxv.

jection which the advocates for Dr Irvine's, or Dr Crawford's theory (as it has been improperly called), will not easily answer. But, independent of this, the theory cannot be admitted; because it proceeds upon mistaken notions respecting specific caloric; because it is inconsistent with the phenomena which it pretends to explain; and because it leads to absurd and contradictory consequences.

Let us suppose, according to the experiments of these philosophers themselves, that the specific caloric of ice is to that of water as 9 : 10*, and that we mix together equal quantities of ice at 32°, and water at 172°; the temperature after mixture (supposing the ice not to melt) ought to be 106°; because for every 9° which the water lost the ice would receive 10°. But as the ice melts, its specific caloric will become equal to that of water; that is to say, it will absorb 0.1 more of caloric than we have supposed. We must therefore diminish the heat of the mixture by $\frac{1}{2}$ of this, or 5°; consequently, according to Dr Irvine's theory, the temperature of the mixture ought to be about 100°; but this is contrary to fact, for it is only 32°. The theory therefore cannot be true. But farther; since equal quantites of ice at 32°, and water at 172°, after mixture, are only of the temperature of 32°, it follows, if Dr

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* I do not know how this was ascertained: Not by mixing water and ice surely; because that would be taking for granted the thing to be proved; because it would give a very different result; and, what is still worse, the specific caloric in that case would differ according to the temperature and the quantity of water. To give an instance: Mr Gadolin concludes, from 180 experiments made by mixing hot water and ice, that the specific caloric of ice is to that of water only as 1 to 2; and had he varied the quantities and the temperatures, he might have obtained several other ratios. See *Ann. de Chim.* xi. 27.

Irvine's theory be true, that the specific caloric of ice is 140°, and that of water 0°, or at least that the specific caloric of ice is infinitely greater than that of water; for the water is cooled down 140°, and ice heated 0°. Consequently the caloric which is sufficient to heat water 140°, is not sufficient to produce any sensible effect upon ice, or rather melted ice, that is to say, water. This consequence is so palpably absurd and contradictory, that it is sufficient to overturn any theory from which it flows. Dr Black's theory therefore must be considered as established.

Liquids converted into elastic fluids

Liquids may, by the application of heat, be converted into elastic fluids, invisible like air, and resembling air in many of their properties. Thus water by boiling is converted into steam; an invisible fluid capable of dilatation and compression, and not inferior in elasticity to air, as is evident from the well-known power of the steam engine. This conversion takes place always at a particular temperature, which is different in every liquid, but always the same in the same liquid, provided the pressure of the atmosphere be the same. This temperature is called the boiling point, because the liquids, as soon as they reach it, begin to boil. The boiling point of a number of liquids, under the common pressure of the atmosphere, may be seen in the following TABLE:

Bodies.	Boiling Point.
Ether	98°
Alcohol	176
Water	212
Nitric acid	248
Sulphuric acid	546
Phosphorus	554
Mercury	600
Linseed oil	600

When the pressure of the atmosphere is removed altogether, the boiling point becomes 120° lower; and this difference seems to hold in all bodies hitherto tried. Thus water, under an exhausted receiver, boils at 92°, alcohol at 56°, and ether at —20°.

By combining with caloric.

Thus it appears that the conversion of liquids into elastic fluids takes place when they are exposed to a certain degree of heat. Dr Black has demonstrated, that it is owing to the very same cause as the conversion of solids into liquids; namely, to the combination of a certain dose of caloric with the liquid, without any increase of temperature. These elastic fluids, then, are compounds of the liquids and caloric. This dose of caloric was also called *latent heat* by Dr Black; Mr Pictet has proposed the phrase *caloric of evaporation;* but the general name, caloric of fluidity, is sufficient. Steam, then, is water combined with a certain dose of caloric. The truth of this position has been proved by the following experiments:

1. When a vessel of water is put upon the fire, the water gradually becomes hotter till it reaches 212°; but afterwards its temperature is not increased. Now caloric must be constantly entering from the fire and combining with the water. But as the water does not become hotter, the caloric must combine with that part of it which flies off in the form of steam: but the temperature of the steam is only 212°; therefore the caloric combined with it does not increase its temperature. We must conclude, then, that the change of water to steam is owing to the combination of this caloric: for it produces no other change.

2. Water may be heated in a Papin's digester to 400° without boiling; because the steam is forcibly com-

pressed, and prevented from making its escape. If the mouth of the vessel be suddenly opened while things are in this state, part of the water rushes out in the form of steam, but the greater part still remains in the form of water, and its temperature instantly sinks to 212°; consequently 188° of caloric have suddenly disappeared. This caloric must have been carried off by the steam. Now as only about $\frac{1}{5}$ of the water is converted into steam, that steam must contain not only its own 188°, but also the 188° lost by each of the other four parts; that is to say, it must contain 188° × 5, or about 940°. Steam, therefore, is water combined with at least 940° of caloric, the presence of which is not indicated by the thermometer. This experiment was first made by Mr Watt.

3. If one part of steam at 212° be mixed with nine parts by weight of water at 62°, the steam instantly assumes the form of water, and the temperature after mixture is 178.6°; consequently each of the nine parts of water has received 116.6° of caloric; consequently the steam has lost $9 \times 116.6° = 1049.4°$ of caloric. But as the temperature of the steam is diminished by 33.3°, we must subtract this sum. There will remain rather more than 1000°, which is the quantity of caloric of fluidity which existed in the steam without increasing its temperature. This experiment cannot be made directly; but it may be made by passing a given weight of steam through a metallic worm, surrounded by a given weight of water. The heat acquired by the water indicates the caloric of fluidity which the steam gives out during its condensation. From an experiment made by Mr Watt, it appears, that the caloric of fluidity of steam is about 1000°.

By the experiments of Dr Black and his friends, it was ascertained, that not only water, but all other liquids during their conversion into vapour, combine with a dose of caloric, without any change of temperature; and that every kind of elastic fluid, during its conversion into a liquid, gives out a portion of caloric without any change of temperature. Dr Black's law, then, is very general, and comprehends every change in the state of a body. The cause of the conversion of a solid into a liquid, is the combination of the solid with caloric; that of the conversion of a liquid into an elastic fluid, is the combination of the liquid with caloric. Liquids are solids combined with caloric; elastic fluids are liquids combined with caloric. This law, in its most general form, may be stated as follows: *Whenever a body changes its state, it either combines with caloric or separates from caloric.*

Gases probably combinations of caloric.

Besides vapours, there is another class of elastic fluids, I mean common air and the gases, which resemble vapours in almost all their properties; but differ from them in this, that they are not condensible by the application of any degree of cold hitherto applied. It is probable that these bodies also owe their fluidity to a certain dose of caloric of fluidity with which their bases are combined. This opinion was first hinted at by Amonton: Dr Black embraced it, and defended it in a very ingenious manner. The presence of caloric of fluidity is at present considered as the cause of the gaseous state of these bodies by all philosophers without exception. We can scarcely hesitate to embrace this opinion, though it has been hitherto impossible to demonstrate its truth; because the affinity of this caloric is so strong, that it cannot be separated, by any method at present known, at least by any method which allows us to ascertain its presence, far less to measure its quantity.

The knowledge of the caloric of fluidity enables us to explain the changes of temperature occasioned by mixing certain bodies together.

1. If four parts of sulphuric acid, and one part by weight of water, be mixed together, each at the temperature of 50°, the mixture immediately acquires the temperature of 300°; consequently it has been heated no less than 270°. Here both the bodies mixed are fluids, consequently both are combined with a certain portion of caloric of fluidity. When the acid and water are mixed, they combine, and acquire a density considerably greater than the mean; consequently they part both with their caloric fluidity, and retain only the caloric of fluidity of the new compound; this, in consequence of the increased density, is smaller. Hence the rise of temperature; which is owing to the sudden separation of the excess of the caloric of fluidity. Many other mixtures occasion a rise of temperature from the same cause.

2. When equal quantities of snow and common salt at 32° are mixed together, they suddenly melt, and their temperature sinks to 0°. Here two solids suddenly assume the liquid form; but for this change a dose of caloric is necessary. The sudden fall of the temperature is owing to the suddenness with which they absorb the necessary dose of caloric of fluidity. They absorb it from all bodies whose temperature is not lower than 0°. Such is the cause of the fall of the thermometer when two solids, or a liquid and a solid which suddenly assume the liquid form, are mixed together.

SECT. VII.

OF THE QUANTITY OF CALORIC IN BODIES.

Real zero, what.

By means of the thermometer, we learn that there is no body which does not contain caloric, because there is none so cold that it cannot be made colder: and cooling a body is nothing else but abstracting a part of the caloric which it contains. It is evident, however, that the thermometer is not capable of indicating even the relative quantity of caloric contained; since the presence of the caloric of fluidity is not indicated by it at all. Thus steam at 212° contains 1000° more caloric than water at 212°, yet the temperature of each is the same. Is there then any method of ascertaining the absolute quantity of caloric which a body contains? At what degree would a thermometer stand (supposing the thermometer capable of measuring so low), were the body to which it is applied totally deprived of caloric? or, what degree of the thermometer corresponds to the real zero?

Irvine's attempt to discover it

The first person, at least since men began to think accurately on the subject, who conceived the possibility of determining this question, was Dr Irvine of Glasgow. He invented a theorem, in order to ascertain the real zero, which has, I know not for what reason, been ascribed by several writers to Mr Kirwan. He took it for granted (and the fact is proved by all the experiments hitherto made), that the specific caloric of bodies continues the same in every degree of temperature, as long as they remain in the same state, that is to say, as long as they continue either solid or fluid, or in a state of vapour; but that the specific caloric of the same body while solid is less than while fluid, and less while fluid than while in a state of vapour. He took it for granted, too, that the 140 degrees of caloric which enter ice during its solution, without raising its temperature, enter merely in consequence of the increased specific caloric of the water, and that they are exactly proportional to this increased specific caloric. He took it for granted, likewise, that the specific caloric of bodies is proportional to their *absolute caloric*, or to all the caloric which existed in each.

On these data he reasoned in the following manner: Let A be a body in a state of fluidity; B the same body in a state of solidity. If the specific caloric of A and of B be known, and if it be known how many degrees the caloric, disengaged during the change of B into A, would raise the temperature of A, it may be found by an easy process how many degrees all the caloric contained in B would raise the temperature of A; and the sum of these two numbers will represent in degrees the whole quantity of caloric in A: for the quantity of caloric in A must be just equal to the caloric in B, together with what entered into it in passing from the state of B to that of A. Let the specific caloric of A be 6, that of B 1; and let the quantity of caloric disengaged during the change of A into B be sufficient to raise the temperature of A 500°. If the specific caloric be proportional to the absolute caloric, it must contain exactly 6 times as much caloric as B. The 500° which entered into A when it changed its state, must be just 5 times as great as all the caloric of B; because when added to the caloric of B, it formed the caloric in A, which is just 6 times as great as the caloric in B. Therefore to discover the caloric in B, we have only to divide 500 by 5, or, which is the same thing, to state this proportion 6 — 1 : 500 : : 1 : 100. The caloric in B, therefore, in this case, is just as much as would raise the temperature of A 100°. Therefore if to 100°, the caloric of B, be added 500°, = caloric disengaged in the passage of A to B, this will give 600°, = to all the caloric in A. Therefore, in all cases, the difference between the numbers expressing the specific caloric of the solid and fluid, is to the number expressing the specific caloric of the solid, as the quantity of caloric disengaged during the passage of the fluid into a solid is to the quantity of caloric in the fluid.

Dr Crawford embraced this theorem; and concluded, from a number of experiments made on purpose to ascertain the fact, that the real zero was 1268° below 0, or 1300° below the freezing point.

This subject deserves to be considered with attention. If this theorem in fact furnishes us with the real zero, it is one of the most important discoveries which has ever been made in chemistry; but if it proceeds on erroneous principles, it will only involve us in endless mazes of error and absurdity.

Unsuccessful.

In the first place, if the real zero has any meaning at all, it must signify the degree to which the thermometer (supposing it could be used) would sink on being applied to a body which contained no heat. It must therefore be a fixed point; and were the theorem which we are examining well founded, experiments upon every different substance, if conducted with accuracy, would lead to the same result. Let us see whether this be the case.

From Dr Crawford's experiments, it follows, as we have seen, that the real zero is 1268° below 0.

Mr Kirwan, from comparing the specific caloric of water and ice, fixed the real zero at 1048° below 0.

From the experiments of Lavoisier and La Place on a mixture of water and quicklime, in the proportion of 9 to 16, it follows, that the real zero is 2736° below 0.

From their experiments on a mixture of 4 parts of sulphuric acid and 3 parts of water, it follows, that the real zero is 5803.4° below 0.

Their experiments on a mixture of 4 parts of sulphuric acid and 5 of water place it at 2073.3° below 0.

Their experiments on $9\frac{1}{3}$ parts of nitric acid and 1 of lime, place it at $\frac{1889}{-0.01783}$ below 32°, $= + 10616°$ *.

These results differ from one another so enormously, and the last of them, which places the real zero far above a red heat, is so absurd, that they are alone sufficient to convince us that the data on which they are founded are not true. Should it be said that their difference is not owing to any defect in the theorem, but to inaccuracies in making the experiments, I answer, that the theorem itself is founded on similar experiments; and if experiments of this nature, even in the hands of the most accurate chemists, cannot be freed from such enormous errors, how can we depend on any consequences deduced from them? and where, then, is our evidence for the truth of the theorem?

But, farther, there is no proof whatever that the specific caloric of bodies is proportional to their absolute caloric. If the specific caloric of bodies has any mean-

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* See Seguin, *Ann. de Chim.* v. 231.

ing at all, it can only be, that the same quantity of caloric raises the temperature of one body a greater number of degrees than it does another. When we say that the specific caloric of A is = 6, and that of B = 1, what do we mean, unless that the quantity of caloric which raises B 6° raises A only 1°, or that what raises B 60° or 600°, raises A only 10° or 100°? When we say that the specific caloric of water is 10, and that of ice 9, do we not mean, that the quantity of caloric which raises the ice 10 or 100°, raises water only 9° or 90°? Yet during the change of ice into water, 140° of caloric enter it without raising its temperature; a quantity greater than what can be accounted for by the difference of specific caloric by 126°. The quantity that disappears, therefore, is *not* proportional to the difference of specific caloric; and therefore any theory which depends on that supposition cannot be well-founded. When water is converted into steam, 1000° of caloric disappear; yet the specific caloric of steam is to that of water, according to Dr Crawford's own experiments, only as 155 to 100: so that no less than 483° disappear, which cannot be accounted for according to this theory.

Dr Irvine's theorem, therefore, is insufficient for ascertaining the real zero; and hitherto no method has been discovered which can solve this problem. We are therefore entirely ignorant of the quantity of caloric which exists in bodies.

SECT. VIII.

OF COLD.

Sensations of heat and cold.

In the preceding Sections of this Chapter I have examined the different changes which caloric produces upon bodies, either by combining with them, or separating from them. Caloric is equally capable of combining with our own bodies, or of being separated from them. In the first case, we experience the sensation of *heat;* in the second, of *cold.* When I put my hand upon a hot iron, part of the caloric leaves the iron, and enters my hand; this produces the sensation of heat. On the contrary, when I put my hand upon a lump of ice, the caloric rapidly leaves my hand, and combines with the ice; this produces the sensation of cold. The sensation of heat is occasioned by caloric passing into our bodies; the sensation of cold by caloric passing out of our bodies. We say that a body is hot when it communicates caloric to the surrounding bodies; we call it cold when it absorbs caloric from other bodies. The strength of the sensations of heat and cold depends upon the rapidity with which the caloric enters or leaves our bodies; and this rapidity is proportional to the difference of the temperature between our bodies and the hot or cold substance, and to the conducting power of that substance. The higher the temperature of a body is, the stronger a sensation of heat does it communicate; and the lower the temperature, the stronger a sensation of cold: and when the temperature is the same, the sensations depend upon the conducting power of the substance.

Thus what in common language is called *cold*, is nothing else than the absence of the usual quantity of caloric. When we say that a substance is *cold*, we mean merely that it contains less caloric than usual, or that its temperature is lower than that of our bodies.

Cold ascribed to frigorific particles.

There have been philosophers, however, who maintained that cold is produced not by the abstraction of caloric merely, but by the addition of a positive something, of a peculiar body endowed with specific qualities. This was maintained by Muschenbroeck and De Mairan, and seems to have been the general opinion of philosophers about the commencement of the 18th century. According to them, cold is a substance of a saline nature, very much resembling nitre, constantly floating in the air, and wafted about by the wind in very minute corpuscles, to which they gave the name of *frigorific particles.*

Their existence disproved.

They were induced to adopt this hypothesis, because they could not otherwise account for the freezing of water. According to them, these frigorific particles insinuate themselves like wedges between the molecules of water, destroy their mobility, and thus convert water into ice. Dr Black, by discovering the cause of the freezing of water, banished the frigorific particles from the regions of philosophy; because the advocates for them never brought any other proof for their existence than the convenience with which they accounted for certain appearances. Of course, as soon as these appearances were explained, without their use, every reason for supposing their existence was destroyed.

The only fact which gives any countenance to the opinion that cold is a body, has been furnished by the following very curious experiment of Mr Pictet. Two concave tin mirrors being placed at the distance of 10½ feet from each other, a very delicate air thermometer was put into one of the foci, and a glass matrass full of snow into the other. The thermometer sunk several degrees, and rose again when the matrass was removed. When nitric acid was poured upon the snow (which increases the cold), the thermometer sunk 5° or 6° lower. Here *cold* seems to have been emitted by the snow, and reflected by the mirrors to the thermometer, which could not happen unless cold were a substance. The experiment is certainly highly interesting, and deserving a more accurate examination than has been hitherto bestowed on it. In order to explain it, we must suppose, with Dr Hutton, that caloric is constantly radiating from all bodies. On that supposition, it is evident that the temperature of the thermometer, like that of all other bodies, is maintained partly by the irradiation of caloric from the surrounding bodies. It must therefore, since it is placed in the focus of one of the mirrors, be affected by whatever body is placed in the focus of the other. If that body be colder than the surrounding bodies, less caloric will be irradiated from it and thrown upon the thermometer; consequently the thermometer will be depressed till the deficiency is supplied by some other channel.

A very great degree of cold may be produced by mixing together different solids, which suddenly become liquid. The cause of this has been already explained. But as such mixtures are often employed in chemistry, in order to be able to expose bodies to the influence of a low temperature, it will be worth while to enumerate the different substances which may be employed for that purpose, and the degree of cold which each of them is capable of producing.

Of freezing mixtures.

The first person who made experiments on freezing mixtures was Fahrenheit. But the subject was much more completely investigated by Mr Walker in a paper published in the Philosophical Transactions for 1795. Since that time several curious additions have been made by Professor Lowitz, particularly the introduction of *muriat of lime*, which produces a very great degree of cold when mixed with snow*. The experiments of Lowitz have been lately repeated and extended by Mr Walker†. The result of all these experiments may be seen in the following TABLE:

TABLE *of Freezing Mixtures.*

Mixtures.	Thermometer sinks.
Muriat of ammonia . . 5 parts Nitre . . . . 5 Water 16	From 50° to 10°
Muriat of ammonia . . 5 Nitre . . . . 5 Sulphat of soda . . . . . 8 Water 16	From 50° to 4°
Nitrat of ammonia . . 1 Water 1	From 50° to 4°

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* *Ann. de Chim.* xxii. 297, and xxix. 281.

† *Phil. Trans.* 1801, p. 120.

TABLE *of Freezing Mixtures continued.*

Mixtures.	Thermometer sinks.
Nitrat of ammonia . . 1 part Carbonat of soda . . . 1 Water 1	From 50° to 7°
Sulphat of soda . . . . 3 Diluted nitric acid . . 2	From 50° to 3°
Sulphat of soda . . . . 6 Muriat of ammonia . . 4 Nitre . . . . 2 Diluted nitric acid . . 4	From 50° to 10°
Sulphat of soda . . . . 6 Nitrat of ammonia . . 5 Diluted nitric acid . . 4	From 50° to 14°
Phosphat of soda . . . 9 Diluted nitric acid . . 4	From 50° to 12°
Phosphat of soda . . . 9 Nitrat of ammonia . . 6 Diluted nitric acid . . 4	From 50° to 21°
Sulphat of soda . . . . 8 Muriatic acid 5	From 50° to 0°
Sulphat of soda . . . . 5 Diluted sulphuric acid 4	From 50° to 3°
Snow . . . . 1 Common salt 1	From 32° to 0°
Snow or pounded ice . 2 Common salt 1	From 0° to —5°

TABLE *of Freezing Mixtures continued.*

Mixtures.	Thermometer sinks.
Snow or pounded ice 1 part Common salt . . . . . . 5 Muriat of ammonia and nitre 5	From —5° to —18°
Snow or pounded ice 12 Common salt . . . . . . 5 Nitrat of ammonia . . 5	From —18° to —25°
Snow and diluted nitric acid.	From 0° to —46°
Snow . . . . 2 Diluted sulphuric acid 1 Diluted nitric acid . . 1	From —10° to —56°
Snow . . . . 1 Diluted sulphuric acid 1	From 20° to —60°
Muriat of lime . . . . . 3 Snow 2	From 32° to —50°
Muriat of lime . . . . . 2 Snow 1	From 0° to —66°
Muriat of lime . . . . . 3 Snow 1	From —40° to —73°
Diluted sulphuric acid 10 Snow 8	From —68° to —91°
Potass . . . . 4 Snow 3	From 32° to —51°

Book I.

In order to produce these effects, the salts employed must be fresh crystallized, and newly reduced to a very fine powder. The vessels in which the freezing mixture is made should be very thin, and just large enough to hold it, and the materials should be mixed together as quickly as possible. The materials to be employed in order to produce great cold ought to be first reduced to the temperature marked in the Table, by placing them in some of the other freezing mixtures; and then they are to be mixed together in a similar freezing mixture. If, for instance, we wish to produce a cold = — 46°, the snow and diluted nitric acid ought to be cooled down to 0°, by putting the vessel which contains each of them into the 12th freezing mixture in the above Table, before they are mixed together. If a still greater cold is required, the materials to produce it are to be brought to the proper temperature by being previously placed in the second freezing mixture. This process is to be continued till the required degree of cold has been procured *.

SECT. IX.

OF COMBUSTION.

HAVING examined the properties of caloric, and the changes which it produces on other bodies, it now only remains for us to consider the different methods by

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* Walker, *Phil. Trans.* 1795.

which caloric may be evolved and made sensible. These methods may be reduced to four; namely, COMBUSTION, PERCUSSION, FRICTION, and the action of LIGHT. The present Section will be employed in the consideration of *combustion*, and the three remaining sources of caloric will be discussed in the three following Sections.

Phenomena of combustion.

There is perhaps no phenomenon more wonderful in itself, more interesting on account of its utility, or which has more closely occupied the attention of chemists, than *combustion*. When a stone or a brick is heated, it undergoes no change except an augmentation of temperature; and when left to itself, it soon cools again and becomes as at first. But with combustible bodies the case is very different. When heated to a certain degree in the open air, they suddenly become much hotter of themselves, continue for a considerable time intensely hot, sending out a copious stream of caloric and light to the surrounding bodies. This emission, after a certain period, begins to diminish, and at last ceases altogether. The combustible has now undergone a most complete change; it is converted into a substance possessing very different properties, and no longer capable of combustion. Thus when charcoal is kept for some time at the temperature of 500°, or perhaps a little higher, it kindles, becomes intensely hot, and continues to emit light and caloric for a long time. When the emission ceases, the charcoal has all disappeared, except an inconsiderable residuum of ashes; being almost entirely converted into carbonic acid gas, which makes its escape unless the experiment be conducted in proper vessels. If it be collected, it is found to exceed greatly in weight the whole of the charcoal consumed.

The first attempt to explain combustion was crude and unsatisfactory. A certain elementary body, called *fire*, was supposed to exist, possessed of the property of devouring certain other bodies, and converting them into itself. When we set fire to a grate full of charcoal, we bring, according to this hypothesis, a small portion of the element of fire, which immediately begins to devour the charcoal, and to convert it into fire. Whatever part of the charcoal is not fit for being the food of fire is left behind in the form of ashes.

Hooke's theory

A much more ingenious and satisfactory hypothesis was proposed in 1665 by Dr Hooke. According to this extraordinary man, there exists in common air a certain substance, the very same, as may (he tells us) be proved by numerous experiments, which is fixed in salt. This substance has the property of dissolving all combustibles; but only when their temperature is considerably raised. The solution takes place with such rapidity, that it occasions both heat and light, which in his opinion are mere motions. The dissolved substance is partly in the state of air, partly coagulated in a liquid or solid form. The quantity of this solvent present in a given bulk of air is incomparably less than in the same bulk of saltpetre. Hence the reason that a combustible continues burning but for a short time in a given bulk of air: The solvent is soon saturated, and then of course the combustion is at an end. Hence also the reason that combustion succeeds best when there is a constant supply of fresh air, and that it may be greatly accelerated by forcing in air with bellows *.

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* Hooke's *Micographia*, p. 103. See also his *Lampas*.

Adopted by Mayow.

About ten years after the publication of Hooke's *Micographia*, his theory was adopted by Mayow, without acknowledgment, in a tract which he published at Oxford on saltpetre*. We are indebted to him for a number of very ingenious and important experiments, in which he anticipated several modern chemical philosophers; but his reasoning is for the most part absurd, and the additions which he made to the theory of Hooke are exceedingly extravagant. To the solvent of Hooke he gives the name of *spiritus nitro-aereus*. It consists, he supposes, of very minute particles, which are constantly at variance with the particles of combustibles, and from their quarrels all the changes of things proceed. Fire consists in the rapid motion of these particles, heat in their less rapid motion. The sun is merely nitro-aerial particles moving with great rapidity. They fill space. Their motion becomes more languid according to their distance from the sun; and when they approach near the earth, they become pointed, and constitute *cold*†.

Theory of Beccher and Stahl

The attention of chemical philosophers was soon drawn away from the theory of Hooke and Mayow to one of a very different kind, first proposed by Beccher,

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* *De Sal-nitro et Spiritu Nitro-aereo.*

† Though Mayow's theory was not original, and though his additions to it be absurd, his tract itself displays great genius, and contains a vast number of new views, which have been fully confirmed by the recent discoveries in chemistry. He pointed out the cause of the increase of weight in metals when calcined; he ascertained the changes produced upon air by respiration and combustion; and employed in his researches an apparatus similar to the present pneumatic apparatus of chemists. Perhaps the most curious part of the whole treatise is his fourteenth chapter, in which he displays a much more accurate knowledge of *affinities* than any of his contemporaries, or even successors for many years.

but new modelled by his disciple Stahl with so much skill, arranged in such an elegant systematic form, and furnished with such numerous appropriate and convincing illustrations, that it almost instantly caught the fancy, raised Stahl to the highest rank among philosophers, and constituted him the founder of the Stahlian theory of combustion.

According to Stahl, all combustible substances contain in them a certain body, known by the name of PHLOGISTON, to which they owe their combustibility. This substance is precisely the same in all combustibles which owe their diversity to the other principles with which the phlogiston is combined. Combustion, and all its attendant phenomena, depend upon the separation and dissipation of this principle; and when it is once separated, the remainder of the body is incombustible. Phlogiston, according to Stahl, seems to be precisely the same thing with the element of fire. The heat and the light, which make their appearance during combustion, are merely two properties of phlogiston when in a state of liberty.

Improved.

The celebrated Macquer, to whose illustrious labours several of the most important branches of chemistry owe their existence, was probably the first person who perceived a striking defect in this theory of Stahl. Sir Isaac Newton had proved that light is a body; it was absurd, therefore, to make it a mere property of phlogiston or the element of fire. Macquer accordingly considered phlogiston as nothing else but light fixed in bodies. This opinion was embraced by a great number of the most distinguished chemists; and many ingenious arguments were brought forward to prove its truth. But if phlogiston be only light fixed in bodies, whence comes the heat that manifests itself during combustion? Is this heat merely a property of light? Dr Black proved that heat is capable of combining with, or becoming fixed in bodies which are not combustible, as in ice and water; and concluded of course, that it is not a property but a body. This obliged philosophers to take another view of the nature of phlogiston.

According to them, there exists a peculiar matter, extremely subtile, capable of penetrating the densest bodies, astonishingly elastic, and the cause of heat, light, magnetism, electricity, and even of gravitation. This matter, the *ether* of Hooke and Newton, is also the substance called phlogiston, which exists in a fixed state in combustible bodies. When set at liberty, it gives to the substances called caloric and light those peculiar motions which produce in us the sensations of heat and light. Hence the appearance of caloric and light in every case of combustion; hence, too, the reason that a body after combustion is heavier than it was before; for as phlogiston is itself the cause of gravitation, it would be absurd to suppose that it possesses gravitation; it is more reasonable to consider it as endowed with a principle of levity.

Altered by Priestley,

Some time after this last modification of the phlogistic theory, Dr Priestley, who was rapidly extending the boundaries of pneumatic chemistry, repeated many experiments formerly made on combustion by Hooke, Mayow, Boyle, and Hales, besides adding many of his own. He soon found, as they had done before him, that the air in which combustibles had been suffered to burn till they were extinguished, had undergone a very remarkable change; for no combustible would afterwards burn in it, and no animal could breathe it with-

Book I.

out suffocation. He concluded that this change was owing to phlogiston; that the air had combined with that substance; and that air is necessary to combustion, by attracting the phlogiston, for which it has a strong affinity. If so, phlogiston cannot be light any more than caloric; for if it separates from the combustible merely by combining with air, it cannot surely display itself in the form of light. The question then recurred with double force, What is phlogiston?

By Crawford,

The celebrated Dr Crawford, without attempting to answer this question, made a considerable improvement in the theory of combustion, evidently suggested by the discoveries of Dr Black. According to him, the phlogiston of the combustible combines during combustion with the air, and at the same time separates the caloric and light with which that fluid had been previously united. The heat and the light, then, which appear during combustion, exist previously in the air. This theory was very different from Stahl's, and certainly a great deal more satisfactory. But still the question, What is phlogiston? remained to be answered.

And Kirwan.

Mr Kirwan, who had already raised himself to the first rank among chemical philosophers, by many important discoveries, and many ingenious investigations of some of the most difficult parts of chemistry, attempted to answer this question, and to prove that phlogiston is the same with hydrogen. This opinion, which Mr Kirwan informs us was first suggested by the discoveries of Dr Priestley, met with a very favourable reception from the chemical world, and was adopted either in its full extent, or with certain modifications, by Bergman, Morveau, Crell, Wiegleb, Westrum, Hermstadt, Kärsten, Bewley, Priestley, and Delametherie. The object of Mr Kirwan was to prove, that hydrogen exists as a component part of every combustible body; that during combustion it separates from the combustible body and combines with the oxygen of the air. This he attempted in a treatise published on purpose, intitled *An Essay on Phlogiston and the Constitution of Acids.*

Destroyed by Lavoisier.

During these different modifications of the Stahlian theory, the illustrious Lavoisier was assiduously occupied in studying the phenomena of combustion. He seems to have attached himself to this subject, and to have seen the defects of the prevailing theory as early as 1770. The first precise notions, however, of what might be the real nature of combustion, were suggested to him by Bayen's paper on the oxides of mercury, which he heard read before the Academy of Sciences in 1774. These first notions, or rather conjectures, he pursued with unwearied industry; assisted by the numerous discoveries which were pouring in from all quarters, and by a long series of the most laborious and accurate experiments and disquisitions ever exhibited in chemistry, he fully established the existence of this general law—"In every case of combustion, oxygen combines with the burning body." This noble discovery, the fruit of genius, industry, and penetration, has reflected new light on every branch of chemistry, has connected and explained a vast number of facts formerly insulated and inexplicable, and has new modelled the whole, and moulded it into the form of a science.

After Mr Lavoisier had convinced himself of the existence of this general law, and had published his proofs to the world, it was some time before he was able to gain a single convert, notwithstanding his unwearied assiduity, and the great weight which his talents, his reputation, his fortune, and his situation naturally gave him. At last Mr Berthollet, at a meeting of the Academy of Sciences in 1785, solemnly renounced his old opinions, and declared himself a convert. Mr Fourcroy, professor of chemistry in Paris, followed his example. And in 1787, Morveau, during a visit to Paris, was prevailed upon to relinquish his former opinions, and embrace those of Lavoisier and his friends. The example of these celebrated men was soon followed by all the young chemists in France.

Mr Lavoisier's explanation of combustion depends upon the two laws discovered by himself and Dr Black. When a combustible body is raised to a certain temperature, it begins to combine with the oxygen of the atmosphere, and this oxygen during its combination lets go the caloric and light with which it was combined while in the gaseous state. Hence their appearance during every combustion. Hence also the change which the combustible undergoes in consequence of combustion.

Thus Lavoisier explained combustion without having recourse to phlogiston; a principle merely supposed to exist, because combustion could not be explained without it. No chemist had been able to exhibit phlogiston in a separate state, or to give any proof for its existence, excepting only its conveniency in explaining combustion. The proof for its existence consisted entirely in the impossibility of explaining combustion without it. Mr Lavoisier, therefore, by giving a satisfactory explanation of combustion, without having recourse to phlogiston, proved, that there was no reason for supposing any such principle at all to exist.

But the hypothesis of Mr Kirwan, who made phlogiston the same with hydrogen, was not overturned by this explanation, because there could be no doubt that such a substance as hydrogen actually exists. But hydrogen, if it be phlogiston, must constitute a component part of every combustible, and it must be separate from the combustible in every case of combustion. These were points, accordingly, which Mr Kirwan undertook to prove. If he failed, or if the very contrary of his suppositions holds in fact, his hypothesis of course fell to the ground.

Lavoisier and his associates saw at once the important uses which might be made of Mr Kirwan's essay. By refuting an hypothesis which had been embraced by the most respectable chemists in Europe, their cause would receive an eclat which would make it irresistible. Accordingly the essay was translated into French, and each of the sections into which it is divided was accompanied by a refutation. Four of the sections were refuted by Lavoisier, three by Berthollet, three by Fourcroy, two by Morveau, and one by Monge. And, to do the French chemists justice, never was there a refutation more complete. Mr Kirwan himself, with that candour which distinguishes superior minds, gave up his opinion as untenable, and declared himself a convert to the opinion of Lavoisier.

Thus Mr Lavoisier destroyed the existence of phlogiston altogether, and established a theory of combustion almost precisely similar to that which had been proposed long ago by Dr Hooke. The theory of Hooke is only expressed in general terms; that of Lavoisier is much more particular. The first was a hypothesis or fortunate conjecture which the infant state of the science did not enable him to verify; whereas Lavoisier was led to his conclusions by accurate experiments and a train of ingenious and masterly deductions.

Theory of Lavoisier liable to objections.

According to the theory of Lavoisier, which is now almost generally received, and considered by chemists as a full explanation of the phenomenon, combustion consists in two things; first, a decomposition; second, a combination. The oxygen of the atmosphere being in the state of gas, is combined with caloric and light. During combustion this gas is *decomposed*, its caloric and light escape, while its base *combines* with the combustible and forms the product. This product is incombustible; because its base, being already saturated with oxygen, cannot combine with any more. This theory is evidently liable to several objections, which require to be examined before it can be admitted.

First difficulty

1. It supposes that the whole of the caloric and light which escapes during combustion, was previously combined with the oxygen, and was the cause of its existing in a gaseous state; and that it makes its escape because the product of combustion does not combine with it. But in many cases the product of combustion is a gas as well as the oxygen. This is the case in particular with charcoal, which, when burnt, leaves for a product carbonic acid gas. Now one would naturally suppose, that when the product is a gas, all the caloric and light which existed in the oxygen gas would be necessary for maintaining the gaseous state of the product, especially as the quantity of the product exceeds that of the oxygen.

Obviated by Lavoisier.

This objection was foreseen by Mr Lavoisier, and he made a set of experiments in order to obviate it. From these experiments it appears, that nearly one half of the caloric which existed previously in the oxygen gas, decomposed during the combustion of the charcoal, is absorbed by the gaseous product; so that the caloric and light emitted by burning charcoal is only half what is emitted by the same proportion of burning phosphorus. Hence it follows that different gaseous bodies contain different proportions of caloric and light; and that when the product of combustion is a gas, the caloric and light which appear during combustion are only the excess of what the oxygen gas contained above what is absorbed by the product.

Second difficulty

2. Since the whole of the caloric and light which appear during combustion are set free from the oxygen, because it changes its state from a gas to a solid or a liquid, or at least a gas which requires less caloric and light, one would naturally suppose that in every case of combustion the oxygen employed must be in the state of a gas. But this is very far from being the case; as violent combustions take place when the oxygen employed is solid, or liquid as when it is in the state of a gas. Thus if nitric acid be poured upon linseed oil, or oil of turpentine, a very rapid combustion takes place, and abundance of caloric and light is emitted. Here the oxygen forms a part of the liquid nitric acid, and is already combined with azot; or, according to the language of the French chemists, the azot has undergone combustion. Now, in this case, the oxygen is not only in a liquid state, but it has also undergone the change produced by combustion. So that oxygen is capable of giving out caloric and light, not only when liquid, but even after combustion; which is directly contrary to the theory.

Farther; gunpowder, when kindled, burns with great rapidity in close vessels, or under an exhausted receiver. This substance is composed of nitre, charcoal, and sulphur: the two last of which ingredients are combustible; the first supplies the oxygen, being composed of nitric acid and potass. Here the oxygen is not only already combined with azot, but forms a component part of a solid; yet a great quantity of caloric and light is emitted during the combustion, and almost the whole product of the combustion is in the state of gas. This appears doubly inconsistent with the theory; for the caloric and light must be supposed to be emitted from a solid body during its conversion into gas, which ought to require more caloric and light for its existence in the gaseous state than the solid itself contained.

Removed by Brugnatelli.

Mr Brugnatelli, the celebrated professor of chemistry at Pavia, seems to have been the first who saw this objection in its proper light. He has endeavoured to obviate it in the following manner:

According to this very acute philosopher, the substance commonly called *oxygen* combines with bodies in two states: 1. Retaining the greatest part of the caloric and light with which it is combined when in the state of gas; 2. After having let go all the caloric and light with which it was combined. In the first state, he gives it the name of *thermoxygen*; in the second, of *oxygen*. Thermoxygen exists as a component part, not only of gaseous bodies, but also of several liquids and solids. It is only in those cases where thermoxygen is a component part of liquids or solids that caloric and light are emitted. All metals, according to him, combine with thermoxygen; those substances, on the contrary, which by combustion are converted into acids, combine with oxygen[*]. This ingenious theory obviates the objection completely, provided its truth can be established in a satisfactory manner. But as the evidence for it rests almost entirely upon its convenience in explaining several difficult points in the phenomena of combustion, we must consider it rather in the light of an ingenious conjecture than as a theory fully established.

Third difficulty.

3. If gaseous bodies contain caloric and light, as the theory supposes, and if, during their combination with other bodies, and their consequent condensation, they let go this caloric and light, one would naturally expect that caloric and light would be emitted during the condensation of other gases as well as oxygen: but this never happens unless oxygen be concerned. Hydrogen, when in the gaseous state, may be made to combine with azot; but no emission of caloric or light attends this combination. Ammoniacal gas and muriatic acid gas combine together whenever they are mixed, and the result is a concrete salt: but even in this case, where two gases are suddenly converted into a solid body, no light, and but very little caloric, is perceptible. Now the theory assigns no reason why the emission of caloric and light should be confined to the condensation of oxygen more than the other gases.

But though caloric and light are never disengaged during the combination and condensation of gases, unless oxygen forms a constituent part of one of them, they are disengaged during the combination of certain bodies which are not gaseous, independent of the presence of oxygen; I mean, during the combination of

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[*] *Ann. de Chim.* xxix. 182.

Book I.

sulphur with certain metals, and even earthy bodies. I have observed the same phenomenon also during the combination of phosphorus and lime. This curious fact, first examined with attention by the Dutch chemists, shews us that the most important phenomenon of combustion, the emission of caloric and light, is not confined to the combinations of oxygen with other bodies. Consequently the new meaning of the term *combustion*, assigned by the French chemists, who make it synonymous with the combination of a body with oxygen, is inaccurate. The explanation which has been given of this phenomenon, namely, that it is occasioned by the decomposition of water, which is said to be always present, is unsatisfactory; because it takes place equally, however dry and pure the sulphur and the metal be. It is very probable indeed that water cannot be perfectly excluded; and this would account for the presence of a little sulphurated hydrogen gas which is always emitted. But the decomposition of water will not explain the emission of the caloric and light; for the oxygen of water must have parted already with its caloric and light, as a copious emission of them accompanies the combustion of hydrogen.

Theory of combustion incomplete.

Upon the whole, it cannot be denied that Lavoisier's theory does not afford a sufficient explanation of combustion. Lavoisier has indeed succeeded completely in establishing one very important step; namely, that during combustion oxygen always combines with the burning body. But another step must be made before we can explain why caloric and light are emitted during the combinations in which oxygen is concerned, and scarcely ever during other combinations. Till this step be made, the theory of combustion must be considered as imperfect.

Scheele's theory.

An attempt indeed, and a very ingenious one, was made as early as 1775, to point out the connection between oxygen, caloric, and light. This attempt was made by Mr Scheele, one of the most extraordinary men that ever existed. When very young, he was bound apprentice to an apothecary at Gottenburg, where he first felt the impulse of that genius which afterwards made him so conspicuous. He durst not indeed devote himself openly to chemical experiments; but he contrived to make himself master of the science by devoting those hours to study which were assigned him for sleep. He afterwards went to Sweden, and settled as an apothecary at Köping. Here Bergman first found him, saw his merit, and encouraged it, adopted his opinions, defended him with zeal, and took upon himself the charge of publishing his treatises. Encouraged and excited by this magnanimous conduct, the genius of Scheele, though unassisted by education or wealth, burst forth with astonishing lustre; and at an age when most philosophers are only rising into notice, he had finished a career of discoveries which have no parallel in the annals of chemistry. Whoever wishes to behold ingenuity combined with simplicity, whoever wishes to see the inexhaustible resources of chemical analysis, whoever wishes for a model in chemical researches—has only to peruse and to study the works of Scheele*.

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* This Newton of chemistry died in 1786, at the age of 44. His moral character, according to Mr Erhart, and others who were the companions of his youth, and Messrs Gadolin, Espling, and those who knew him in his latter days, was irreproachable and praise-worthy. His outward appearance was not expressive of the great mind which lay con-

Book I.

In 1777, Scheele published a treatise, intitled *Chemical Experiments on Air and Fire*, which perhaps exhibits a more striking display of the extent of his genius than all his other publications put together. After a vast number of experiments, conducted with astonishing ingenuity, he concluded, that caloric is composed of a certain quantity of oxygen combined with phlogiston; that radiant heat, a substance which he supposed capable of being propagated in straight lines like light, and not capable of combining with air, is composed of oxygen united with a greater quantity of phlogiston, and light of oxygen united with a still greater quantity. He supposed, too, that the difference between the rays depends upon the quantity of phlogiston: the red, according to him, contains the least; the violet the most phlogiston. By *phlogiston* Mr Scheele seems to have meant *hydrogen*. It is needless therefore to examine his theory, as it is now known that the combination of hydrogen and oxygen forms not caloric but water*. The whole fabric, therefore, has

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cealed as it were under a veil. He seldom joined in the usual conversations and amusements of society, having as little leisure as inclination to do so; for what little time he had to spare from the hurry of his profession (an apothecary), was constantly filled up in the prosecution of experiments. It was only when he received visits from his friends, with whom he could converse upon his favourite science, that he indulged himself in a little relaxation. For such friends he had a sincere affection, as he had also for those that lived at a distance, and even for such as were not personally known to him. He kept up a regular correspondence with Messrs Erhart, Meyer, Kirwan, Crell, and several other chemists. See Crell's *Life of Scheele*.

* This candid philosopher afterwards acknowledged, that the proofs for the composition of water were complete; but we do not know exactly how he attempted to reconcile his theory of heat with the belief that

tumbled to the ground; but the importance of the materials will always be admired, and the ruins of the structure shall remain eternal monuments of the genius of the builder.

SECT. X.

OF PERCUSSION.

Caloric by percussion,

It is well known that heat is produced by the percussion of hard bodies against each other. When a piece of iron is smartly and quickly struck with a hammer, it becomes red hot; and the production of sparks by the collision of flint and steel is too familiar a fact to require being mentioned. No heat, however, has ever been observed to follow the percussion of liquids, nor of soft bodies which easily yield to the stroke.

Owing partly to condensation,

It has long been known that hammering increases the density of metals. The specific gravity of iron before hammering is 7.788; after being hammered, 7.840: that of platinum before hammering is 19.50; after it, 23.00. Now condensation diminishes the specific caloric of bodies. After one of the clay pieces used in Wedgewood's thermometer has been heated to 120°, it is reduced to one half of its former bulk, though it has lost only two grains of its weight, and its specific caloric is at the same time diminished one third*. But we cannot conceive the specific caloric of a body to be

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water is composed of oxygen and hydrogen; two opinions which are certainly incompatible.

* T. Wedgewood, *Phil. Trans.* 1792.

Book I.

diminished without its giving out at the same time a quantity of caloric; and we know for certain that caloric is evolved during condensation. A thermometer placed within a condenser rises several degrees every time air is thrown in*. We can even see a reason for this: When the particles of a body are forced nearer each other, the repulsive power of the caloric combined with them is increased, and consequently a part of it will be apt to fly off. Now, after a bar of iron has been heated by the hammer, it is much harder and brittler than before. It must then have become denser, and consequently must have parted with caloric. It is an additional confirmation of this, that the same bar cannot be heated a second time by percussion until it has been exposed for some time to a red heat. It is too brittle, and flies to pieces under the hammer. Now brittleness seems in most cases owing to the absence of the usual quantity of caloric. Glass *unannealed*, or, which is the same thing, that has been cooled very quickly, is always extremely brittle. When glass is in a state of fusion, there is a vast quantity of caloric accumulated in it, the repulsion between the particles of which must of course be very great; so great indeed, that they would be disposed to fly off in every direction with inconceivable velocity, were they not confined by an unusually great quantity of caloric in the surrounding bodies: consequently if this surrounding caloric be removed, the caloric of the glass flies off at once, and more caloric will leave the glass than otherwise would leave it, because the velocity of the particles must be greatly increased. Probably then the brittleness of glass

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* Darwin, *Phil. Trans.* 1788.

is owing to the deficiency of caloric; and we can scarcely doubt that the brittleness of iron is owing to the same cause, if we recollect that it is removed by the application of new caloric. Part therefore of the caloric which appears in consequence of percussion seems to proceed from the body struck; and this is doubtless the reason why those bodies, the density of which is not increased by percussion, as liquids and soft substances, are not heated at all.

And partly to combustion.

I say, *part* of the caloric, because, often at least, part of it is probably owing to another cause. By condensation, as much caloric is evolved as is sufficient to raise the temperature of some of the particles of the body high enough to enable it to combine with the oxygen of the atmosphere. The combination actually takes place, and a great quantity of additional caloric is separated by the decomposition of the gas. That this happens during the collision of flint and steel cannot be doubted; for the sparks produced are merely small pieces of iron heated red hot by uniting with oxygen during their passage through the air, as any one may convince himself by actually examining them. Mr Lane has shewn that iron produces no sparks in the vacuum of an air-pump; but Mr Kirwan has observed that they are produced under common spring water; and we know that iron at a certain temperature is capable of decomposing water.

It is not so easy to account for the emission of caloric on the percussion of two incombustibles. In the last Chapter, mention was made of the light emitted during the percussion of two stones of quartz, flint, felspar, or any other equally hard. Caloric is also emitted during this percussion, as is evident from the whole of the phenomenon. We must either suppose that all the caloric is produced by mere condensation, which is not probable, or acknowledge that we cannot explain the phenomenon. This is almost the only instance of the evolution of caloric and light, where the agency of oxygen cannot be demonstrated or even rendered probable. The phenomenon, therefore, is of importance, and may perhaps, when more accurately examined, give us some information concerning that unknown step in combustion, which must be made before the theory can be completed.

SECT. XI.

OF FRICTION.

Emission of caloric by friction

Caloric is not only evolved by percussion, but also by friction. Fires are often kindled by rubbing pieces of dry wood smartly against one another. It is well known that heavy loaded carts sometimes take fire by the friction between the axle-tree and the wheel. Now in what manner is the caloric evolved or accumulated by friction? Not by increasing the density of the bodies rubbed against each other, as happens in cases of percussion; for heat is produced by rubbing soft bodies against each other, the density of which therefore cannot be increased by that means, as any one may convince himself by rubbing his hand smartly against his coat. It is true, indeed, that heat is not produced by the friction of liquids, but then they are too yielding

Not owing to condensation,

Nor to decrease of specific caloric,

to be subjected to strong friction. It is not owing to the specific caloric of the rubbed bodies decreasing; for Count Rumford found that there was no sensible decrease *, nor, if there were a decrease, would it be sufficient to account for the vast quantity of heat which is sometimes produced by friction.

Count Rumford took a cannon cast solid and rough as it came from the foundery; he caused its extremity to be cut off, and formed, in that part, a solid cylinder attached to the cannon $7\frac{3}{4}$ inches in diameter and $9\frac{8}{10}$ inches long. It remained joined to the rest of the metal by a small cylindrical neck. In this cylinder a hole was bored 3.7 inches in diameter, and 7.2 inches in length. Into this hole was put a blunt steel borer, which by means of horses was made to rub against its bottom; at the same time a small hole was made in the cylinder perpendicular to the bore, and ending in the solid part a little beyond the end of the bore. This was for introducing a thermometer to measure the heat of the cylinder. The cylinder was wrapt round with flannel to keep in the heat. The borer pressed against the bottom of the hole with a force equal to about 10,000 lb. avoirdupois, and the cylinder was turned round at the rate of 32 times in a minute. At the beginning of the experiment the temperature of the cylinder was 60°; at the end of 30 minutes, when it had made 960 revolutions, its temperature was 130°. The quantity of metallic dust or scales produced by this friction amounted to 837 grains. Now, if we were to suppose that all the caloric was evolved from these scales, as they amounted to just $\frac{1}{948}$ part of the cylinder, they

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* Nicholson's *Journal*, ii. 106.

must have given out 948° to raise the cylinder 1°, and consequently 66360° to raise it 70° or to 130°, which is certainly incredible*.

Nor to combustion;

Neither is the caloric evolved during friction owing to the combination of oxygen with the bodies themselves or any part of them. By means of a piece of clock-work, Mr Pictet made small cups (fixed on the axis of one of the wheels), to move round with considerable rapidity, and he made various substances rub against the outsides of these cups, while the bulb of a very delicate thermometer placed within them marked the heat produced. The whole machine was of a size sufficiently small to be introduced into the receiver of an air-pump. By means of this machine a piece of adamantine spar was made to rub against a steel cup in air: sparks were produced in great abundance during the whole time, but the thermometer did not rise. The same experiment was repeated in the exhausted receiver of an air-pump (the manometer standing at four lines); no sparks were produced, but a kind of phosphoric light was visible in the dark. The thermometer did not rise. A piece of brass being made to rub in the same manner against a much smaller brass cup in air, the thermometer (which almost filled the cup) rose 0.3°, but did not begin to rise till the friction was over. This shews us that the motion produced in the air carried off the caloric as it was evolved. In the exhausted receiver it began to rise the moment the friction began, and rose in all 1.2°. When a bit of wood was made to rub against the brass cup in the air, the thermometer rose 0.7°, and on substituting also a wooden cup it rose

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* Nicholson's *Journal*, ii. 106.

2.1°, and in the exhausted receiver 2.4°, and in air condensed to $1\frac{1}{4}$ atmospheres it rose 0.5°*.

If these experiments be not thought conclusive, I have others to relate, which will not leave a doubt that the heat produced by friction is not connected with the decomposition of oxygen gas. Count Rumford contrived, with his usual ingenuity, to inclose the cylinder above described in a wooden box filled with water, which effectually excluded all air, as the cylinder itself and the borer were surrounded with water, and at the same time did not impede the motion of the instrument. The quantity of water amounted to 18.77 lbs. avoirdupois, and at the beginning of the experiment was at the temperature of 60°. After the cylinder had revolved for an hour at the rate of 32 times in a minute, the temperature of the water was 107°; in 30 minutes more it was 178°; and in two hours and 30 minutes after the experiment began, the water *actually boiled.* According to the computation of Count Rumford, the caloric produced would have been sufficient to heat 26.58 lbs. avoirdupois of ice-cold water boiling hot; and it would have required 9 wax candles of a moderate size, burning with a clear flame all the time the experiment lasted, to have produced as much heat. In this experiment all access of water into the hole in the cylinder where the friction took place was prevented. But in another experiment, the result of which was precisely the same, the water was allowed free access†.

And consequently at present inexplicable.

The caloric, then, which appears in consequence of friction, is neither produced by an increase of the den-

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* Pictet *sur le Feu*, ch. ix.

† Nicholson's *Journal*, ii. 106.

sity, nor by an alteration in the specific caloric of the substances exposed to friction, nor is it owing to the decomposition of the oxygen of the atmosphere—Whence then is it derived? This question cannot at present be answered: but this is no reason for concluding, with Count Rumford, that there is no such substance as caloric at all, but that it is merely a *peculiar kind of motion;* because the facts mentioned in the preceding part of this Chapter demonstrate the existence of caloric as a substance. Were it possible to prove that the accumulation of caloric by friction is *incompatible* with its being a substance, in that case Count Rumford's conclusion would be a fair one; but this surely has not been done. We are certainly not yet sufficiently acquainted with the laws of the motion of caloric, to be able to affirm with certainty that friction cannot cause it to accumulate in the bodies rubbed. This we know at least to be the case with electricity. Nobody has been hitherto able to demonstrate, in what manner it is accumulated by friction; and yet this has not been thought a sufficient reason to deny its existence.

Analogy between caloric and electricity.

Indeed there seems to be a very close analogy between caloric and electric matter. Both of them tend to diffuse themselves equally, both of them dilate bodies, both of them fuse metals, and both of them kindle combustible substances. Mr Achard has proved, that electricity can be substituted for caloric even in those cases where its agency seems peculiarly necessary; for he found that, by constantly supplying a certain quantity of the electric fluid, eggs could be hatched just as when they are kept at the temperature of 103°. An accident indeed prevented the chickens from actually coming out; but they were formed and living, and within two days of bursting their shell. Electricity has also a great deal of influence on the heating and cooling of bodies. Mr Pictet exhausted a glass globe, the capacity of which was 1200.199 cubic inches, till the manometer within it stood at 1.75 lines. In the middle of this globe was suspended a thermometer, which hung from the top of a glass rod fixed at the bottom of the globe, and going almost to its top. Opposite to the bulb of this thermometer two lighted candles were placed, the rays of which, by means of two concave mirrors, were concentrated on the bulb. The candles and the globe were placed on the same board, which was supported by a non-conductor of electricity. Two feet and a half from the globe there was an electrifying machine, which communicated with a brass ring at the mouth of the globe by means of a metallic conductor. This machine was kept working during the whole time of the experiment; and consequently a quantity of electric matter was constantly passing into the globe, which formed an atmosphere not only within it, but at some distance round, as was evident from the imperfect manner in which the candles burned. When the experiment began the thermometer stood at 49.8°. It rose to 70.2° in 732″. The same experiment was repeated, but no electric matter thrown in; the thermometer rose from 49.8° to 70.2° in 1050″; so that the electricity hastened the heating almost a third. In the first experiment the thermometer rose only to 71.3°, but in the second it rose to 77°. This difference was doubtless owing to the candles burning better in the second than the first experiment; for in other two experiments made exactly in the same manner, the maximum was equal both when there was and was not electric matter present. These experiments were repeated with this difference, that the candles were now insulated, by placing their candlesticks in vessels of varnished glass. The thermometer rose in the electrical vacuum from 52.2° to 74.7° in 1050″; in the simple vacuum in 965″. In the electrical vacuum the thermometer rose to 77°; in the simple vacuum to 86°. It follows from these experiments, that when the globe and the candles communicated with each other, electricity hastened the heating of the thermometer; but that when they were insulated separately, it retarded it*. One would be apt to suspect the agency of electricity in the following experiment of Mr Pictet: Into one of the brass cups formerly described, a small quantity of cotton was put to prevent the bulb of the thermometer from being broken. As the cup turned round, two or three fibres of the cotton rubbed against the bulb, and without any other friction the thermometer rose five or six degrees. A greater quantity of cotton being made to rub against the bulb, the thermometer rose 15° †.

I do not mean to draw any other conclusion from these facts, than that electricity is very often concerned in the heating of bodies, and that probably some such agent is employed in accumulating the heat produced by friction. Supposing that electricity is actually a substance, and taking it for granted that it is different from caloric, does it not in all probability contain caloric as well as all other bodies? Has it not a tendency to accumulate in all bodies by friction, whether conductors or non-conductors? May it not then be accumulated in those bodies which are rubbed against one ano-

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* Pictet, *sur le Feu*, chap. vi.

† Ibid. ch. ix.

ther? or, if they are good conductors, may it not pass through them during the friction in great quantities? May it not part with some of its caloric to these bodies, either on account of their greater affinity or some other cause? and may not this be the source of the caloric which appears during friction?

SECT. XII.

OF LIGHT AS A SOURCE OF CALORIC.

Light heats bodies.

THE last of the sources of caloric, namely, the agency of light, would require a set of experiments made on purpose to elucidate it. It has been long known, that when coloured bodies are exposed to the light of the sun or of combustible bodies, their temperature is raised in proportion to the darkness of their colour. To ascertain this point, Dr Hooke made a curious set of experiments, which were repeated long after by Dr Franklin. This philosopher exposed upon snow pieces of cloth of different colours (white, red, blue, black,) to the light of the sun, and found that they sunk deeper, and consequently acquired heat, in proportion to the darkness of their colour. This experiment has been repeated with more precision by Mr Davy. He exposed to the light six equal pieces of copper painted white, yellow, red, green, blue, and black, in such a manner that only one side of the pieces was illuminated. To the dark side of each was attached a bit of cerate, which melted when heated to 76°. The cerate attached to the blackened copper became first fluid, that attached to the

Book I.

blue next, then that attached to the green and red, then that to the yellow, and last of all that attached to the white*. Now it is well known that dark-coloured bodies, even when equally exposed to the light, reflect less of it than those which are light-coloured. But since the same quantity falls upon each, it is evident that dark-coloured bodies must absorb and retain more of it than those which are light-coloured. That such an absorption actually takes place is evident from the following experiment. Mr Thomas Wedgewood placed two lumps of luminous or phosphorescent marble on a piece of iron heated just under redness. One of the lumps of marble which was blackened over gave out no light; the other gave out a great deal. On being exposed a second time in the same manner, a faint light was seen to proceed from the clean marble, but none at all could be perceived to come from the other. The black was now wiped off, and both the lumps of marble were again placed on the hot iron: The one that had been blackened gave out just as little light as the other†. In this case, the light which ought to have proceeded from the luminous marble disappeared: it must therefore have been stopped in its passage out, and retained by the black paint. Now black substances are those which absorb the most light, and they are the bodies which are most heated by exposure to light. Cavallo observed, that a thermometer with its bulb blackened stands higher than one which had its bulb clean, when exposed to the light of the sun, the light of day, or the light of a lamp‡. Mr Pictet made the same observation; and took care to

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* Beddoes's Contributions, p. 44.

† *Phil. Trans.* 1792.

‡ *Phil. Trans.* 1780.

ascertain, that when the two thermometers were allowed to remain for some time in a dark place, they acquired precisely the same height. He observed, too, that when both thermometers had been raised a certain number of degrees, the clean one fell a good deal faster than the other *. But it is not a small degree of heat alone which can be produced by means of light. When its rays are concentrated by a burning glass, they are capable of setting fire to combustibles with ease, and even of producing a temperature at least as great, if not greater, than what can be procured by the most violent and best conducted fires. In order to produce this effect, however, they must be directed upon some body capable of absorbing and retaining them; for when they are concentrated upon transparent bodies, or upon fluids, mere air for instance, they produce little or no effect whatever. We may conclude, therefore, in general, that in all cases when light produces heat it is absorbed.

From these facts it was concluded, that the fixation of light in bodies always raises their temperature. On the other hand, it was known that the fixation of a certain quantity of caloric always occasions the appearance of light; for when bodies are raised to a certain temperature they always become red hot. Hence it was concluded that light and caloric reciprocally evolve each other; and this was explained by supposing that they have the property of repelling each other. The philosophers who adopted this opinion, reasoned in the following manner:

There is no body in nature which does not contain

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* *Sur le Feu*, chap. iv.

Supposed owing to the mutual repulsion of light and caloric.

caloric; and light has such an influence upon every thing, it produces such important changes upon the animal and vegetable kingdoms, it can be extricated from such a vast number of bodies, that in all probability we may conclude, with regard to it also, that it exists in all, or in almost all the bodies in nature. We have no means of ascertaining either the quantity of light or of caloric that exists in bodies; but if we were to judge from the quantity which appears during combustion, we must reckon it very considerable. Now, may there not exist a repulsion between the particles of caloric and light? It is not easy, at least, to see why light flies off during combustion with such rapidity, if this be not the case. If such a repulsion actually exists, it will follow that caloric and light cannot be accumulated in the same body beyond a certain proportion. If the caloric exceed, it will tend to drive off the light; if the light, on the contrary, happen to prevail, it will displace the caloric.

If caloric and light actually exist in all bodies, there must be an affinity between them and all other bodies; and this affinity must be so great, as to render ineffectual the repulsion which exists between light and caloric. Let us suppose now, that these two substances exist in all bodies in certain proportions, it will follow, that the more either of caloric or light is added to any body, the stronger must the repulsion between their particles become; and if the accumulation be still going on, this repulsion will soon become great enough to balance their affinity for the body in which they exist, and consequently will dispose them to fly off. If caloric, for instance, be added to a body, whenever the body arrives at a certain temperature it becomes luminous, because part of the light which was formerly combined with it is driven off. This temperature must depend partly upon the affinity between the body and caloric, and partly upon its affinity for light. Pyrophori, for instance, the affinity between which and light does not seem to be very great, become luminous at a very moderate temperature. This is the case with the pyrophorus of Canton. A great many hard bodies become luminous when they are exposed to a moderate heat; flour, for instance, carbonat of barytes, spar, sea shells, and a great many others, which are enumerated by Mr Thomas Wedgewood*.

The same ingenious gentleman has observed, that gold, silver, copper, and iron, become luminous when heated in times inversely proportional to their specific calorics†. Now the specific calorics of these metals are in the following order:

Iron,
Copper,
Silver,
Gold.

They become luminous, therefore, when exposed to the same degree of heat, in the following order:

Gold,
Silver,
Copper,
Iron.

Now the smaller the specific caloric of any body is, the less must be the quantity of caloric necessary to raise it a given number of degrees; the sooner therefore must it arrive at the temperature at which it gives out

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* *Phil. Trans.* 1792, p. i.

† *Phil. Trans.* 1792, p. i.

light. It was natural to expect, then, if the emission of light from a body by the application of heat be owing to the repulsion between caloric and light, that those bodies should become luminous soonest in which that repulsion increases with the greatest rapidity; and this we see is precisely the case. The only question to be determined before drawing this conclusion is, Whether the same quantity of caloric entered all of them? That depends upon their conducting power, which, according to Ingenhousz, is in the following order:

Silver,
Gold,
Copper,
Iron.

We see, then, that this conducting power is nearly in the order in which these metals become luminous; so that the greatest quantity of caloric would enter those which become soonest luminous. Now this is just what ought to happen, provided the expulsion of light from a luminous body, by the application of heat, be owing to the repulsion between the particles of caloric and light.

The repulsion between the different rays of light and caloric does not seem to be equal: the repulsion between the blue rays and caloric seems to be greater than that between the red rays and caloric; and the repulsion between all the rays and caloric seems to be directly as their refrangibility: accordingly, when heat is applied to a body, the blue rays escape sooner, and at a lower temperature, than the red rays and others which are most refrangible. When sulphur, for instance, is burnt at a low temperature, the colour of the flame is blue; and when examined by the prism it is found to consist of the violet, indigo, blue, and sometimes of a small quantity of the green rays*; but when this substance is burnt at a high temperature the colour of the flame is white, all the rays separating together. When bodies have continued to burn for some time, they may be supposed to have lost the greater part of the most refrangible rays; hence the red appearance of bodies, charcoal for instance, that have burnt for some time, the only rays which remain to separate being the orange, yellow, and red†.

The blue rays seem not only to repel caloric with greater force, but likewise to have a greater affinity for other bodies than the red rays have; for they decompose the oxide of silver (or rather the muriat of silver) much sooner, and to a greater extent, than the red rays‡: hence we see the reason why the application of the blue rays to Mr Wilson's pyrophori and to the diamond causes an extrication of red rays.

We have seen already that the gases are not heated red hot by the application of heat. It would follow from this, that the gases do not contain light: but the contrary is certain; for light is actually extricated during the combustion of hydrogen, and must therefore have existed either in the oxygen or hydrogen gas, or in both. Probably therefore the reason that heat does not extricate light from the gases is, that the affinity betwen their bases and light is exceedingly strong: it would therefore require a more than usual temperature to produce its extrication; and on account of the great dilatability of these gases, which always tends to diminish the repulsion between the caloric and light, this

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* Morgan, *Phil. Trans.* 1785. † Ibid. ‡ Sennebier.

temperature cannot be applied. It is easy to see, upon the supposition that there exists a repulsion between caloric and light, why the accumulation of light should produce heat, and why light only occasions heat in those bodies that absorb it.

Objections to which this theory is liable.

But this theory, ingenious and plausible as it appears, is not beyond the reach of objections, and objections, too, altogether incompatible with its truth. Were the repulsion between caloric and light the only cause of the luminousness of hot bodies, the continual application of heat would surely in time separate the whole of the light which was combined with the body, and then it would cease to be luminous altogether; but we have no reason to suppose that bodies ever cease to become luminous by the continued application of heat. Claveus kept melted, and consequently red hot, gold for months in a furnace; but he does not say that its luminousness was diminished, far less destroyed*; and had such a remarkable phenomenon taken place, certainly he would not have failed to inform us; but so far from that, he expressly says that it suffered no alteration†.

Whether light would continue to extricate a great deal of caloric during so long a time has never been

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* Shaw's *Boyle*, iii. 268.

† A gentleman, to whom I mentioned this objection, observed, that in the case of bodies long exposed to heat, the light, which appears to proceed from them, might, in fact, be extricated from the atmosphere by the caloric communicated to it from the heated body. This thought is new and ingenious, and might easily be put to the test of experiment. Some of the facts mentioned in the text are rather hostile to it; but should it prove well founded, it would go far to remove most of the difficulties in which the theory of light is at present involved.

tried: but we have no reason for supposing that its power to produce that effect is ever exhausted; for bodies, after being exposed to the sun for years, and even for ages, are just as much heated by it as ever. But these effects, far from being inexhaustible, ought, according to the theory, to come very speedily to an end.

But waving this altogether; we have no proof that the absorption of light raises the temperature of bodies. The rays of the sun indeed, and of burning bodies, raise the temperature of the substances by which they are absorbed; but these rays contain both caloric and light. The rise of temperature, therefore, may be owing, not to the absorption of light, but to the absorption of caloric. And that this is actually the case can scarcely be doubted, if we recollect that the rays of the moon, which consist of pure light, never raise the temperature of bodies. On the other hand, bodies are never made red hot without being exposed to the action of light as well as of caloric: the light, then, which they emit, instead of being displaced by the caloric, may have been absorbed along with the caloric. The light evolved when pyrophori are slightly heated, may be owing, not to the repulsion between caloric and light, but to an attraction between them; while the constant appearance of caloric and light together, during combustion, affords even some reason for believing that such an attraction exists.

CHAP. VI.

OF SIMPLE BODIES IN GENERAL.

Simple bodies

SUCH are the properties of *Simple bodies*, as far as they have been hitherto investigated. Their number amounts to 29. But all the substances, which chemists have not yet succeeded in decompounding, are by no means included in this first Book. Besides the 29 bodies described in the preceding chapters, there are 14 others*, whose component parts are still unknown. So that the number of undecompounded bodies amounts to 43. But these 14 resemble so closely other bodies, whose component parts are known, that it would be improper to separate them: a circumstance which renders it exceedingly probable that they also are compounds, and formed of similar ingredients with the other bodies of the classes to which they belong.

Divisible into,

The 29 simple bodies naturally divide themselves into two distinct classes, which may be distinguished by the titles of *repelling* and *attracting bodies*.

1. Repelling, and,

1. The repelling bodies are only two; namely, caloric and light. As the particles of these bodies mutually repel each other, they are never found cohering together, and constituting a mass of caloric or a mass of light. They agree together in many of their proper-

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* These are the ten earths, two alkalies, and two acids.

ties. They radiate from hot or luminous bodies with a velocity amounting to nearly 200,000 miles in a second; they are transmitted, refracted, and reflected by some bodies; while they have the property of combining with others. Caloric is the cause of fluidity; it produces expansion, and occasions in us the sensation of heat: Light, on the other hand, produces the sensation of vision. These two substances do not sensibly affect the weight of bodies. There is an intimate connection between them; but upon what that connection depends is unknown.

2. Attracting.

2. The attracting bodies are 27 in number. As their particles mutually attract, they are capable of cohering together, and are often found together. They may be arranged under two divisions. The first division comprehends under it only oxygen; the second includes the simple combustibles and metals. Oxygen has the property of combining with all the bodies comprehended under the second division. This combination constitutes the first step in what, in common language, is called combustion, and the only part of that important process which has been completely ascertained. What remains after combustion is the compound formed by the combination of the combustible body with oxygen. Sulphur, phosphorus, and azot, when combined with oxygen, form sulphuric, phosphoric, and nitric acids; hydrogen and oxygen form water; metallic bodies and oxygen, earthy-like powders called *oxides.*

Gases,

Three of the 27 attracting bodies can only be exhibited separately under the form of a gas; these three are oxygen, hydrogen, and azot. This gas is considered at present as a compound of three different ingredients. These are *caloric*, *light*, and the *substance* from which the gas takes its name, which is called the *base* of the gas. Thus oxygen gas is composed of caloric, light, and oxygen. If the caloric and light could be separated, it is supposed that the oxygen, hydrogen, and azot, would be obtained in a solid or fluid state. There is a great difference, then, between oxygen and oxygen gas, hydrogen and hydrogen gas; azot and azotic gas. Thus hydrogen is the base deprived of its caloric and light; hydrogen gas the base combined with caloric and light; and so of the others. But as this theory has not been demonstrated, we must consider it rather in the light of a probable conjecture than as an established fact.

And solids.

The remaining 24 attracting bodies may be exhibited in a solid state, and the greatest number of them are usually in that state. One of them, namely carbon, can neither be melted nor volatilized by the strongest heat to which we can expose it. All the rest may be melted by the application of heat; several of them may be converted into vapour; and it is probable that they would all assume that form, if a sufficiently high temperature could be applied.

These 26 bodies differ exceedingly from each other in their combustibility. Phosphorus is the most combustible: arsenic and manganese, among the metals, combine with oxygen at the temperature of the atmosphere; while no temperature is sufficient to make gold and platinum exhibit the phenomena of combustion.

Such is the present state of our knowledge of simple substances. But it will be worth while to take a view of the theories of the ancients, the various modifications which they underwent, and the steps by which chemists have been gradually led to the opinions at present received.

Ancients believed in four elements.

It seems to have been an opinion established among philosophers in the remotest ages, that there are only four simple bodies; namely, *fire*, *air*, *water*, and *earth*. To these they gave the name of *elements*, because they believed that all substances are composed of these four. This opinion, variously modified indeed, was maintained by all the ancient philosophers. We now know that all these supposed elements are compounds: *fire* is composed of caloric and light; *air* of oxygen and azotic gases; *water* of oxygen and hydrogen; and *earth*, as will appear afterwards, of ten different substances.

Elements of the alchymists.

The doctrine of the four elements seems to have continued undisputed till the time of the alchymists. These men having made themselves much better acquainted with the analysis of bodies than the ancient philosophers had been, soon perceived that the common doctrine was inadequate to explain all the appearances which were familiar to them. They substituted a theory of their own in its place. According to them, there are three elements, of which all bodies are composed; namely, *salt*, *sulphur*, and *mercury*, which they distinguished by the appellation of the *tria prima*. These principles were adopted by succeeding writers, particularly by Paracelsus, who added two more to their number; namely, *phlegm* and *caput mortuum*.

It is not easy to say what the alchymists meant by *salt*, *sulphur*, and *mercury*: probably they had affixed no precise meaning to the words. Every thing which is fixed in the fire they seem to have called *salt*, every inflammable substance they called *sulphur*, and every substance which flies off without burning was *mercury*. Accordingly they tell us, that all bodies may by fire be decomposed into these three principles; the salt remains behind fixed, the sulphur takes fire, and the mercury flies off in the form of smoke. The phlegm and caput mortuum of Paracelsus were the water and earth of the ancient philosophers.

Mr Boyle attacked this hypothesis in his *Sceptical Chemist ;* and several of his other publications proved, that the chemists comprehended under each of the terms salt, sulphur, mercury, phlegm, and earth, substances of very different properties ; that there is no proof that all bodies are composed of these principles ; and that these principles themselves are not elements but compounds. The refutation of Mr Boyle was so complete, that the hypothesis of the *tria prima* seems to have been almost immediately abandoned by all parties.

Altered by Beccher,

Meanwhile a very different hypothesis was proposed by Beccher in his *Physica Subterranea ;* a hypothesis to which we are indebted for the present state of the science, because he first pointed out chemical analysis as the true method of ascertaining the elements of bodies. According to him, all terrestrial bodies are composed of *water*, *air*, and three *earths;* namely, the *fusible*, the *inflammable* or *sulphureous*, and the *mercurial.* The three earths, combined in nearly equal proportions, compose the metals ; when the proportion of mercurial earth is very small, they compose stones ; when the fusible predominates, the resulting compounds are the precious stones ; when the sulphureous predominates, and the fusible is deficient, the compounds are the colorific earths : Fusible earth and water compose a universal acid, very much resembling sulphuric acid, from which all other acids derive their acidity : Water, fusible earth, and mercurial earth, constitute common salt ; sulphureous earth, and the universal acid, form sulphur.

And Stahl.

Stahl modified the theory of Beccher considerably. He seems to have admitted the universal acid as an element; the mercurial earth he at last discarded altogether; and to the sulphureous earth he sometimes gives the name of *phlogiston,* sometimes of *ether.* Earths he considered as of different kinds, but containing all a certain element called *earth.* So that, according to him, there are five elements, air, water, phlogiston, earth, the universal acid. He speaks too of heat and light; but it is not clear what his opinion was respecting them.

Gradually banished from the science.

Stahl's theory was gradually modified by succeeding chemists. The universal acid was tacitly discarded, and the different known acids were considered as distinct undecomposed or simple substances: the different earths were distinguished from each other, and all the metallic calces were considered as distinct substances. For these changes chemistry was chiefly indebted to Bergman. While the French and German chemists were occupied with theories about the universal acid, that illustrious philosopher, and his immortal friend and fellow-labourer Scheele, loudly proclaimed the necessity of considering every undecomposed body as simple till it has been decomposed, and of distinguishing all those substances from each other which possess distinct properties. These cautions, and the consequent arrangement of chemical bodies into distinct classes by Bergman, soon attracted attention, and were at last tacitly acceded to.

Thus the elements of Stahl were in fact banished from the science of chemistry; and in place of them were substituted a great number of bodies which were considered as simple, because they had not been analysed. These were phlogiston, acids, alkalies, earths, metallic calces, water, and oxygen. The rules established by Bergman and Scheele are still followed; but subsequent discoveries have shewn, that most of the bodies which they considered as simple are compounds; while several of their compounds are now placed among simple bodies, because the existence of phlogiston, which they considered as a component part of these bodies, is now given up.

Present state.

As the term *simple substance* in chemistry means nothing more than a body whose component parts are unknown, it cannot be doubted that, as the science advances towards perfection, many of those bodies which we consider at present as simple will be decomposed; and most probably a new set of simple bodies will come into view of which we are at present ignorant. These may be decomposed in their turn, and new simple bodies discovered; till at last, when the science reaches the highest point of perfection, those really simple and elementary bodies will come into view of which all substances are ultimately composed. When this happens (if it be not above the reach of the human intellect), the number of simple substances will probably be much smaller than at present. Indeed, it has been the opinion of many distinguished philosophers in all ages, that there is only one kind of matter; and that the difference which we perceive between bodies depends upon varieties in the figure, size, and density of the primary atoms when grouped together. This opinion was adopted by Newton; and Boscovich has built upon it an exceedingly ingenious and instructive theory. But the full demonstration of this theory is perhaps beyond the utmost stretch of human sagacity.

BOOK II.

OF

COMPOUND BODIES.

COMPOUND BODIES are substances composed of two or more simple bodies combined together. Now as the simple bodies are 29 in number, if they were all capable of combining together, the compounds formed by them would amount to a great many thousands: But all the simple substances are not capable of combining with each other; neither hydrogen, for instance, nor azot, have ever been combined with metals. This diminishes their number considerably. Besides, we are still too little acquainted with the nature of caloric and light to be able to treat separately of the compounds into which they enter. Several numerous classes of compounds have been already described in the last Book: for the oxides, sulphurets, phosphurets, and alloys, are real compounds. All these circumstances render the compounds which form the subject of this Book much less numerous than might be at first supposed.

Compounds of two kinds.

Compound bodies are of two kinds. Some of them are formed by the combination of two or more *simple* substances with each other. Thus phosphoric acid is composed of phosphorus and oxygen; ammonia, of hydrogen and azot, and oil of hydrogen and carbon. Others are formed by the combination of two or more *compound* bodies with each other. Thus phosphat of ammonia is composed of phosphoric acid and ammonia; volatile liniment, of oil and ammonia. The first of these kinds of compounds I call PRIMARY COMPOUNDS; to the second I give the name of SECONDARY COMPOUNDS. It will be very convenient to describe each of these separately.

DIVISION I.

OF

PRIMARY COMPOUNDS.

THE primary compounds, omitting the sulphurets, phosphurets, carburets, and alloys, may be arranged under the five following classes:

1. Alkalies.
2. Earths.
3. Oxides.
4. Acids.
5. Compound combustibles.

These shall be the subject of the five following Chapters.

CHAP. I.

OF ALKALIES.

THE word ALKALI is of Arabian origin, and was introduced into chemistry after it had been applied to a plant which still retains the name of *kali*. When this plant is burnt, the ashes washed in water, and the water evaporated to dryness, a white substance remains, which was called *alkali*. According to Albertus Magnus, who uses the word, it signifies *fæx amaritudinis*, “ the dregs of bitterness[*]. Alkali may be obtained from other substances besides kali. Chemists gradually discovered that bodies, differing from one another in several of their properties, had been confounded together under the same name. The word, in consequence, became general, and is now applied to all bodies which possess the following properties :

Properties of alkalies.

1. Incombustible.
2. A hot caustic taste.
3. Volatilized by heat.
4. Soluble in water even when combined with carbonic acid.
5. Capable of converting vegetable blues to green.

The alkalies at present known are three in number; 1. Potass; 2. Soda; 3. Ammonia.

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[*] *Theatrum Chemicum*, ii. 470.

The two first are called *fixed alkalies*, because they require a red heat to volatilize them; the last is called *volatile alkali*, because it readily assumes a gaseous form, and consequently is dissipated by a very moderate degree of heat.

SECT. I.

OF POTASS.

Method of procuring potass.

If a sufficient quantity of wood be burnt to ashes, and these ashes be afterwards washed repeatedly with water till it comes off free from any taste, and if this liquid be filtrated and evaporated to dryness, the substance which remains behind is *potass*; not, however, in a state of purity, for it is contaminated with several other substances, but sufficiently pure to exhibit many of its properties. In this state it occurs in commerce under the name of *potash*. When heated to redness, many of its impurities are burnt off: it becomes much whiter than before, and is then known in commerce by the name of *pearl-ash*. Still, however, it is contaminated with many foreign bodies, and is itself combined with carbonic acid gas, which blunts all its properties. It may be obtained perfectly pure by the following process:

Mix it with twice its weight of quicklime, and ten times its weight of pure water: Boil the mixture for some hours in a clean iron vessel, or allow it to remain for 48 hours in a close glass vessel, shaking it occasionally. Then pass it through a filter. Boil the liquid

Book II.

obtained in a silver vessel very rapidly, till it is so much concentrated as to assume when cold the consistence of honey. Then pour upon it a quantity of alcohol equal in weight to one-third of the pearl-ash employed. Shake the mixture, put it on the fire, let it boil for a minute or two, then pour it into a glass vessel and cork it up. The solution gradually separates itself into two strata: the lowest consists of the impurities, partly dissolved in water and partly in a solid state; the uppermost consists of the pure potass dissolved in alcohol, and is of a reddish-brown colour. Decant this alcohol solution into a silver bason, and evaporate it rapidly till a black charry crust forms on the surface, and the liquid below acquires such consistence as to become solid on cooling. Then remove the black crust, and pour the solution into a porcelain vessel. When cold, it concretes into a fine white substance, which is pure potass. It must be broken to pieces, and put into an air-tight phial.

For this process we are indebted to Berthollet. The following, which was first proposed by Lowitz of Petersburgh, is less expensive. The potash of commerce and quicklime are to be boiled together as above described. The filtered liquor is then to be evaporated till a thick pellicle appears on its surface, and afterwards allowed to cool; and all the crystals which have formed are to be separated, for they consist of foreign salts. The evaporation is then to be continued in an iron pot; and, during the process, the pellicle which forms on the surface is to be carefully taken off with an iron skimmer. When no more pellicle appears, and when the matter ceases to boil, it is to be taken off the fire, and must be constantly agitated with an iron spatula while cooling. It is then to be dissolved in double its own weight of cold water. This solution is to be filtered and evaporated in a glass retort* till it begins to deposite regular crystals. If the mass consolidates ever so little by cooling, a small quantity of water is to be added, and it must be heated again. When a sufficient number of crystals have been formed, the liquor which swims over them, and which has assumed a very brown colour, must be decanted off, and kept in a well-closed bottle till the brown matter has subsided, and then it may be evaporated as before, and more crystals obtained †.

The theory of these processes is obvious: The lime separates the carbonic acid, for which it has a stronger affinity; and the alcohol or the evaporation separate all the other foreign ingredients.

Black's discovery of the cause of its causticity:

As potass is never obtained at first in a state of purity, but always combined with carbonic acid, it was long before chemists understood to what the changes produced upon it by lime were owing. According to some, it was deprived of a quantity of mucilage, in which it had formerly been enveloped; while, according to others, it was rendered more active by being more comminuted. At last, in 1756, Dr Black proved, by the most ingenious and satisfactory analysis, that the *potass* which the world had considered as a simple substance, was really a compound, consisting of potass and carbonic acid; that lime deprived it of this acid; and that it became more active by becoming more simple.

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* Dr Kennedy observes, very justly, that a glass retort ought not to be employed, because potass in this state dissolves glass. *Edin. Trans.* v. 97.

† Nicholson's *Journal*, i. 164.

Book II.

Meyer's theory.

While Dr Black was thus occupied in Scotland, Mr Meyer was employed in Germany in the same researches; from which, however, he drew very different conclusions. His Essays on Lime appeared in 1764. Pouring into lime-water a solution of potass (*carbonat of potass*), he obtained a precipitate, which he found not to differ from lime-stone. The alkali had therefore deprived the lime of its causticity and its active properties; and these very properties it had itself acquired. From which he concluded, that the causticity of lime was owing to a particular acid with which it had combined during its calcination. The alkali deprived the lime of this acid, and therefore had a stronger affinity for it. To this acid he gave the name of *acidum pingue* or *causticum*. It was, according to him, a subtile elastic mixt, analogous to sulphur, approaching very nearly to the nature of fire, and actually composed of an acid principle and fire. It was expansible, compressible, volatile, astringent, capable of penetrating all vessels, and was the cause of causticity in lime, alkalies, and metals. This theory was exceedingly ingenious, and it was supported by a vast number of new and important facts. But notwithstanding the reputation and acknowledged genius and merit of its author, it never gained many followers; because the true theory of causticity, which had been already published by Dr Black, soon became known on the continent; and, notwithstanding some opposition at first, soon carried conviction into every unprejudiced mind. Even Mr Meyer himself readily acknowledged its truth and importance, though he did not at first, on that account, give up his own theory.

That potass was known to the ancient Gauls and Germans cannot be doubted, as they were the inventors of soap, which, Pliny informs us, they composed of ashes and tallow. These ashes (for he mentions the ashes of the beech tree particularly) were nothing else but potass; not, however, in a state of purity [*]. The κονια, too, mentioned by Aristophanes and Plato, appears to have been a ley made of the same kind of ashes. The alchymists were well acquainted with it; and it has been in every period very much employed in chemical researches. It may be said, however, with justice, that till Berthollet published his process in the year 1782, chemists had never examined potass in a state of complete purity [†].

Properties of potass.

Potass is a brittle substance of a white colour, and a smell resembling that which is perceived during the slacking of quicklime. Its taste is remarkably acrid; and it is so exceedingly corrosive, that when applied to any part of the body, it destroys it almost instantaneously. On account of this property, it has been called *caustic*, and is often used by surgeons under the name of the *potential cautery*, to open abscesses, and destroy useless or hurtful excrescences. Its specific gravity is 1.7085 [‡].

When heated it melts; at a red heat it swells, and

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[*] Plinii, lib. xviii. c. 51.

[†] Potass was long distinguished by the name of *vegetable alkali*, because it is obtained from vegetables, and because it was long thought to be peculiar to the vegetable kingdom; but this is now known to be a mistake. It was called also *salt of tartar*, because it may be obtained by burning the salt called *tartar*. Mr Kirwan has given it the name of *tartarin*, Dr Pearson has called it *vegalkali*, Klaproth *kali*, and Dr Black *lixiva*. By most British chemists it is called *potash*; but this term, in common language, signifies the carbonat of potass, or the potash of commerce.

[‡] Hassenfratz, *Ann. de Chim.* xxviii. 11.

evaporates slowly in a white acrid smoke. A strong heat gives it a greenish tinge, but produces no other alteration in it.

When exposed to the air, it soon attracts moisture, and is converted into a liquid; at the same time it combines with carbonic acid, for which it has a strong affinity.

It has a very strong affinity for water. At the common temperature of the air, one part of water dissolves two parts of potass. The solution is transparent, very dense, and almost of the consistence of oil. It is in this state that potass is usually employed by chemists. When four parts of potass in powder and one of snow are mixed together, the mixture becomes liquid, and at the same time absorbs a quantity of caloric. This mixture was employed by Lowitz to produce artificial cold. When the aqueous solution of potass is evaporated to a proper consistency, the potass crystallizes. The shape of its crystals is very different, according to the way in which they have been produced. When allowed to form in the cold, they are octahedrons in groups, and contain 0.43 of water: When formed by evaporation on the fire, they assume the figure of very thin transparent blades of extraordinary magnitude, which, by an assemblage of lines crossing each other in prodigious numbers, present an aggregate of cells or cavities, commonly so very close, that the vessel may be inverted without losing one drop of the liquid which it contains*.

Potass is not altered by exposure to the light. It cannot be combined with oxygen, hydrogen, azot, car-

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* Nicholson's *Journal*, i. 164.

bon, nor charcoal; nor has it any action, as far as is known, upon these bodies.

Sulphuret of potass.

There is a strong affinity between potass and sulphur. When three parts of sulphur and one of potass are triturated together in a glass mortar, the sulphur acquires a green colour, the mixture becomes hot, and exhales an alliaceous odour. It gradually attracts moisture from the air, and is totally soluble in water *. When two parts of potass and one of sulphur are heated in a crucible, they melt and combine, and form *sulphuret of potass*. The potash of commerce may be also employed; for the carbonic acid separates in the form of a gas during the combination of the potass and sulphur. When the fusion is complete, the sulphuret is to be poured upon a marble slab; and as soon as it congeals, it must be broken to pieces, and set by into a well-corked phial.

Sulphuret of potass, thus prepared, is of a brown colour, not unlike the liver of animals. Hence it was formerly called *hepar sulphuris*, "liver of sulphur;" but when exposed to the air, it soon becomes green, and even white. It is hard, brittle, and has a glassy fracture. Its taste is acrid, caustic, and bitter, and it leaves a brown stain upon the skin. It has no other smell than that of sublimed sulphur. When exposed to a violent heat, the sulphur sublimes, and the potass remains in a state of purity. This sulphuret converts vegetable blues to green, and soon destroys them. When heated with charcoal, it dissolves, and combines with it †.

When sulphuret of potass is exposed to the air, or

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* Fourcroy, ii. 203.

† Ibid.

Book II.

Hydrogenated sulphuret.

when it is moistened with water, its properties very soon change. It acquires a green colour, and exhales the odour of sulphurated hydrogen gas. This change is owing to the formation of a quantity of sulphurated hydrogen, in consequence of the decomposition of the water. This new-formed substance combines with the sulphuret, and converts it into *hydrogenated sulphuret of potass*, which is soluble in water, and has a brownish green colour. It may be formed also by boiling in water two parts of potass and one part of sulphur. Sulphuret of potass produces no change upon air, but hydrogenated sulphuret gradually absorbs oxygen. When inclosed in a vessel with a quantity of air, it soon absorbs all the oxygen of that portion, and leaves nothing but azotic gas. This fact, which was first observed by Scheele, induced him to use hydrogenated sulphuret to measure the quantity of oxygen contained in any given portion of atmospheric air. Hydrogenated sulphuret is capable of oxidating and dissolving almost all the metals. We are indebted to Mr Berthollet for the first accurate account of the difference between these two substances *.

Action of potass on phosphorus,

Potass cannot be combined with phosphorus by any method at present known. But when potass, dissolved in water, is heated over phosphorus in a retort, the water is gradually decomposed, part of the phosphorus is converted into phosphoric acid, and a great quantity of phosphorated hydrogen gas is emitted, which takes fire as usual as soon as it comes into contact with the air of the atmosphere. It was by this process that Gemgembre first obtained phosphorated hydrogen gas.

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* *Ann. de Chim.* xxv. 233.

On metallic bodies.

Potass does not combine with any of the metals; but some of the metals which have a strong affinity for oxygen, when put into a solution of potass in water, especially if heat be applied, are gradually oxidated. This is the case with molybdenum, zinc, and iron. Tin also is oxidated in a very small proportion; and this seems also to be the case with manganese.

It is capable of dissolving a considerable number of the metallic oxides; and in some cases it deprives them of a dose of their oxygen. Thus when poured upon the red oxide of iron it soon converts it into the black. The cause of this change is unknown. It has been ascertained, that the oxides of the following metals are soluble in potass.

Mercury,
Copper (scarcely),
Tin,
Lead,
Nickel,
Zinc,
Antimony (acidulous),
Tellurium,
Arsenic,
Cobalt,
Manganese,
Tungsten,
Molybdenum.

But the nature of these solutions has not hitherto been examined with any degree of attention; though the subject is remarkably curious, and promises to throw light both upon the nature of alkalies and metals.

Its affinities.

The affinities of potass are as follows:

Sulphuric acid,
Nitric,
Muriatic,
Sebacic,
Phosphoric,
Fluoric,
Oxalic,

Tartarous,
Arsenic,
Succinic,
Citric,
Formic,
Lactic,
Benzoic,
Sulphurous,
Acetous,
Mucous,
Boracic,
Nitrous,
Carbonic,
Prussic,
Oil,
Water,
Sulphur.

Composition.

Potass has never yet been decomposed. Several chemists, indeed, have conjectured, that it is a compound of lime and azot; and some persons have even endeavoured to prove this by experiment; but none of their proofs are at all satisfactory. We ought, therefore, in strict propriety, to have assigned it a place in the First Book: but this would have separated the alkalies from each other, and would have introduced a degree of confusion, which would have more than counterbalanced the logical exactness of the arrangement. Besides, we are certain, from a variety of facts, that all the alkalies are compounds: One of them has actually been decompounded; and the other two have been detected in the act of formation, though the ingredients which compose them have not hitherto been discovered. Morveau and Desormes have lately announced, that they consider potass as a compound of hydrogen and lime. Their proof is, that lime was produced when potass alone, of all the bodies present, could contain it; and this production was always preceded by the combustion of hydrogen *. But as they have not published their experiments, we must suspend our judgment till we see the strength of the evidence on which their opinion has been formed.

Potass is of the highest importance, not only in chemistry, where it is employed for a great variety of purposes, but also in many arts and manufactures; as washing, bleaching, dyeing, glass-making, and others, as will afterwards appear. It is employed also in surgery and medicine.

SECT. II.

OF SODA.

Soda, called also *fossil* or *mineral alkali* †, because it was thought peculiar to the mineral kingdom, was known to the ancients (though not in a state of purity) under the names of νιτρον and *nitrum* ‡.

Method of procuring soda.

It is found in large quantities combined with carbonic acid in different parts of the earth, especially in Egypt;

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[*] *Jour. de Phys.* lii. 55.

[†] Dr Pearson has proposed to distinguish it by the name of *fossalkali*; Klaproth calls it *natron*.

[‡] The λιτρον of the Athenians was evidently the same substance; and so was the נתר of the Hebrews.

and common salt is a compound of soda and muriatic acid. But the soda of commerce is obtained from the ashes of different species of the *salsola*, a genus of plants which grow upon the sea shore, especially from the *salsola soda*, from which the alkali has obtained its name. The soda of commerce is also called *barilla*, because the plant from which it is obtained bears that name in Spain. Almost all the algæ, especially the fuci, contain also a considerable quantity of soda. The ashes of these plants are known in this country by the name of *kelp*; in France they are called *varec*.

The soda, or barilla of commerce, is far from being pure; besides carbonic acid it contains common salt, and several other foreign ingredients; but it may be obtained perfectly pure by the processes described in the last Section for purifying potass.

Soda and potass resemble each other so nearly, that they were confounded together till Du Hamel published his dissertation on common salt in the Memoirs of the French Academy for 1736. He first proved that the base of common salt is soda, and that soda is different from potass. His conclusions were objected to by Pott, but finally confirmed by Margraff in 1758.

Its properties.

Soda is of a greyish-white colour, and agrees exactly with potass in its taste, smell, and action upon animal bodies; but its specific gravity is only 1.336 .

Heat produces on it exactly the same effects as upon potass. When exposed to the air, it absorbs moisture and carbonic acid, and is soon reduced to the consistence of paste; but it does not liquefy like potass; in a

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[*] Hassenfratz, *Ann. de Chim.* xxviii. 11.

Chap. I.

few days it becomes dry again, and crumbles into powder.

It has a strong affinity for water, dissolves in it like potass, and may also be obtained in crystals by evaporating its aqueous solution. It is not altered by light; nor does it combine with oxygen, hydrogen, azot, carbon, charcoal, nor metals. Its action upon phosphorus and sulphur is the same with that of potass. The sulphuret and hydrogenated sulphuret of soda possess the properties of the sulphuret and hydrogenated sulphuret of potass, and are formed in the same manner. In its action on metals, metallic oxides, and in its affinities, it also agrees with potass. In short, the two fixed alkalies, in a state of purity, resemble each other very nearly in almost every particular.

The component parts of soda are still unknown; Fourcroy supposed it a compound of magnesia and azot; but this opinion has not been confirmed by experiment. Desormes and Morveau, on the other hand, affirm, that it is composed of magnesia and hydrogen; but the experiments upon which this opinion is founded have not been published. Its importance in manufactures is not inferior to that of potass. For several purposes, indeed, as for the manufacture of soap and glass, it answers even better than potass.

SECT. III.

OF AMMONIA.

Method of procuring ammonia.

PUT into a retort a mixture of three parts of quicklime and one part of sal ammoniac in powder. Plunge the beak of the retort below the mouth of a glass jar filled with mercury, and standing inverted in a bason of mercury. Apply the heat of a lamp to the retort: a gas comes over, which displaces the mercury and fills the jar. This gas is *ammonia*.

Its history.

Ammonia was altogether unknown to the ancients; the alchymists were acquainted with it, though not in a state of purity, being combined with carbonic acid, and often also dissolved in water. Basil Valentine describes the method of obtaining it. It was known by the name of *volatile alkali;* it was also called *hartshorn*, because it was often obtained by distilling the horn of the hart; *spirit of urine*, because it may be obtained by the same process from urine; and *spirit of sal ammoniac*, because it may be obtained from that salt. Dr Black first pointed out the difference between ammonia and carbonat of ammonia, or ammonia combined with carbonic acid; and Dr Priestley discovered the method of obtaining it in a state of purity, by the process described in the beginning of this Section.

Properties.

Ammonia in the state of gas is transparent and colourless like air; its taste is acrid and caustic like that of the fixed alkalies, but not nearly so strong, nor does it, like them, corrode those animal bodies to which it is applied: its smell is remarkably pungent, though not unpleasant when sufficiently diluted. Its use as a stimulant to prevent fainting is well known.

Animals cannot breathe it without death. When a lighted candle is let down into this gas, it goes out three or four times successively; but at each time the flame is considerably enlarged by the addition of another flame of a pale yellow colour, and at last this flame descends from the top of the vessel to the bottom*.

Its specific gravity is 0.000732. Its weight is to that of common air as 3 to 5†.

When exposed to a cold of —45° it is condensed into a liquid, which again assumes the gaseous form when the temperature is raised‡. When passed through a red hot tube of porcelain or glass, it is totally decomposed and converted into hydrogen and azotic gas§.

Liquid ammonia.

It combines very rapidly with water. When a bit of ice is brought into contact with this gas, it melts and absorbs the ammonia, while at the same time its temperature is diminished. Cold water absorbs this gas almost instantaneously, and at the same time heat is evolved, and the specific gravity of the water is diminished. Water is capable of absorbing and condensing more than a third of its weight of ammoniacal gas. The specific gravity of the saturated solution is 0.9054‖. It is in this state that ammonia is usually employed by chemists. The term *ammonia* almost always means this liquid solution of ammonia in water. When heated to the temperature of about 130° the ammonia separates under the form of gas. When exposed to the tem-

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* Priestley, ii. 381.

† Kirwan *On Phlogiston*, p. 28.

‡ Morveau, *Ann. de Chim.* xxix. 292.

§ Priestley.

‖ Priestley, ii. 381. and Davy, *Researches*, p. 66.

perature of —46° it crystallizes, and when suddenly cooled down to —68° it assumes the appearance of a thick jelly, and has scarcely any smell *.

It follows from the experiments of Mr Davy, that a saturated solution of ammonia is composed of

74.63	water
25.37	ammonia
100.	

The following TABLE, drawn up by the same ingenious chemist, exhibits the proportion of water and ammonia contained in 100 parts of liquid ammonia of different specific gravities †.

Specific gravity.	Ammonia.	Water.
0.9054	25.37	74.63
0.9166	22.07	77.93
0.9255	19.54	80.46
0.9326	17.52	82.48
0.9385	15.88	84.12
0.9435	14.53	85.47
0.9476	13.46	86.54
0.9513	12.40	87.60
0.9545	11.56	88.44
0.9573	10.82	89.18
0.9597	10.17	89.83
0.9619	9.60	90.40
0.9684	9.50	90.5
0.9639	9.09	90.91
0 9713	7.17	92.83

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* Fourcroy and Vauquelin, *Ann. de Chim.* xxix. 289.

† Davy, p. 68.

Ammoniacal gas is not altered by light; but when electric sparks are made to pass through it, the bulk of the gas is considerably increased, and it is converted into hydrogen gas and azotic gas [*]. Hence it follows that it is composed of hydrogen and azot.

Decomposed by oxygen gas.

This gas has no effect upon oxygen gas while cold; but when a mixture of the two gases is made to pass through a red hot porcelain tube, a detonation takes place, water is formed, and azotic gas emitted. Hence we see that ammonia is partly combustible. Its hydrogen combines with the oxygen, and forms water, while the azot makes its escape in the form of a gas [†]. If the proportion of oxygen gas be considerable, nitric acid is also formed in consequence of the combination of the azot with the superabundant oxygen [†]. The same decomposition and detonation take place if common air be used instead of oxygen gas.

Hydrogenated sulphuret.

It combines with sulphur in the state of vapour, and forms a sulphuret which decomposes water, and forms *hydrogenated ſulphuret of ammonia*, known formerly by the name of *fuming liquor of Boyle*, because it was first described by that philosopher [§]. It is commonly prepared by distilling a mixture of five parts of sal ammoniac, five parts of sulphur, and six of quick lime. It is a liquid of a red or rather deep orange colour, and exhales a fetid odour in consequence of an excess of ammonia which it contains. Its nature was first pointed out by Berthollet [‖].

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[*] Priestly, ii. 389.

[†] Proust, Nicholson's *Jour.* iii. 328.

[‡] Fourcroy, ii. 236.

[§] Shaw's *Boyle*, ii. 78.

[‖] *Ann. de Chim.* xxv. 233.

Phosphorus produces no change on ammoniacal gas while cold; but when made to pass through phosphorus in a red hot porcelain tube, it is decomposed, and phosphorated hydrogen gas, and phosphorated azotic gas, are formed*.

Prussic acid.

Charcoal absorbs ammoniacal gas, but does not alter its properties while cold. But when the gas is made to pass through red hot charcoal, part of the charcoal combines with it, and forms a substance known by the name of *prussic acid*†.

Neither hydrogen gas nor azotic gas have any action upon it; nor does it produce any effect upon the metals; but liquid ammonia changes some of the metals into an oxide, and then dissolves them. The oxidation is evidently in consequence of the decomposition of part of the water with which the ammonia is combined; for hydrogen gas is emitted during the solution. Copper and zinc are oxidated by the action of ammonia; as are also tin and iron, though only superficially. Scarcely any of the other metals are altered by its action.

Action on metallic bodies.

Liquid ammonia is capable of dissolving the oxides of copper, iron, tin, nickel, zinc, bismuth, and cobalt. When digested upon the oxides of mercury, lead, or manganese, it is decomposed, water is formed by the union of the hydrogen of the ammonia with the oxygen of the oxides, and azotic gas is emitted‡. If a considerable heat be applied, nitric acid is formed at the same time with water§. Several other oxides are

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* Fourcroy, ii. 237.

† Scheele, ii. 183, and Clouet, *Ann. de Chim.* xi. 30.

‡ Scheele.

§ Milner, *Phil. Trans.*—Fourcroy, v. 355.

also partly deoxidated when ammonia is poured into their solutions in acids. The ammoniacal solution of copper is of a fine blue colour, and, according to Sage, capable of crystallizing. When heat is applied, the ammonia is partly driven off, and partly decomposed, by the combination of its hydrogen with the oxygen of the oxide.

Ammonia combines readily with the yellow oxide of gold and with the white oxide of silver, and forms with them two compounds, formerly known by the names of *fulminating gold* and *fulminating silver*; because, when heated or rubbed, they explode with great violence. They are now called *aurat* and *argentat of ammonia*.

Aurat of ammonia.

Aurat of ammonia, or *fulminating gold*, may be prepared by dissolving gold in nitro-muriatic acid, diluting the solution with thrice its weight of water, and then dropping in pure ammonia by little and little as long as any precipitate is formed; taking care not to add too much, because in that case part of the precipitate is again dissolved. The precipitate, which is of a yellow colour, is to be washed in pure water, dried slowly upon filtering paper, and then put into a phial; which, to prevent accidents, ought not to be corked, but its mouth covered with a linen rag or a slip of paper. This powder is fulminating gold; which is composed of five parts of yellow oxide of gold and one part of ammonia*. The preparation of this powder is described by Basil Valentine; and its singular properties excited the attention of all succeeding chemists. Various attempts were made to account for its fulmi-

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* Bergman, ii. 155.

Book II.

nating property, but without success, till Bergman published his dissertation on it in 1769. He demonstrated, that it is a compound of ammonia and yellow oxide of gold; that during its explosion the oxide is reduced, the ammonia decomposed, and the azot, which it contained, set at liberty in the form of gas*. These facts (partly discovered by Scheele) led him to explain the explosion as follows: Ammonia is composed of azot and phlogiston. When heat is applied to fulminating gold, the phlogiston combines with the oxide, and forms gold, while the azot flies off in the form of gas. The experiments of Bergman and Scheele were repeated and confirmed by Berthollet in 1786; and the nature of oxides having been previously ascertained by Lavoisier, he was enabled to give a more satisfactory explanation of the phenomenon. During the explosion, the hydrogen of the ammonia combines with the oxygen of the oxide, and forms water; the gold is reduced, and the azot evolved in the form of gas. The great expansibility of this gas by heat explains the violence of the explosion.

Fulminating gold explodes when struck violently, or when triturated in a mortar, or when heated to a temperature between 248° and 540°. The noise is tremendous; and when in any considerable quantity (12 grains for instance) it lacerates the metallic plate on which it is placed. When heated in close vessels, sufficiently strong to resist its action, it is reduced silently, and without any marks of violence†. Its force was compared with that of gunpowder by the Royal Society, but found inferior.

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* Bergman, ii. 153. and Scheele on Fire, p. 137.

† Berg. ii. 141.

Argentat of ammonia.

Fulminating silver was discovered by Berthollet in 1788. It may be formed by dissolving very pure silver in nitric acid, and then precipitating it by lime water. The precipitate is put upon filtering paper, which absorbs the water and the nitrat of lime with which it was mixed; then pure liquid ammonia is poured upon it, and allowed to remain for 12 hours; it is then decanted off, and the black powder, on which it stood, is placed cautiously, and in very small portions, upon bits of filtering paper. This powder is fulminating silver. Even while moist it explodes with violence when struck by a hard body. When dry, the slightest touch is sufficient to cause it to fulminate. When the liquid decanted off this powder is heated in a glass retort, an effervescence takes place, azotic gas is emitted, and small crystals make their appearance, which are opaque, and have a metallic brilliancy. These fulminate when touched, even though covered by the liquid, and often break in pieces the vessels in which they are kept*.

The theory of this dangerous powder is the same as that of fulminating gold. It is a compound of ammonia and oxide of silver. Friction, or the application of heat, occasions the combination of the oxygen of the oxide with the hydrogen of the ammonia, water is formed, the silver is reduced, and azotic gas emitted.

The affinities of ammonia are the same with those of the fixed alkalies.

Composition of ammonia.

As ammonia has the property of detonating with nitre, chemists had unanimously agreed that it contains phlogiston. Scheele first demonstrated, that when it

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* Berthollet, *Ann. de Chim.* i. 54.

Book II.

is decomposed by means of the oxides of manganese, arsenic, or gold, azotic gas is set at liberty, while the oxide is reduced *. Hence he concluded, that it is composed of azot and phlogiston ; and Bergman coincided with him in opinion. Dr Priestley discovered, that when electric explosions are made to pass through this gas, its bulk is gradually augmented to thrice the space which it formerly occupied ; and a quantity of hydrogen gas is produced. The same ingenious philosopher applied heat to the red oxides of mercury and lead confined in ammoniacal gas. The oxides were reduced, water was evolved, the ammoniacal gas disappeared, and, instead of it, there was found a quantity of azotic gas †. These experiments, and those of Scheele, led to the conclusion, that ammonia is composed of azot and hydrogen : a conclusion which was fully established by the experiments of Berthollet, published in the Memoirs of the French Academy for 1785. This acute philosopher repeated the experiments of Scheele and Priestley, and applied to them the theory of Mr Lavoisier, and added also several very decisive ones of his own. The most important of these is the mutual decomposition of ammonia and oxy-muriatic acid. When these bodies are mixed together, an effervescence takes place, azot is disengaged, a quantity of water formed, and the oxy-muriatic acid is converted into common muriatic acid. Now the substances mixed were ammonia and oxy-muriatic acid, which is composed of oxygen and muriatic acid ; the products were, muriatic acid, azot, and water, which is composed of oxy-

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* Scheele, i. 95. and 155. French Transl.—Scheele on Fire, p. 137.

† Priestley, ii. 396.

gen and hydrogen. The oxygen of the water was furnished by the acid; the other products must have been furnished by the ammonia, which has disappeared. Ammonia, therefore, must be composed of azot and hydrogen. It follows from Mr Berthollet's experiments, that ammonia is composed of 121 parts of azot and 29 of hydrogen. According to Dr Austin, it is composed of 121 parts of azot and 32 of hydrogen*. Hence 100 parts of ammonia are composed of about 80 parts of azot and 20 of hydrogen. The experiments of Berthollet have been still farther confirmed by those made more lately by Mr Davy†.

The component parts of ammonia being thus ascertained, nothing was wanting to render the theory complete but the combining of these substances together, and the forming of ammonia by art. Dr Austin mixed hydrogen and azotic gas together in the proper proportions, and endeavoured to make them combine by the application of heat, by electricity, and by cold; but he found, that while these two substances were in a gaseous state, they could not be combined by any method which he could devise. It could not be doubted, however, that the combination often takes place when these bodies are presented to each other in a different form. Dr Priestley‡ and Mr Kirwan§ had actually produced it even before its composition was known. Accordingly Dr Austin found, that when tin is moistened with nitric acid, and after being allowed to digest for a minute or two, a little potass or lime is added,

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* *Phil. Trans.* 1788.

† *Researches*, p. 56.

‡ *On Air*, ii. 41.

§ *On Hepatic Air*, § iii.

ammonia is immediately exhaled. The nitric acid and the water which it contains are decomposed ; the oxygen of each unites with the tin, and reduces it to the state of an oxide ; and at the same time the hydrogen of the water combines with the azot of the acid, and forms ammonia, which is driven off by the stronger affinity of the potass or lime. Dr Austin succeeded also in forming ammonia by several other methods. He introduced into a glass tube filled with mercury a little azotic gas, and then put into the gas some iron-filings moistened with water. The iron decomposes the water and combines with its oxygen ; and the hydrogen, meeting with azot at the moment of its admission, combines with it, and forms ammonia. This experiment shews, that the gaseous state of the azot does not prevent its combination with hydrogen.

Chap. II.

CHAP. II.

OF EARTHS.

THE word *earth*, in common language, has two meanings; it sometimes signifies the *globe* which we inhabit, and sometimes the *mould* on which vegetables grow. Chemists have examined this mould, and have found that it consists of a variety of substances mixed together without order or regularity. The greatest part of it, however, as well as of the stones which form apparently so large a proportion of the globe, consists of a small number of bodies, which have a variety of common properties. These bodies chemists have agreed to class together, and to denominate *earths*.

Every body which possesses the following properties is an *earth* :

Properties of earths.

1. Insoluble in water, or nearly so; or at least becoming insoluble when combined with carbonic acid.

2. Little or no taste or smell; at least when combined with carbonic acid.

3. Fixed, incombustible, and incapable while pure of being altered by the fire.

4. A specific gravity not exceeding 4.9.

5. When pure, capable of assuming the form of a white powder.

The earths at present known are ten in number; namely,

1. Barytes.
2. Strontian.
3. Lime.
4. Magnesia.
5. Alumina.
6. Yttria.
7. Glucina.
8. Zirconia.
9. Agustina.
10. Silica.

Every one of the above characteristics is not perhaps rigorously applicable to each of these bodies; but all of them possess a sufficient number of common properties to render it useful to arrange them under one class.

SECT. I.

OF BARYTES.

Discovery of barytes.

BARYTES was discovered by Scheele in 1774; and the first account of its properties published by him in his Dissertation on Manganese*. There is a very heavy mineral, most frequently of a flesh colour, of a foliated texture and brittle, very common in Britain and most other countries, especially in copper mines. It was known by the name of *ponderous spar*, and was supposed to be a compound of sulphuric acid and lime. Gahn analysed this mineral in 1775, and discovered that it is composed of sulphuric acid and the new earth discovered by Scheele†. The experiments of these chemists were confirmed by Bergman‡, who gave the earth

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* Scheele, i. 61. and 78. French Translation.

† Bergman's Notes on Scheffer, § 167.

‡ *Opusc.* iii. 291.

the name of *terra ponderosa*. Morveau gave it the name of *barote*, and Kirwan of *barytes*[*]; which last was approved of by Bergman[†], and is now universally adopted. Different processes for obtaining barytes were published by Scheele, Bergman, Wiegleb, and Afswelius; but little addition was made to the properties ascertained by the original discoverer till Dr Hope published his experiments in 1793[‡]. In 1797, our knowledge of its nature was still farther extended by the experiments of Pelletier, Fourcroy, and Vauquelin[||].

Method of procuring it.

Barytes may be obtained from ponderous spar, or *sulphat of barytes*, as it is now called, by the following process, for which we are indebted to Vauquelin. Reduce the mineral to a fine powder; mix it with the eighth part of its weight of charcoal powder, and keep it for some hours red hot in a crucible, and it will be converted into sulphuret of barytes. Dissolve the sulphuret in water, and pour nitric acid into the solution, and the sulphur will be precipitated. The solution, which consists of nitric acid combined with barytes, is to be filtered and evaporated slowly till it crystallizes. Put the crystals into a crucible, and expose it to a strong heat, the nitric acid is driven off, and the barytes remains in a state of purity.

Its properties.

Barytes thus obtained is a greyish-white, porous body, which may be very easily reduced to powder. It has a harsh and more caustic taste than lime; and when taken into the stomach, proves a most violent poison. It has no perceptible smell. It tinges vegetable blues green,

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[*] From Βαρυς, heavy.

[†] *Opus.* iv. 261.

[‡] *Edin. Trans.* iv. 36.

[||] *Ann. de Chim.* xxi. 113. and 276.

and decomposes animal bodies like the fixed alkalies, though not with such energy.

Its specific gravity, according to Fourcroy[*], is 4; but according to Hassenfratz, only 2·374[†]. But there is reason to conclude, from the method employed by this philosopher, that the specific gravities which he assigns are all too low.

When heated it becomes harder, and acquires internally a bluish-green shade. When exposed to the blowpipe on a piece of charcoal, it fuses, bubbles up, and runs into globules, which quickly penetrate the charcoal[‡]. This is probably in consequence of containing water; for Lavoisier found barytes not affected by the strongest heat which he could produce.

When exposed to the air, it immediately attracts moisture; in consequence of which it swells, heat is evolved, and the barytes falls to a white powder, just as happens to quicklime when water is sprinkled on it[§]. After the barytes is thus *slacked*, it gradually attracts carbonic acid, and loses its acrid properties. It cannot therefore be kept pure except in close vessels.

Action on water.

When a little water is poured upon barytes it is slacked like quick lime, but more rapidly, and with the evolution of more heat. The mass becomes white, and swells considerably. If the quantity of water be sufficient to dilute it completely, the barytes crystallizes in cooling, and assumes the appearance of a stone composed of needle-form crystals; but when exposed to the air it gradually attracts carbonic acid and falls to powder[||].

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[*] Fourcroy, ii. 189.

[†] *Ann. de Chim.* xxviii. 11.

[‡] Fourcroy and Vauquelin, *Ann. de Chim.* xxi. 276.

[§] Id. ibid.

[||] Fourcroy, ii. 193.

Water is capable of dissolving 0.05 parts of its weight of barytes. The solution, which is known by the name *barytic water*, is limpid and colourless, has an acrid taste, and converts vegetable blues first to a green, and then destroys them. When exposed to the air, its surface is soon covered with a stony crust, consisting of the barytes combined with carbonic acid.

Boiling water dissolves half its weight of barytes. As the solution cools, the barytes is deposited in crystals; the shape of which varies according to the rapidity with which they have been formed. When most regular, they are flat hexagonal prisms, having two broad sides, with two intervening narrow ones, and terminated at each end by a four-sided pyramid, which in some instances constitutes the larger part of the crystal. When formed slowly they are distinct and large; but when the water is saturated with barytes, they are deposited rapidly, and are generally more slender and delicate. Then, too, they are attached to one another in such a manner as to assume a beautiful foliaceous appearance, not unlike the leaf of a fern *.

These crystals are transparent and colourless, and appear to be composed of about 53 parts of water and 47 of barytes. When exposed to the heat of boiling water, they undergo the *watery fusion;* that is to say, the water which they contain becomes sufficient to keep the barytes in solution. A stronger heat makes the water fly off. When exposed to the air, they attract carbonic acid, and crumble into dust. They are soluble in 17½ parts of water at the temperature of 60°; but boiling water dissolves any quantity whatever: the reason of

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* Hope, *Edin. Trans.* iv. 36.

which is evident; at that temperature their own water of crystallization is sufficient to keep them in solution *.

Light produces no change upon barytes, nor is it capable, as far as is known, of combining with oxygen, hydrogen, azot, carbon, nor charcoal; but it unites readily with sulphur and phosphorus.

Sulphuret.

Sulphuret of barytes may be formed by mixing its two ingredients together and heating them in a crucible. The mixture melts at a red heat, and when cold forms a mass of reddish-yellow colour, without any smell, which is *sulphuret of barytes*. This sulphuret decomposes water with great rapidity, sulphurated hydrogen is formed, which, combining with the sulphuret, converts it into a hydrogenated sulphuret. This change takes place whenever the sulphuret is moistened with water, or even exposed to the atmosphere. When boiling water is poured upon sulphuret of barytes, a great quantity of sulphurated hydrogen is formed almost instantaneously, which combines with the water and occasions the solution of the sulphuret. When the solution cools, a great number of brilliant white crystals are deposited, sometimes in the form of needles, sometimes in six-sided prisms, and sometimes in hexagonal plates. These crystals are composed of sulphurated hydrogen and barytes, and have been called by Berthollet, to whom we are indebted for the first accurate account of them, *hydrosulphuret of barytes*. The liquid which has deposited the hydrosulphuret is of a yellow colour, and holds in solution a *hydrogenated sulphuret of barytes* †.

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* Hope, *Edin. Trans.* iv. 36.

† Berthollet, *Ann. de Chim.* xxv. 233.

Phosphuret.

Phosphuret of barytes may be formed by putting a mixture of phosphorus and barytes into a glass tube close at one end, and heating the mixture by putting the tube upon burning coals. The combination takes place very rapidly. This phosphuret is of a dark brown colour, very brilliant and very fusible. When moistened, it exhales the odour of phosphurated hydrogen gas. When thrown into water, it is gradually decomposed, phosphurated hydrogen gas is emitted, which takes fire when it comes to the surface of the water, and the phosphorus is gradually converted into phosphoric acid *.

Action on metallic bodies.

Barytes has no action on metals; but it is capable of combining with several of the metallic oxides, and forming with them compounds which have not hitherto been examined.

Barytes does not combine with the alkalies. Its component parts are unknown; but it resembles the alkalies in so many of its properties, that one cannot help thinking that the composition of both is analogous.

Affinities.

Its affinities, according to Bergman, observe the following order:

Sulphuric acid,
Oxalic,
Succinic,
Fluoric,
Phosphoric,
Mucous,
Nitric,
Muriatic,
Suberic,

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* Fourcroy, ii. 191.

Sebacic,
Citric,
Tartarous,
Arsenic,
Formic,
Lactic,
Benzoic,
Acetous,
Boracic,
Sulphurous,
Nitrous,
Carbonic,
Prussic,
Sulphur,
Phosphorus,
Water,
Fixed oils.

SECT. II.

OF STRONTIAN.

Discovery of strontian.

About the year 1787, a mineral was brought to Edinburgh, by a dealer in fossils, from the lead mine of Strontian, in Argyleshire, where it is found imbedded in the ore, mixed with several other substances. It is sometimes transparent and colourless, but generally has a tinge of yellow or green. Its hardness is 5. Its specific gravity varies from 3.4 to 3.726. Its texture is generally fibrous; and sometimes it is found crystallized in slender prismatic columns of various lengths*.

This mineral was generally considered as a carbonat of barytes; but Dr Crawford having observed some differences between its solution in muriatic acid and that of barytes, mentioned, in his treatise on *muriat of barytes* published in 1790, that it probably contained a new earth, and sent a specimen to Mr Kirwan that he might examine its properties. Dr Hope made a set of experiments on it in 1791, which were read to the Royal Society of Edinburgh in 1792, and published in the Transactions about the beginning of 1794. These experiments demonstrate, that the mineral is a compound of carbonic acid, and a peculiar earth, whose properties are described. To this earth Dr Hope gave the name of *strontites*. Klaproth analysed it also in 1793, and drew the same conclusions as Dr Hope, though he was ignorant of the experiments of the latter, which remained still unpublished. Klaproth's experiments were published in Crell's *Annals* for 1793† and 1794‡. Kirwan also discovered the most interesting peculiarities of this new earth in 1793, as appears by his letter to Crell, though his dissertation on it, which was read to the Irish Academy in 1794, was not published till 1795. The experiments of these philosophers were repeated and confirmed in 1797 by Pelletier, Fourcroy, and Vauquelin §, and several of the properties of the earth still farther investigated. To the earth thus detected

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* Hope, *Edin. Trans.* iv. 44.

† Vol. ii. 189.

‡ Vol. i. 99. See also Klaproth's *Beitrage*, i. 260. and *Jour. de Min.* N° v. p. 61.

§ *Ann. de Chim.* xxi. 113. and 276. *Jour. de Min.* An. vi. 3.

Klaproth gave the name of *Strontian*, from the place where it was first found; and this name is now generally adopted.

Strontian is found abundantly in different places of the world, and always combined with carbonic acid or sulphuric acid.

Method of procuring it.

The carbonic acid may be expelled from the carbonat, and the strontian obtained pure by mixing the mineral with charcoal powder, and exposing it to a heat of 140° Wedgewood [*]; or by dissolving the mineral in nitric acid, evaporating the solution till it crystallizes, and exposing the crystals in a crucible to a red heat till the nitric acid is driven off. Strontian may be obtained from the sulphat by following exactly the process described in the last Section for obtaining barytes.

Strontian, thus obtained, is in porous masses, of a greyish white colour; its taste is acrid and alkaline; and it converts vegetable blues to green. Its specific gravity, according to Hassenfratz, is 1.647 [†]. It does not act so strongly on animal bodies as barytes, nor is it poisonous [‡].

Its properties.

It does not melt when heated like barytes; but before the blow-pipe it is penetrated with light, and surrounded with a flame so white and brilliant that the eye can scarcely behold it [§].

When water is sprinkled on strontian it is slacked, becomes hot, and falls to powder exactly like barytes; but it is not so soluble in water as that earth. One hundred and sixty-two parts of water, at the temperature of 60°, dissolve nearly one part of strontian. The

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[*] Kirwan.

[†] *Ann. de Chim.* xxviii. 11.

[‡] Pelletier, Ibid. xxi. 120.

[§] Fourcroy, ii. 227.

solution, known by the name of *strontian water*, is clear and transparent, and converts vegetable blues to a green. Hot water dissolves it in much larger quantities; and as it cools the strontian is deposited in colourless transparent crystals. These are in the form of thin quadrangular plates, generally parallelograms, the largest of which seldom exceeds one-fourth of an inch in length. Sometimes their edges are plain, but they oftener consist of two facets, meeting together, and forming an angle like the roof of a house. These crystals generally adhere to each other in such a manner as to form a thin plate of an inch or more in length and half an inch in breadth. Sometimes they assume a cubic form. They contain about 68 parts in 100 of water. They are soluble in 51.4 parts of water, at the temperature of 60°. Boiling water dissolves nearly half its weight of them. When exposed to the air, they lose their water, attract carbonic acid, and fall into powder*. Their specific gravity is 1.46†.

It is not acted on by light, oxygen, hydrogen, azot, carbon, nor charcoal; but it combines readily with sulphur and phosphorus.

Sulphuret and phosphuret.

The sulphuret of strontian may be made by fusing the two ingredients in a crucible. It is soluble in water by means of sulphurated hydrogen, which is evolved. When the solution is evaporated, *hydrosulphuret of strontian* is obtained in crystals, and *hydrogenated sulphuret* remains in solution. These three compounds resemble almost exactly the sulphuret, hydrosulphuret, and hydrogenated sulphuret of barytes; and do not therefore require a particular description. The same

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* Hope, *Edin. Trans.* iv. 44.

† Hassenfratz, *Ann. de Chim.* xxviii. 11.

remark applies to the phosphuret of strontian, which may be prepared by the same process as the phosphuret of barytes*.

Strontian has no action upon metals; but it combines with several of their oxides, and forms compounds which have not hitherto been examined.

It does not combine with alkalies nor with barytes. No precipitation takes place when barytic and strontian water are mixed together †.

Tinges flame red.

Strontian has the property of tinging flame of a beautiful red, or rather purple colour; a property discovered by Dr Ash in 1787. The experiment may be made by putting a little of the salt composed of nitric acid and strontian into the wick of a lighted candle‡; or by setting fire to alcohol, holding muriat of strontian in solution. In both cases the flame is of a lively purple. In this respect it differs from barytes, which when tried in the same way is found to communicate a bluish yellow tinge to flame §.

Affinities.

The affinities of strontian, as ascertained by Dr Hope and Mr Vauquelin, are as follows:

Sulphuric acid,
Phosphoric,
Oxalic,
Tartarous,
Fluoric,
Nitric,
Muriatic,

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* Vauquelin, *Jour. de Min.* An. vi. 17.

† Morveau, *Ann de Chim.* xxxi. 251.

‡ Vauquelin, *Jour. de Min.* An. vi. 10.

§ Pelletier, *Ann. de Chim.* xxi. 137.

Succinic,
Acetous,
Arsenic,
Boracic,
Carbonic.

Barytes and strontian resemble each other in their properties as closely as potass and soda: hence, like these two alkalies, they were for some time confounded. It is in their combination with acids that the most striking differences between these two earths are to be observed.

SECT. III.

OF LIME.

Lime has been known from the earliest ages. The ancients employed it in medicine; it was the chief ingredient in their mortar; and they used it as a manure to fertilize their fields.

Method of obtaining lime.

Lime abounds in most parts of the world, or perhaps I should rather say, that there is no part of the world where it does not exist. It is found purest in limestones, and marbles, and chalk. None of these substances, however, is, strictly speaking, lime; but they are all capable of becoming lime by a well-known process, by keeping them for some time in a white heat: this process is called *the burning of lime.* The product, which in common language is denominated *quicklime,* is the substance known in chemistry by the name of *lime.*

Its properties.

Pure lime is of a white colour, moderately hard, but easily reduced to a powder.

It has a hot burning taste, and in some measure corrodes and destroys the texture of those animal bodies to which it is applied. Its specific gravity is 2.3*. It tinges vegetable blues green, and at last converts them to yellow.

It is incapable of being fused by the most violent heat that can be produced in furnaces, or even by the most powerful burning glasses.

Slacked lime

If water be poured on newly burnt lime, it swells and falls to pieces, and is soon reduced to a very fine powder. In the mean time, so much heat is produced, that part of the water flies off in vapour. If the quantity of lime slacked (as this process is termed) be great, the heat produced is sufficient to set fire to combustibles. In this manner, vessels loaded with lime have sometimes been burnt. When great quantities of lime are slacked in a dark place, not only heat, but light also is emitted, as Mr Pelletier has observed†. When slacked lime is weighed, it is found to be heavier than it was before. This additional weight is owing to the combination of part of the water with the lime; which water may be separated again by the application of a red heat; and by this process the lime becomes just what it was before being slacked ‡. Hence the reason of the heat evolved during the slacking of lime. Part of the water combines with the lime, and thus becomes solid; of course it parts with its caloric of fluidity, and probably also with a considerable quantity of caloric, which exists in water even when in the state of ice: for when

Contains water combined.

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* Kirwan's *Miner.* i. 5.

† *Jour. de Phys.* t. 22.

‡ Dr Black.

two parts of lime and one part of ice (each at 32) are mixed, they combine rapidly, and their temperature is elevated to 122° *. The elevation of temperature during the slacking of barytes and strontian is owing to the same cause.

The smell perceived during the slacking of lime is owing to a part of that earth being elevated along with the vapour of the water ; as evidently appears from this circumstance, that vegetable blues exposed to this vapour are converted to green.

Cause of the difference between limestone and lime,

Limestone and chalk, though they are capable of being converted into lime by *burning*, possess hardly any of the properties of that active substance. They are tasteless, scarcely soluble in water, and do not perceptibly act on animal bodies. Now, to what are the new properties of lime owing ? What alteration does it undergo in the fire ?

It had been long known, that limestone loses a good deal of weight by being burned or *calcined*. It was natural to suppose, therefore, that something is separated from it during calcination. Accordingly, Van Helmont, Ludovicus, and Macquer, made experiments in succession, in order to discover what that *something* is ; and they concluded from them that it is *pure water*, which the lime recovers again when exposed to the atmosphere. As the new properties of lime could hardly be ascribed to this loss, but to some other cause, Stahl's opinion, like all the other chemical theories of that wonderful man, was generally acceded to. He supposed that the new properties which lime acquired by calcination are owing entirely to the more minute division of its particles by the action of the fire. Boyle

According to Stahl;

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* Fourcroy, ii. 175.

indeed had endeavoured to prove, that these properties are owing to the *fixation of fire* in the lime: a theory which was embraced by Newton and illustrated by Hales, and which Meyer new modelled, and explained with so much ingenuity and acuteness as to draw the attention of the most distinguished chemists. But while Meyer was thus employed in Germany, Dr Black of Edinburgh published in 1756 those celebrated experiments which form so brilliant an era in the history of chemistry.

Explained by Dr Black.

He first ascertained, that the quantity of water separated from limestone during its calcination is not nearly equal to the weight which it lost. He concluded in consequence, that it must have lost something else than mere water. What this could be, he was at first at a loss to conceive; but recollecting that Dr Hales had proved, that limestone, during its solution in acids, emits a great quantity of *air*, he conjectured that *this* might probably be what it lost during calcination. He calcined it accordingly, and applied a pneumatic apparatus to receive the product. He found his conjecture verified; and that the *air* and the *water* which separated from the lime were together precisely equal to the loss of weight which it had sustained. Lime therefore owes its new properties to the loss of *air;* and limestone differs from lime merely in being combined with a certain quantity of *air:* for he found that, by restoring again the same quantity of *air* to lime, it was converted into limestone. This air, because it existed in lime in a fixed state, he called *fixed air*. It was afterwards examined by Dr Priestley and other philosophers, found to possess peculiar properties, and to be that species of gas now known by the name of *carbonic acid gas*. Lime then is a simple substance, and limestone is composed of carbonic acid and lime. Heat separates the carbonic acid, and leaves the lime in a state of purity.

When lime is exposed to the open air, it gradually attracts moisture, and falls to powder; after which it soon becomes saturated with carbonic acid, and is again converted into carbonat of lime or unburnt limestone.

Lime-water.

Water, at the common temperature of the atmosphere, dissolves about 0.002 parts of its weight. This solution is called *lime-water*. It is limpid, has an acrid taste, and changes vegetable blue colours to green. One ounce troy of lime-water contains about one grain of lime. It is usually formed by throwing a quantity of lime in powder into pure water, allowing it to remain for some time in a close vessel, and then decanting the transparent solution from the undissolved lime. When lime-water is exposed to the air, a stony crust soon forms on its surface composed of carbonat of lime; when this crust is broken it falls to the bottom and another succeeds it; and in this manner the whole of the lime is soon precipitated, by absorbing carbonic acid from the air.

If lime-water be slowly distilled in a glass retort to dryness, and then more lime-water poured in, and the distillation repeated three or four times successively, the lime, according to Trommsdorff, may be obtained in crystals.

Lime does not combine with oxygen, hydrogen, azot, carbon, nor charcoal; but it combines with sulphur and phosphorus.

Sulphuret.

Sulphuret of lime may be formed by mixing its two component parts, reduced to a powder, and heating them in a crucible. They undergo a commencement of fusion, and form an acrid reddish mass. When it is exposed to the air, or moistened with water, its colour becoming greenish-yellow, sulphurated hydrogen is formed, and the sulphuret is converted into a hydrogenated sulphuret, which exhales a very fetid odour of sulphurated hydrogen gas. This hydrogenated sulphuret may be formed also by boiling a mixture of lime and sulphur in about ten times its weight of water, or by sprinkling quicklime with sulphur and then moistening it: the heat occasioned by the slacking of the lime is sufficient to form the combination. When this hydrogenated sulphuret is exposed to the air, it imbibes oxygen, which combines at first with the hydrogen, and afterwards with the sulphur, and converts the compound into sulphat of lime *. When the solution of hydrogenated sulphuret of lime is kept in a close vessel, the sulphur gradually precipitates, and hydrosulphuret of lime remains in solution.

Hydrogenated sulphuret.

The hydrogenated sulphuret of lime has the property of dissolving charcoal by the assistance of heat, and of retaining it in solution †. It acts very powerfully upon metals and metallic oxides.

Phosphuret.

Phosphuret of lime may be formed by the following process: Put into the bottom of a glass tube, close at one end, one part of phosphorus; and, holding the tube horizontally, introduce five parts of lime in powder, so that they shall be about two inches above the phosphorus. Then place the tube horizontally among burning coals, so that the part of it which contains the lime may be made red hot, while the bottom of the tube containing the phosphorus remains cold. When the lime be-

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* Berthollet.

† Fourcroy, ii. 174.

comes red hot, raise the tube, and draw it along the coals till that part of it which contains the phosphorus is exposed to a red heat. The phosphorus is immediately volatilized, and passing through the hot lime combines with it. During the combination the mass becomes of a glowing red heat, and a quantity of phosphorated hydrogen gas is emitted, which takes fire when it comes into the air.

Phosphuret of lime has a deep brown colour, and is moulded into the shape of the tube. It has no smell, and falls to pieces in the air. It is insoluble in water; but it has the property of decomposing that liquid. Phosphorated hydrogen gas is emitted, which takes fire as soon as it comes to the surface of the water. Part of this gas combines with the phosphuret, and forms a kind of hydrogenated phosphuret. Hence it happens that if phosphuret of lime, after being kept for some time in water, be taken out and dried, it flames when muriatic acid is poured upon it, owing to the rapid emission of phosphorated hydrogen gas *.

Action on metallic bodies.

Lime facilitates the oxidation of several of the metals, and it combines with a great number of the metallic oxides, and forms salts which have not hitherto been examined, if we except the compounds which it forms with the oxides of mercury and lead, which have been described by Berthollet.

The red oxide of mercury, boiled with lime-water, is partly dissolved, and the solution yields by evaporation small transparent yellow crystals †. This compound may be called *mercuriat of lime*.

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* Fourcroy, ii. 172.

† Berthollet, *Ann. de Chim.* i. 61.

Lime-water also dissolves the red oxide of lead, and (still better) litharge. This solution, evaporated in a retort, gives very small transparent crystals, forming prismatic colours, and not more soluble in water than lime. It is decomposed by all the sulphats of alkalies, and by sulphurated hydrogen gas. The sulphuric and muriatic acids precipitate the lead. It blackens wool, the nails, the hair, white of eggs; but it does not affect the colour of silk, the skin, the yolk of egg, nor animal oil. It is the lead which is precipitated on these coloured substances in the state of oxide; for all acids can dissolve it. The simple mixture of lime and oxide of lead blackens these substances; a proof that the salt is easily formed*. This salt may be called *plumbat of lime.*

Lime does not combine with alkalies, nor with the two earths already described.

The affinities of lime are arranged by Bergman in the following order:

Affinities.

Oxalic acid,
Sulphuric,
Tartarous,
Succinic,
Phosphoric,
Mucous,
Nitric,
Muriatic,
Suberic,
Sebacic,
Fluoric,
Arsenic,
Formic,

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* Berthollet, *Ann. de Chim.* i. 52.

Lactic,
Citric,
Benzoic,
Sulphurous,
Acetous,
Boracic,
Nitrous,
Carbonic,
Prussic,
Sulphur,
Phosphorous,
Water,
Fixed oil.

Of mortar.

One of the most important uses of lime is the formation of *mortar* as a cement in building. Mortar is composed of quicklime and sand reduced to a paste with water. When dry it becomes as hard as stone, and as durable; and adhering very strongly to the surfaces of the stones which it is employed to cement, the whole wall becomes in fact nothing else than one single stone. But this effect is produced very imperfectly unless the mortar be very well prepared.

The lime ought to be pure, completely free from carbonic acid, and in the state of a very fine powder: the sand should be free from clay, and partly in the state of fine sand, partly in that of gravel: the water should be pure; and if previously saturated with lime so much the better. The best proportions, according to the experiments of Dr Higgins, are three parts of fine sand, four parts of coarser sand, one part of quicklime recently slacked, and as little water as possible.

The stony consistence which mortar acquires is owing, partly to the absorption of carbonic acid, and partly to the combination of part of the water. This last circumstance is the reason that if to common mortar one fourth part of lime, reduced to powder without being slacked, be added, the mortar when dry acquires much greater solidity than it otherwise would do. This was first proposed by Loriot*; and a number of experiments were afterwards made by Morveau†. The proportions which this philosopher found to answer best are the following.

Fine sand	0.3
Cement of well baked bricks . .	0.3
Slacked lime	0.2
Unslacked lime	0.2
	1.0

The same advantages may be attained by using as little water as possible in slacking the lime. This was first pointed out by La Faye‡.

Higgins found that the addition of burnt bones improved mortar by giving it tenacity, and rendering it less apt to crack in drying: but they ought never to exceed one fourth of the lime employed.

When a little manganese is added to mortar, it acquires the important property of hardening under water, so that it may be employed in constructing those edifices which are constantly exposed to the action of water. Limestone is found not unfrequently combined with manganese; and in that case it becomes brown by calcination, instead of white. These native limestones are employed for making *water mortar*; but good water mortar may be made by the following process, first proposed by Morveau: Mix together 4 parts of

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[*] *Jour. de Phys.* iii. 231.

[†] *Ibid.* vi. 311.

[‡] *Ibid.* ix. 437.

blue clay, 6 parts of black oxide of manganese, and 90 parts of limestone, all in powder. Calcine this mixture to expel the carbonic acid, mix it with sixty parts of sand, and form it into mortar with a sufficient quantity of water*.

The best mortar for resisting water is made by mixing with lime puzzollano, a volcanic sand brought from Italy. Morveau informs us that *basaltes*, which is very common in this country, may be substituted for puzzollano. It must be heated in a furnace, thrown while red hot into water, and then passed through a sieve to reduce it to the proper size†.

SECT. IV.

OF MAGNESIA.

Discovery of magnesia.

About the beginning of the eighteenth century, a Roman canon exposed a white powder to sale at Rome as a cure for all diseases. This powder he called *magnesia alba*. He kept the manner of preparing it a profound secret; but in 1707 Valentini informed the public that it might be obtained by calcining the lixivium which remains after the preparation of nitre‡; and two years after, Slevogt discovered that it might be precipitated by potass from the mother ley§ of

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* *Ann. de Chim.* xxxvii. 259.

† *Ibid.* p. 262.

‡ *De Magnesia Alba.*

§ *The mother ley* is the liquid that remains after as much as possible of any salt has been obtained from it. Common salt, for instance, is obnitre[*]. This powder was generally supposed to be *lime* till Frederic Hoffman observed that it formed very different combinations with other bodies[†]. But little was known concerning its nature, and it was even confounded with lime by most chemists, till Dr Black published his celebrated experiments on it in 1755. Margraff published a dissertation on it in 1759[‡], and Bergman another in 1775, in which he collected the observations of these two philosophers, and which he enriched also with many additions of his own[§]. Butini of Geneva likewise published a valuable dissertation on it in 1779.

Method of procuring it.

As magnesia has never yet been found native in a state of purity, it may be prepared in the following manner: *Sulphat of magnesia*, a salt composed of this earth and sulphuric acid, exists in sea water, and in many springs, particularly in some about Epsom, from which circumstance it was formerly called *Epsom salt*. This salt is to be dissolved in water, and half its weight of potass added. The magnesia is immediately precipitated, because potass has a stronger affinity for sulphuric acid. It is then to be washed with a sufficient quantity of water, and dried.

Its properties.

Magnesia thus obtained is a very soft white powder, which has very little taste, and is totally destitute of smell.—Its specific gravity is about 2.3[‖]. It converts delicate vegetable blues (paper, for instance, stained with the petals of the mallow) to green.

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tained by evaporating sea water. After as much salt has been extracted from a quantity of sea water as will crystallize, there is still a portion of liquid remaining. This portion is the mother ley.

[*] *Diss. de Magnesia Alba.*

[†] *Obs. Phys. Chim.* 1722. p. 115. and 194.

[‡] *Opusc.* ii. 20.

[§] *Ibid.* i. 365.

[‖] Kirwan's *Miner.* i. 8.

It is not melted by the strongest heat which it has been possible to apply; but Mr Darcet observed that, in a very high temperature, it became somewhat agglutinated. When formed into a cake with water, and then exposed to a violent heat, the water is gradually driven off, and the magnesia contracts in its dimension; at the same time, as Mr Tingry informs us, it acquires the property of shining in the dark when rubbed upon a hot iron plate.

It is almost insoluble in water; for, according to Mr Kirwan, it requires 7900 times its weight of water at the temperature of 60° to dissolve it. It is capable, however, of combining with water in a solid state, like the three earths already described; for 100 parts of magnesia, thrown into water, and then dried, are increased in weight 0.18 parts*. Even when combined with carbonic acid (for which it has a strong affinity) it is capable of absorbing and retaining $1\frac{1}{2}$ times its own weight of water, without letting go a drop; but on exposure to the air, this water evaporates, though more slowly than it would from lime.

Magnesia has never yet been obtained in a crystallized form.

When exposed to the air, it attracts carbonic acid gas and water; but exceedingly slowly. Butini left a quantity of it for two years in a porcelain cup merely covered with paper; its weight was only increased $\frac{1}{134}$ part.

Magnesia does not combine with oxygen, azot, hydrogen, carbon, nor charcoal; neither does it combine

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* Bergman, i. 371.

with phosphorus, at least no person has hitherto been able to form a phosphuret of magnesia.

There is an affinity between sulphur and magnesia. The sulphuret may be formed by exposing a mixture of two parts of magnesia and one part of sulphur to a gentle heat in a crucible. The result is a yellow powder, slightly agglutinated, which emits very little sulphurated hydrogen gas when thrown into water. A moderate heat is sufficient to drive off the sulphur[*].

It has no action upon the metals; nor does it combine, as far as is known at present, with the metallic oxides, unless some intermediate substance be present. Neither does magnesia combine with the alkalies.

Action on barytes.

There seems to be little affinity between magnesia and barytes; at least no mixture of the two earths is fusible in the strongest heat which it has been possible to apply[†]. Muriat of magnesia, indeed, and muriat of barytes, occasion a precipitate; but the nature of this precipitate has not been examined[‡].

Strontian.

Mr Kirwan has shown that there is but little affinity between strontian and magnesia. They do not melt when exposed to a strong heat, at least when the strontian exceeds or equals the lime[||].

Lime.

Equal parts of lime and magnesia, mixed together, and exposed by Lavoisier to a very violent heat. did not melt; neither did they melt when Mr Kirwan placed them in the temperature of 150° Wedgewood.—The following Table, drawn up by Mr Kirwan from his own experiments, shews the effect of heat on these two earths mixed together in different proportions.

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[*] Fourcroy, ii. 165.

[†] Lavoisier, *Mem. Par.* 1782.

[‡] Morveau, *Ann. de Chim.* xxxi. 253.

[||] *Irish Trans.* v. 246, 247.

Chap. II.

Proportions.	Heat.	Effect.
80 Lime 20 Mag.	150° Wedg.	Went through the crucible.
75 Lime 25 Mag.	160	Went through the crucible.
66 Lime 33 Mag.		Went through the crucible.
20 Lime 80 Mag.	165	Did not melt.
33 Lime 66 Mag.	138	Did not melt.
30 Lime 10 Mag.	156	Melted into a fine greenish yellow glass; but the crucible was corroded throughout.

Its affinities

The affinities of magnesia, according to Bergman, are as follows :

Oxalic acid,
Phosphoric,
Sulphuric,
Fluoric,
Sebacic,
Arsenic,
Mucous,
Succinic,
Nitric,
Muriatic,
Tartarous,
Citric,
Formic,
Lactic,
Benzoic,

Acetous,
Boracic,
Sulphurous,
Carbonic,
Prussic,
Sulphur.

Magnesia is used only in medicine. It is administered internally to remove acidity in the stomach.

SECT. V.

OF ALUMINA.

History of alumina.

ALUM is a salt which was well known to the ancients, and employed by them in dyeing, but they were ignorant of its component parts. The alchymists discovered that it is composed of sulphuric acid and an earth; but the nature of this earth was long unknown. Stahl and Neumann supposed it to be lime; but in 1727 Geoffroy junior proved this to be a mistake, and demonstrated, that the earth of alum constitutes a part of clay *. In 1754, Margraff showed that the basis of alum is an earth of a peculiar nature different from every other; an earth which is an essential ingredient in clays, and gives them their peculiar properties†. Hence this earth was called *argill;* but Morveau afterwards gave it the name of *alumina*, because it is obtained in the state of greatest purity from alum. The properties of alumina were still farther examined by Macquer in 1758 and

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* *Mem. Par.* 1727.

† *Mem. Berlin*, 1754 and 1759, Margraff, ii. 1.

1762 *, by Bergman in 1767 and 1771 †, and by Scheele in 1776 ‡; not to mention several other chemists who have contributed to the complete investigation of this earth. A very ingenious treatise on it was published by Saussure, junior, in 1801 §.

Method of obtaining it.

Alumina may be obtained by the following process: Dissolve alum in water, and add to the solution ammonia as long as any precipitate is formed. Decant off the fluid part, and wash the precipitate in a large quantity of water, and then allow it to dry. The substance thus obtained is *alumina*.

Its properties.

The earth thus obtained assumes two very different appearances according to the way in which the precipitation has been conducted. If the alum has been dissolved in as little water as possible, the alumina has the appearance of a white earth, light, friable, very spongy, and attaching itself strongly to the tongue. In this state Saussure distinguishes it by the name of *spongy alumina*.

But if the alum has been dissolved in a great quantity of water, the alumina is obtained in a brittle transparent yellow coloured mass, splitting in pieces like roll sulphur when held in the hand: its fracture is smooth and chonchoidal; it does not adhere to the tongue, and has not the common appearance of an earthy body. In this state Saussure gives it the name of *gelatinous alumina* ||.

Alumina has little taste; when pure, it has no smell; but if it contains oxide of iron, which it often does, it

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* *Mem. Paris.*

† Bergm. i. 287. and v. 71.

‡ Scheele, i. 191. French Transl.

§ *Jour. de Phys.* lii. 280.

|| *Jour. de Phys.* lii. 290.

Book II.

emits a peculiar smell when breathed upon, known by the name of *earthy smell*[*]. This smell is very perceptible in common clays. The specific gravity of alumina is 2.00 [†].

Contracts when heated.

When heat is applied to alumina it gradually loses weight, in consequence of the evaporation of a quantity of water with which, in its usual state, it is combined, at the same time its bulk is considerably diminished. The spongy alumina parts with its moisture very readily, but the gelatinous retains it very strongly. Spongy alumina, when exposed to a red heat, loses 0.58 parts of its weight; gelatinous, only 0.43: Spongy alumina loses no more than 0.58 when exposed to a heat of 130° Wedgewood: Gelatinous in the same temperature loses but 0.4825. Yet Saussure has shown that both species, after being dried in the temperature of 60°, contain equal proportions of water [‡].

Alumina undergoes a diminution of bulk proportional to the heat to which it is exposed. This contraction seems owing, in low temperatures, to the loss of moisture: but in high temperatures it must be owing to a more intimate combination of the earthy particles with each other; for it loses no perceptible weight in any temperature, however high, after being exposed to a heat of 130° Wedgewood [§].

Wedgewood's pyrometer.

Mr Wedgewood took advantage of this property of alumina, and by means of it constructed an instrument for measuring high degrees of heat. It consists of pieces of clay of a determinate size, and an apparatus for measuring their bulk with accuracy: One of these

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[*] Saussure, *Jour. de Phys.* lii. 287.

[†] Kirwan's *Miner.* i. 1.

[‡] Ibid. p. 291.

[§] Ibid.

pieces is put into the fire, and the temperature is estimated by the contraction of the piece*. The contraction of the clay-pieces is measured by means of two brass rules fixed upon a plate. The distance between which at one extremity is 0.5 inch, and at the other extremity 0.3 inch, and the rules are exactly 24.0 inches in length, and divided into 240 equal parts called degrees. These degrees commence at the widest end of the scale. The first of them indicates a red heat, or 947° Fahrenheit. The clay-pieces are small cylinders, baked in a red heat, and made so as to fit 1° of the scale. They are not composed of pure alumina, but of a fine white clay.

Unfortunately the contraction of these pieces is not always proportional to the degree of heat to which they have been exposed, nor do they correspond exactly with each other. The instrument, notwithstanding, is certainly valuable, and has contributed considerably towards the extension of our knowledge.

Action of a very violent heat.

Alumina when exposed to a very violent heat, produced by directing a stream of oxygen gas upon burning charcoal, undergoes a commencement of fusion, and is converted into a white enamel, semitransparent and excessively hard †. If we put any confidence in the calculation of Saussure, the temperature necessary for producing this effect is as high as 1575° Wedgewood ‡.

Action of water.

Alumina is scarcely soluble in water, but may be diffused through that liquid with great facility. Its affinity for water, however, is very considerable. In its usual

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* See a particular description of this thermometer in *Phil. Trans.* lxii. and lxiv.

† Morveau, *Jour. de l'Ecole Polytechnique*, I. iii. 299.

‡ *Jour. de Phys.* 1794.

state it is combined with more than its own weight of water, and we have seen with what obstinacy it retains it. Even this combination of alumina and water is capable, in its usual state of dryness, of absorbing $2\frac{1}{2}$ times its weight of water, without suffering any to drop out. It retains this water more obstinately than any of the earths hitherto described. In a freezing cold it contracts more, and parts with more of its water, than any other earth; a circumstance which is of some importance in agriculture *.

Crystallized alumina.

Alumina has no effect upon vegetable blues. It cannot be crystallized artificially; but it is found native in beautiful transparent crystals, exceedingly hard, and having a specific gravity of 4. It is distinguished in this state by the name of *sapphyr*.

Alumina, as far as is known at present, is not affected by light, oxygen, hydrogen, nor azot; neither does it combine with sulphur, phosphorus, nor with carbon. But charcoal combines with it, and forms a black compound †, which is frequently found native.

Action on oxides.

It does not combine with metals, but it has a strong affinity for metallic oxides, especially for those oxides which contain a maximum of oxygen. Some of these compounds are found native. Thus, the combination of alumina and red oxide of iron often occurs in the form of a yellow powder, which is employed as a paint, and distinguished by the name of *ochre*.

Aluminated alkali.

There is a strong affinity between fixed alkali and alumina. When heated together, they combine and form a loose mass without any transparency. Liquid fixed alkali dissolves alumina by the assistance of heat,

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[*] Kirwan's *Miner.* i. 9.

[†] Nicholson's *Journal*, ii. 101.

and retains it in solution. The alumina is precipitated again by dropping an acid into the solution. This is the method employed by chemists to procure alumina in a state of complete purity; for alumina, unless it be dissolved in alkali, almost always retains a little oxide of iron, which disguises its properties. Liquid ammonia is also capable of dissolving a very minute proportion of newly precipitated alumina.

Alumina combines with barytes and strontian,

Barytes and strontian also combine with alumina, both when heated with it in a crucible, and when boiled with it in water. The result, in the first case, is a greenish or bluish-coloured mass, cohering but imperfectly: in the second, two compounds are formed; the first, containing an excess of alumina, remains in the state of an insoluble powder; the other, containing an excess of barytes or strontian, is held in solution by the water *.

And lime.

Alumina has a strong affinity for lime, and readily enters with it into fusion. The combination may be formed also by mixing together solutions of lime and of alumina in muriatic acid. A precipitate immediately appears, and the solution becomes gelatinous †.

The effect of heat on various mixtures of lime and alumina will appear from the following Table ‡.

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* Vauquelin, *Ann. de Chim.* xxix. 270.

† Morveau, *Ann. de Chim.* xxxi. 253.

‡ Kirwan, i. 65.

Effect of heat on mixtures of lime and alumina.

Proportions.	Heat.	Effect.
75 Lime 25 Alumina	150° Wedg.	Not melted.
66 Lime 33 Alumina	150	Remained a powder.
33 Lime 66 Alumina	*	Melted.
25 Lime 75 Alumina	*	Melted.
20 Lime 80 Alumina	*	Melted.

Magnesia and alumina.

Magnesia and alumina have no action whatever on each other, even when exposed to a heat of 150° Wedgewood †.

Lime, magnesia, and alumina.

From the experiments of Achard, it appears that no mixture of lime, magnesia, and alumina, in which the lime predominates, is vitrifiable, except they be nearly in the proportions of three parts lime, two magnesia, one alumina; that no mixture in which magnesia predominates will melt in a heat below 166°; that mixtures in which the alumina exceeds are generally fusible, as will appear from the following Table ‡.

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* These three experiments were made by Ehrman: The heat was produced by directing a stream of oxygen gas on burning charcoal, and is the most intense which it has been hitherto possible to produce.

† Kirwan's *Miner.* i. 57.

‡ Ibid. p. 72.

Chap. II.

3 Alumina 2 Lime 1 Magnesia	A porcelain.
3 Alumina 1 Lime 2 Magnesia	A porcelain.
3 Alumina 1 Lime 3 Magnesia	Porous porcelain.
3 Alumina 2 Lime 3 Magnesia	Porous porcelain.
3 Alumina 2 Lime 2 Magnesia	Porcelain.

Affinities.

The affinities of alumina are as follows:

Sulphuric acid,
Nitric,
Muriatic,
Oxalic,
Arsenic,
Fluoric,
Sebacic,
Tartarous,
Succinic,
Mucous,
Citric,
Phosphoric,
Formic,
Lactic,
Benzoic,

Acetous,
Boracic,
Sulphurous,
Nitrous,
Carbonic,
Prussic.

None of the earths is of more importance to mankind than alumina; it forms the basis of china and stoneware of all kinds, and of the crucibles and pots employed in all those manufactures which require a strong heat. It is absolutely neccssary to the dyer and calico-printer, and is employed too with the greatest advantage by the fuller and cleaner of cloth.

SECT. VI.

OF YTTRIA.

History of Yttria.

SOME time before 1788, Captain Arhenius discovered in the quarry of Ytterby in Sweden a peculiar mineral different from all those described by mineralogists. Its colour is black, and its fracture exactly like that of glass. It is magnetic and soft enough to be scratched by a knife, and often even by the nail. Its specific gravity is 4.0497 *. A description of it was published by Geijer in 1788 in Crell's Annals, and by Rinman in his Miner's Lexicon. Professor Gadolin analyzed this

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* Gadolin, Crell's *Annals*, 1796. i. 313.—Vauquelin, *Ann. de Chim* xxxvi. 146.

mineral in 1794, and found it to contain a new earth; but though his analysis was published in the Stockholm Transactions for 1794, and in Crell's Annals for 1796, it was some time before it drew the attention of chemical mineralogists. The conclusions of Gadolin were confirmed by Ekeberg in 1797, who gave to the new earth the name of *yttria* *. They were still farther confirmed and extended by Vauquelin in 1800 †, and likewise by Klaproth about the same time ‡. We may therefore consider the peculiar nature of yttria as sufficiently established.

Its properties.

Hitherto yttria has only been found in the black mineral first analysed by Gadolin, and hence called *Gadolinite*. In that mineral it is combined with oxides of iron and of manganese, a little lime, and a considerable quantity of silica. When separated from these substances, it has the appearance of a fine white powder, and has neither taste nor smell. It is not melted by the application of heat. It has no action on vegetable blues: It is not soluble in water.

It is not soluble in pure alkalies; but it dissolves readily in carbonat of ammonia. It combines readily with acids, and forms with them salts which have a sweet taste, and at the same time a certain degree of austerity. Its other properties have not yet been examined.

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* Crell's *Annals*, 1799, ii. 63.

† *Ann. de Chim.* xxxvi. 143.

‡ Ibid. xxxvii. 86.

SECT. VII.

OF GLUCINA.

History of Glucina.

The beryl is a transparent stone, of a green colour, and a considerable degree of hardness, which is found crystallized in the mountains of Siberia, and in many other parts. Vauquelin analysed this mineral in 1798, at the request of Hauy, to determine whether it was formed of the same ingredients with the emerald, as Hauy had conjectured from mineralogical considerations. The result of the analysis was a confirmation of the suspicions of Hauy, and the discovery of a new earth, to which Vauquelin and his associates gave the name of *glucina**.

How obtained.

To obtain glucina pure, the beryl or hyacinth, reduced to powder, is to be fused with thrice its weight of potass. The mass is to be diluted with water, dissolved in muriatic acid, and the solution evaporated to dryness. The residuum is to be mixed with a great quantity of water, and the whole thrown on a filter. The silica, which constitutes more than half the weight of the stone, remains behind; but the glucina and the other earths, being combined with muriatic acid, remain in solution. Precipitate them by means of carbonat of potass. Wash the precipitate, and then dissolve it in sulphuric acid. Add to the solution sulphat of potass;

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* *Ann. de Chim.* xxvi. 155.

evaporate it to the proper consistency, and set it by to crystallize. Alum crystals gradually form. When as many of these as possible have been obtained, pour into the liquid carbonat of ammonia in excess, then filter, and boil the liquid for some time. A white powder gradually appears, which is *glucina*.

Its properties.

Glucina thus obtained is a soft light white powder, without either taste or smell; which has the property of adhering strongly to the tongue. It has no action on vegetable colours. It is altogether infusible by heat; neither does it harden or contract in its dimensions, as is the case with alumina.

It is insoluble in water, but forms with a small quantity of that liquid a paste which has a certain degree of ductility.

It does not combine with oxygen nor with any of the simple combustibles; but sulphurated hydrogen dissolves it, and forms with it a hydrosulphuret, similar to other hydrosulphurets in its properties [*].

Glucina is soluble in the liquid fixed alkalies, in which it agrees with alumina. It is insoluble in ammonia, but soluble in carbonat of ammonia, in which respect it agrees with yttria; but it is about five times more soluble in carbonat of ammonia than that earth.

It combines with all the acids, and forms with them sweet tasted salts [†], as is the case also with yttria.

Its other properties have not been examined.

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[*] Fourcroy, ii. 159.

[†] Hence the name *glucina* from γλυκος, *sweet*.

SECT. VIII.

OF ZIRCONIA.

History of Zirconia.

AMONG the precious stones which come from the island of Ceylon, there is one called *jargon* or *zircon*, which is possessed of the following properties.

Its colour is various; grey, greenish-white, yellowish, reddish-brown, and violet. It is often crystallized, either in right angular quadrangular prisms surmounted with pyramids, or octahedrals consisting of double quadrangular pyramids. It has generally a good deal of lustre, at least internally. It is mostly semitransparent. Its hardness is from 10 to 16: Its specific gravity from 4.416 to 4.7 *.

It loses scarcely any of its weight in a melting heat; for Klaproth, who analysed it in 1789, found that 300 grains, after remaining in it for an hour and a half, were only one-fourth of a grain lighter than at first †. Neither was it attacked either by muriatic or sulphuric acid, even when assisted by heat. At last, by calcining it with a large quantity of soda, he dissolved it in muriatic acid, and found that 100 parts of it contained 31.5 of silica, 0.5 of a mixture of nickel and iron, and 68 of a new earth, possessed of peculiar properties, which has received the name of *zirconia* from the mineral in which it was detected. Owing probably to the scarcity of the zircon, nobody attempted to repeat the analysis of Kla-

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* Kirwan's *Min.* i. 333.

† *Jour. de Phys.* xxxvi. 180.

proth, or to verify his discovery. In 1795 he published his analysis of the *hyacinth*, another mineral from the same island, in which he also detected a large proportion of zirconia, expressing his hopes that it would induce chemists to turn their attention to the subject*. This analysis induced Guyton-Morveau in 1796 to examine the hyacinths of Expailly in France. They proved similar to the hyacinths of Ceylon, and contained the proportion of zirconia indicated by Klaproth †. These experiments were soon after repeated, and the nature of the new earth still farther examined by Vauquelin ‡.

How obtained.

Zirconia has hitherto been found only in the zircon and hyacinth. It may be obtained pure by the following process: Reduce the mineral to powder, mix it with thrice its weight of potass, and fuse it in a crucible. Wash the mass in pure water till the whole of the potass be extracted; then dissolve the residuum as far as possible in diluted muriatic acid. Boil the solution to precipitate any silica which may have been dissolved; then filter, and add a quantity of potass. The zirconia precipitates in the state of a fine powder.

Its properties.

Zirconia, thus prepared, has the form of a fine white powder, which feels somewhat harsh when rubbed between the fingers. It has neither taste nor odour. It is infusible before the blow-pipe; but when heated violently in a charcoal crucible, it undergoes a kind of imperfect fusion, acquires a grey colour, and something of the appearance of porcelain. In this state it is very

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* Beitrage, i. 231.

† *Ann. de Chim.* xxi. 72.

‡ Ibid. xxii. 158. and *Jour. de Min,* An. v. 97.

Book II.

hard, its specific gravity is 4.3, and it is no longer soluble in acids.

Zirconia is insoluble in water; but it has a considerable affinity for that liquid. When dried slowly, after being precipitated from a solution, it retains about the third of its weight of water, and assumes a yellow colour, and a certain degree of transparency, which gives it a great resemblance to gum arabic *.

It does not combine with oxygen, simple combustibles, nor metals; but it has a strong affinity for several metallic oxides, especially for oxide of iron, from which it is very difficult to separate it.

It is insoluble in liquid alkalies, neither can it be fused along with them by means of heat; but it is soluble in alkaline carbonats.

Scarcely any experiments have been made to ascertain its affinity for the different earths. It is known, however, that a mixture of alumina and zirconia is capable of fusion.

Zirconia combines with all the acids, and forms salts, which have a peculiar astringent taste, and are many of them insoluble in water. The order of its affinities, as far as it has been ascertained, is as follows:

Vegetable acids,
Sulphuric,
Muriatic,
Nitric.

This earth has not hitherto been applied to any use. Its scarcity, and the difficulty of procuring it in a state of purity, exclude it at present from any chance of being employed for the purposes of domestic economy.

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* Vauquelin, *Ann. de Chim.* xxii. 158.

SECT. IX.

OF AGUSTINA.

History.

THERE is a mineral found at Georgienstadt in Saxony resembling almost exactly the beryl of Siberia, and for that reason distinguished by the name of *Saxon beryl.* Trommsdorf, who analysed this mineral in 1799, has announced, that it contains a new earth, to which he has given the name of *agustina* *. As Trommsdorf's experiments have not hitherto been repeated, the existence of this earth must still continue doubtful till the conclusions of the discoverer be confirmed by other philosophers.

The properties of agustina, according to Trommsdorf, are the following†:

Properties.

1. When pure it resembles alumina.

2. It is not more soluble, either by the dry or moist way, in fixed alkalies than in their carbonats.

3. Neither ammonia nor its carbonat have any action on it.

4. It retains carbonic acid but feebly.

5. It hardens when heated, but does not acquire any taste.

6. It is insoluble in water.

7. It combines with acids, and forms with them salts which have little or no taste. It dissolves in acids

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* Because the salts which it forms have little or no taste.

† *Ann. de Chim.* xxxiv. 133.

equally well after it has been hardened by exposure to heat as when it is newly precipitated.

8. With sulphuric acid it forms a salt which is insipid, and scarcely soluble ; but an excess of acid renders it soluble, and capable of crystallizing in stars.

9. With an excess of phosphoric acid it forms a very soluble salt.

10. With acetous acid it forms a salt scarcely soluble.

SECT. X.

OF SILICA.

History of Silica.

THERE is a very hard white stone, known by the name of *quartz*, very common in almost every part of the world. Sometimes it is transparent and crystallized, and then is called *rock crystal*. Very frequently it is in the form of sand. As this stone, and several others which resemble it, as flint, agate, calcedony, &c. have the property of melting into a glass when heated along with fixed alkali, they were classed together by mineralogists under the name of *vitrifiable stones*. Mr Pott, who first described their properties in 1746, gave them the name of *siliceous stones*, on the supposition that they were all chiefly composed of a peculiar earth called *siliceous* earth or *silica*. This earth was known to Glauber, who describes the method of obtaining it : but it was long before its properties were accurately ascertained. Geoffroy* endeavoured to prove that it might be

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* *Mem. Par.* 1746, p. 286.

converted into lime, and Pott[*] and Beaumé[†] that it might be converted into alumina; but these assertions were refuted by Cartheuser[‡], Scheele[§], and Bergman[||]. To this last chemist we are indebted for the first accurate detail of the properties of silica[¶].

Method of procuring it.

Silica may be obtained pure by the following process: Mix together, in a crucible, one part of pounded flint or quartz, and three parts of potass, and apply a heat sufficient to melt the mixture completely. Dissolve the mass formed in water, saturate the potass with muriatic acid, and evaporate to dryness. Towards the end of the evaporation the liquid assumes the form of a jelly; and when all the moisture is evaporated, a white mass remains behind. This mass is to be washed in a large quantity of water and dried; it is then silica in a state of purity.

Its properties.

Silica, thus obtained, is a fine white powder, without either taste or smell. Its particles have a harsh feel, as if they consisted of very minute grains of sand. Its specific gravity is 2.66[**].

It may be subjected to a very violent heat without undergoing any change. Lavoisier and Morveau exposed it to the action of a fire maintained by oxygen gas without any alteration[††]. Saussure indeed has succeeded in fusing, by means of the blow-pipe, a portion of it so extremely minute as scarcely to be perceptible without a glass. According to the calculation of

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[*] *Lithogn.* p. 3. Præf.

[†] *Man. de Chym.*

[‡] *Miner. Abh.*

[§] Scheele, i. 191.

[||] *Sur les Terres Geoponiques*, 1773, *Opusc.* v. 59.

[¶] *Opusc.* ii. 26.

[**] Kirwan's *Min.* i. 10.

[††] *Jour. de l'Ecole Polytechn.* I. iii. 299.

this philosopher, the temperature necessary for producing this effect is equal to 4043° Wedgewood.

It is insoluble in water except when newly precipitated, and then one part of it is soluble in 1000 parts of water [*]. It has no effect on vegetable colours.

It is capable of absorbing about one-fourth of its weight of water, without letting any drop from it; but on exposure to the air, the water evaporates very readily [†]. When precipitated from potass by means of muriatic acid and slow evaporation, it retains a considerable portion of water, and forms with it a transparent jelly; but the moisture gradually evaporates on exposure to the air.

Silica may be formed into a paste with a small quantity of water: this paste has not the smallest ductility, and when dried forms a loose, friable, and incoherent mass [‡].

Silica is capable of assuming a crystalline form. Crystals of it are found in many parts of the world. They are known by the name of *rock crystal.* When pure they are transparent and colourless like glass: they assume various forms; the most usual is a hexagonal prism, surmounted with hexagonal pyramids on one or both ends, the angles of the prism corresponding with those of the pyramids. Their hardness is very great, amounting to 11. Their specific gravity is 2.653 [§].

There are two methods of imitating these crystals by art. The first method was discovered by Bergman. He dissolved silica in fluoric acid, and allowed the solution to remain undisturbed for two years. A number

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[*] Kirwan's *Min.* i. 10.

[†] Ibid.

[‡] Scheele.

[§] Kirwan's *Min.* i. 242.

of crystals were then found at the bottom of the vessel, mostly of irregular figures, but some of them cubes with their angles truncated. They were hard, but not to be compared in this respect with rock crystal *.

The other method was discovered by accident. Professor Seigling of Erfurt had prepared a liquor silicum, which was more than usually diluted with water, and contained a superabundance of alkali. It lay undisturbed for eight years in a glass vessel, the mouth of which was only covered with paper. Happening to look to it by accident, he observed it to contain a number of crystals; on which he sent it to Mr Trommsdorf, professor of chemistry at Erfurt, who examined it. The liquor remaining amounted to about two ounces. Its surface was covered by a transparent crust, so strong that the vessel might be inverted without spilling any of the liquid. At the bottom of the vessel were a number of crystals, which proved on examination to be sulphat of potass and carbonat of potass †. The crust on the top consisted partly of carbonat of potass, partly of crystallized silica. These last crystals had assumed the form of tetrahedral pyramids in groups; they were perfectly transparent, and so hard that they struck fire with steel ‡.

Silica neither combines with oxygen, simple combustibles, nor metals; but it combines with many of the metallic oxides by fusion, and forms various coloured glasses and enamels.

Combines with fixed alkalies,

There is a strong affinity between silica and fixed al-

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* Bergman, ii. 32.

† Potass combined with sulphuric acid and carbonic acid.

‡ Nicholson's *Journal*, i. 217.

kalies. It may be combined with them either by fusing them along with it in a crucible, or by boiling the liquid alkalies over it. When the potass exceeds the silica considerably, the compound is soluble in water, and constitutes what was formerly called *liquor silicum*, and now *silicated potass* or *soda*. When the silica exceeds, the compound is transparent and colourless like rock crystal, and is neither acted on by water, air, nor, excepting one, by acids. This is the substance so well known under the name of *glass*.

Silica is not acted on by ammonia, whether in the gaseous or liquid state.

Barytes,

There is a strong affinity between barytes and silica. When barytic water is poured into silicated potass, the two earths are precipitated together in a state of combination *. They may be also combined by means of heat. The compound is of a greenish colour, and coheres but imperfectly †. The effect of heat on various mixtures of barytes and silica will appear from the following experiments of Mr Kirwan ‡.

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* Morveau, *Ann. de Chim.* xxxi. 250.

† Vauquelin, Ibid. xxix. 271.

‡ Kirwan's *Min.* i. 57.

Proportions.	Heat.	Effect.
80 Silica 20 Barytes	155° Wedg.	A white brittle mass.
75 Silica 20 Barytes	150	A brittle hard mass, semi-transparent at the edges.
66 Silica 33 Barytes	150	Melted into a hard somewhat porous porcelain mass.
50 Silica 50 Barytes	148.	A hard mass not melted.
20 Silica 80 Barytes	148	The edges were melted into a pale greenish matter between a porcelain and enamel.
25 Silica 75 Barytes	150	Melted into a somewhat porous porcelain mass.
33 Silica 66 Barytes	150	Melted into a yellowish and partly greenish white porous porcelain.

Strontian,

Strontian and alumina combine with each other nearly in the same manner.

And lime.

There is also a strong affinity between silica and lime. When lime-water is poured into silicated potass, a precipitate appears, as Stucke discovered. This precipitate is a compound of silica and lime *. These two earths may be combined also by means of heat. They form a glass, provided the quantity of lime be not inferior to that of silica. The effect of heat upon these earths,

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* Gadolin, *Ann. de Chim.* xxii. 110.—Morveau, Ibid. xxxi. 250.

Effect of heat on mixtures of lime and silica;

mixed in various proportions, will appear from the following experiments of Mr Kirwan *.

Proportions.	Heats.	Effect.
50 Lime 50 Silica	150° Wedg.	Melted into a mass of a white colour, semitransparent at the edges, and striking fire, though feebly, with steel: it was somewhat between porcelain and enamel.
80 Lime 20 Silica	156	A yellowish white loose powder.
20 Lime 80 Silica	156	Not melted, formed a brittle mass.

Magnesia and silica;

Equal parts of magnesia and silica melt with great difficulty into a white enamel when exposed to the most violent heat which can be produced †. They are infusible in inferior heats in whatever proportion they are mixed ‡.

Alumina and silica;

There is a strong affinity between alumina and silica. When equal portions of silicated and aluminated potass are mixed together, a brown zone immediately appears, which may be made, by agitation, to pass through the whole liquid. After standing about an hour, the mixture assumes the consistence of jelly §. When formed into a paste with water, and dried, they cohere, and contract a considerable degree of hardness. When baked in the temperature of 160° Wedgewood,

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* Kirwan's *Min.* i. 56.

† Lavoisier, *Mem. Par.* 1787, p. 598.

‡ Achard, *Mem. Berl.* 1780. p. 33.

§ Morveau, *Ann. de Chim.* xxxi. 249.

they become very hard, but do not fuse*. Achard found them infusible in all proportions in a heat probably little inferior to 150° Wedgewood. But when exposed to a very strong heat, they are converted into a kind of opaque glass, or rather enamel. Porcelain, stoneware, brick, tiles, and other similar substances, are composed chiefly of this compound. Mixtures of silica and alumina in various proportions constitute *clays;* but these are seldom uncontaminated with some other ingredients.

And lime, magnesia, and silica.

It follows from the experiments of Achard, that equal parts of lime, magnesia, and silica, may be melted into a greenish coloured glass, hard enough to strike fire with steel; that when the magnesia exceeds either of the other two, the mixture will not melt; that when the silica exceeds, the mixture seldom melts, only indeed with him in the following proportions; three silica, two lime, one magnesia, which formed a porcelain; and that when the lime exceeds, the mixture is generally fusible†.

A mixture of silica and alumina may also be combined with barytes or strontian by means of heat. The mixture melts readily into a greenish coloured porcelain‡.

Lime, silica, and alumina;

From the experiments of Achard and Kirwan, we learn, that, in mixtures of lime, silica, and alumina, when the lime exceeds, the mixture is generally fusible either into a glass or a porcelain, according to the proportions. The only infusible proportions were,

2	3	Lime
1	1	Silica
2	2	Alumina

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* Kirwan's *Min.* i. 58.

† *Mem. Berl.* 1780, p. 33. and *Jour. de Phys.* xxiv.

‡ Kirwan.

That if the silica exceeds, the mixture is frequently fusible into an enamel or porcelain, and perhaps a glass; and that when the alumina exceeds, a porcelain may often be attained, but not a glass*.

Magnesia, silica, and alumina;

As to mixtures of magnesia, silica, and alumina, when the magnesia exceeds, no fusion takes place at 150°. When the silica exceeds, a porcelain may often be attained; and three parts silica, two magnesia, and one alumina form a glass. When the alumina exceeds, nothing more than a porcelain can be produced†.

And lime, magnesia, silica, and alumina.

Achard found that equal parts of lime, magnesia, silica, and alumina, melted into a glass. They fused also in various other proportions, especially when the silica predominated.

Silica differs from all the other earths in not combining with any of the acids except the fluoric, phosporic, and boracic, to which also we may add the muriatic.

Silica is one of the most important of the earths. It is the chief ingredient of those stones which seem to constitute the basis of this terrestrial globe. It is an essential ingredient in mortar, in all kinds of stoneware, and in glass.

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[*] Kirwan's *Min.* i. 73.

[‡] Ibid. i. 72.

SECT. XI.

REMARKS ON ALKALIES AND EARTHS.

Fixed alkalies and earths

THE fixed alkalies and earths, taken in the order in which they have been described in the preceding Sections, constitute a regular series. The difference between the properties of potass and silica, which occupy the two extremities of this series, is very considerable; but the difference between the properties of any two contiguous bodies in the series is but small. Barytes, for instance, agrees with the fixed alkalies in so many particulars, that it might, without any impropriety, be arranged under the head of alkalies; and this has actually been done by Fourcroy. The same remark applies to strontian. These two bodies agree with lime also so nearly that they have been arranged with it by almost all chemists. Again, if we compare lime and magnesia, we shall find them to correspond in the greater number of their properties. In like manner, magnesia corresponds with alumina; and the difference between alumina, yttria, glucina, and zirconia, is but small; while the correspondence between these last earths and silica is no less striking.

Belong to one class.

Perhaps, therefore, in strict propriety, the fixed alkalies and earths ought to be comprehended together in one general class: But the division of them into alkalies and earths was made at an early period, before the properties of the bodies comprehended under them had been examined; and this division has been still retained, though it is no easy matter to say what particular bodies ought to be arranged under each of these heads. Luckily the point is not of much consequence. The common division has been followed in the two preceding chapters. But some modern chemists, especially Fourcroy, have placed barytes and strontian among the alkalies. No fault can be found with this arrangement, because the division of these bodies into earths and alkalies is perfectly arbitrary. But surely if barytes and strontian be placed among alkalies, lime ought not to be excluded; for barytes and strontian do not possess a single alkaline property of which lime is destitute. And if lime be reckoned among the alkalies, no good reason can be given why magnesia should be excluded. The truth is, that these bodies graduate into each other so nicely that they can scarcely be placed in different classes. This is a sufficient reason for preferring the common division to the new one proposed by Fourcroy.

Difference between earths and alkalies.

When only potass, soda, and ammonia, are reckoned alkalies, and all the other bodies are considered as earths, the alkalies and earths may be distinguished from each other with precision; but this cannot be done if barytes and strontian be placed among the alkalies.

The essential properties of the alkalies are the following.

1. May be volatilized.

2. Soluble in alcohol.

3. Compounds which they form with carbonic acid and with oils, soluble in water.

The essential properties of the earths are the following.

1. Perfectly fixed.

2. Insoluble in alcohol.

3. Compounds which they form with carbonic acid and with oils, insoluble in water.

Earths may be divided into *alkaline* and *proper*.

The earths may very properly be subdivided into two subordinate genera; namely, *alkaline earths* and *earths proper*. The alkaline earths are barytes, strontian, and lime. They agree with alkalies in taste, causticity, solubility in water, and in their effect on vegetable colours. The earths proper are, alumina, yttria, glucina, zirconia, and silica. They are tasteless, insoluble in water, and have no effect on vegetable colours. Magnesia is the link which unites these two genera together, partaking equally of the properties of both. Like the alkaline earths, it tinges vegetable blues green; and, like the earths proper, it is tasteless and insoluble in water. Some of the characteristic properties of the different earths are exhibited in the following TABLE.

Characteristics of the earths.

Earths.	Solubility in 1 of water.	Tinge veg. blues green.	Soluble in potass.	Sol. in carb. of ditto.	Soluble in carb. of ammonia.	Sol. in muriatic acid *.
Barytes	0.05	1				1
Strontian	0.005	2				2
Lime	0.002	3				3
Magnesia	0.000	4				4
Alumina	0 000		1			5
Yttria	0 000				1	6
Glucina	0.000		2		2	7
Zirconia	0.000			1		8
Silica	0.000		3			

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* After being precipitated.

It deserves attention, that a considerable number of these bodies may be divided into pairs, which have a striking resemblance to each other. These pairs are,

1.	Potass Soda	3.	Yttria Glucina
2.	Barytes Strontian	4.	Alumina Zirconia

But the resemblance between alumina and zirconia, which constitute the last pair, is not so close as that between the bodies which form the other pairs. Ammonia, magnesia, and silica, have none of them corresponding substances.

All the alkalies and earths combine with acids, except silica. None of them are combustible, if we except ammonia, and it is not combustible unless it be decomposed; of course none of them are capable of combining with oxygen. Neither do any of them combine with carbon, hydrogen, or azot. The alkalies and alkaline earths combine with sulphur; alkaline earths only combine with phosphorus: neither alkalies nor earths combine with metals; but they have an affinity for several of the metallic oxides.

Of their component parts.

As none of the earths have been hitherto decompounded, we must, in the present state of chemistry, consider them as simple bodies. Many attempts, indeed, have been made to shew that there was but one earth in nature, and that all others were derived from it. The earth generally made choice of as the simplest was silica*. But none of these attempts, notwithstanding the ingenuity of several of the authors, has been attended with the smallest shadow of success.

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* Mr Sage, however, pitched upon lime.

Chap. II.

Some time ago an attempt was made to prove that all the earths are metallic oxides, and that they can actually be reduced to the state of metals.

Baron had long ago suspected that alumina had somewhat of a metallic nature; and Bergman had been induced, by the great weight of barytes, and several other appearances, to conjecture that in it was a metallic oxide: But the first chemist who ventured to hint that all earths might be metallic oxides was Mr Lavoisier*. About the year 1790, soon after the publication of Mr Lavoisier's book, Mr Tondi and professor Ruprecht, both of Schemnitz, announced, that they had obtained from barytes, by the application of a strong heat, a metal of the colour of iron, and attracted by the magnet, which they called *borbonium;* from magnesia another, which they called *austrum;* a third from lime, also called *austrum;* and a fourth from alumina, which they denominated *apulum.* Their method of proceeding was to apply a violent heat to the earths, which were surrounded with charcoal in a Hessian crucible, and covered with calcined bones in powder.

But their experiments were soon after repeated by Klaproth, Savoresi, and Tihauski; and these accurate chemists soon proved, that the pretended metals were all of them *phosphurets of iron.* The iron, by the violence of the heat, had been extracted from the crucible, and the phosphorus from the bones. The earths therefore must still continue a distinct class of bodies: and, as Klaproth has observed, the properties of most of them are so exceedingly different from those of metallic oxides, that the supposition of their being composed

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* *Chemistry*, p. 217. English Transl.

Book II.

of the same ingredients is contrary to every fact, and to every analogy with which we are acquainted. Some of the earths indeed agree with metallic oxides in some of those properties which are considered as peculiarly characteristic, and seem therefore to constitute the link which unites the earths with the oxides*. This is the case in particular with yttria and zirconia. But the reason of this coincidence must remain a secret, till the component parts of the earths be ascertained. It is to be hoped that this important point will not remain much longer a desideratum in chemistry. Desormes and Morveau have announced that they have ascertained, by experiment, that potass is composed of lime and hydrogen, and soda of lime and hydrogen. From other experiments, they have been led to infer, that lime is composed of carbon, azot, and hydrogen; and magnesia of lime and azot†. But we must suspend our belief till these philosophers have published the proof which led them to draw these conclusions, and till their experiments have been confirmed by other chemists.

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[*] The properties alluded to are, forming coloured salts with acids, being precipitated by prussic alkali, and by an infusion of nut-galls.

[†] *Jour. de Phys.* lii. 55.

CHAP. III.

OF OXIDES.

Oxides explained.

All the simple combustibles, except hydrogen, are capable of combining with different proportions of oxygen. The compounds which are produced by this combination are of two kinds; some possess the properties of an acid, others not. These last have received the name of *oxides*, to distinguish them from the acids. The term *oxide* is at present applied to all combinations of bodies with oxygen, which do not possess the properties of acids. Oxides always contain less oxygen than the acids with the same base. It is remarkable enough that each of the four simple combustibles combines with three doses of oxygen. Sulphur and phosphorus form each one oxide and two acids; carbon and azot, on the contrary, form two oxides and one acid each.

As the oxides of sulphur and phosphorus do not differ remarkably from pure sulphur and phosphorus, the description of them was given while treating of these combustible bodies themselves; but the oxides of carbon, hydrogen, and azot, remain still to be examined. This shall be the business of the following Sections.

SECT. I.

OF THE OXIDES OF CARBON.

Charcoal.

CARBON and oxygen form two oxides, known by the names of *charcoal* and *gaseous oxide of carbon*. But this last might be more properly denominated *carbonic oxide*.

CHARCOAL is composed of 64.3 parts of carbon and 35.7 of oxygen. It is obtained abundantly from vegetables by a kind of imperfect combustion. But its properties have been already described in the third Section of the second Chapter of this Book.

Method of obtaining carbonic oxide.

CARBONIC OXIDE was first described by Dr Priestley[*]; but we are indebted to Mr Cruikshank[†] for ascertaining its nature and composition. It may be obtained by the following process: Mix together equal weights of charcoal-powder and black oxide of iron, previously dried as completely as possible, and expose them to a red heat in a gun-barrel or earthen-ware retort. There comes over a great quantity of gas as soon as the mixture is red hot. This gas consists of carbonic acid and carbonic oxide. The carbonic acid may be separated by causing the gas as it comes over pass through lime formed into a very thin paste with water. The carbonic acid combines with the lime; but the carbonic oxide passes through it unaltered. The oxide of zinc, or any other oxide which does not readily part with its oxygen, may be substituted for the black oxide of iron.

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[*] *On Air*, i. 297.

[†] Nicholson's *Journal*, v. 1.

Carbonic oxide gas may be procured in a state of still greater purity, by mixing together equal quantities of very dry iron-filings and pounded carbonat of lime, and exposing the mixture to a red heat. The carbonic acid which comes over towards the beginning of the process is to be separated by means of lime. The theory of this operation is obvious: The charcoal decomposes the carbonic acid of the chalk, and combines with a dose of its oxygen. The abstraction of this dose converts the carbonic acid into carbonic oxide, while the addition of it converts the charcoal also into carbonic oxide. Hence we see that charcoal has a stronger affinity for oxygen than carbonic oxide has.

Its properties and component parts.

Carbonic oxide gas thus obtained, is invisible and elastic like air. Combustible bodies do not burn in it; nor can animals breathe it without suffocation. Its specific gravity is 0.001167, or it is to air as 22 : 23. When mixed with air or oxygen gas, it does not explode, but burns with a lambent blue flame, and the product is carbonic acid. Mr Cruikshank found that 30 grains of carbonic oxide combine by combustion with about 13.6 grains of oxygen, and the carbonic acid formed amounts to about 43.6 grains. Hence it follows that carbonic oxide is composed of

69 carbonic oxide
31 oxygen

100

But 100 parts of carbonic acid are composed of 18 carbon and 82 oxygen. Consequently

Carbon. Oxygen Carbonic Oxide.
18 + 82 = 69 + 31 oxygen,

From which it follows that 69 carbonic oxide is composed of 18 carbon and 51 oxygen.

Therefore carbonic oxide contains 26 carbon
74 oxygen
———
100

Charcoal is composed of 64.3 carbon
35.7 oxygen
———
100.0

Therefore 26 parts of carbon, in order to form charcoal, must combine with 14 parts of oxygen; consequently carbonic oxide is composed of 40 charcoal
60 oxygen.
———
100

Hence it follows that carbon combined with one dose of oxygen constitutes charcoal; combined with two doses it constitutes carbonic oxide. The first dose is 0.54, the second 2.31. Therefore

Carbon.		Oxygen.		Charcoal.				
1	+	0.54	=	1.54	Oxygen.		Carbonic Oxide.	
				1.55	+	2.31	=	3.86.

Carbonic oxide was confounded with carbonated hydrogen gas, till Mr Cruickshank published his examination of it. It appears from his experiments, that it sometimes contains a little carbonated hydrogen gas mixed with it.

SECT. II.

OF WATER.

WATER is a well-known liquid, found in abundance in every part of the world, and absolutely necessary for the existence of animals and vegetables.

When pure, in which state it can be obtained only by distillation, it is transparent, and destitute of colour, taste, and smell.

Weight of water.

A cubic foot of water, at the temperature of 55°, weighs, according to the experiments of Professor Robison of Edinburgh, 998.74 avoirdupois ounces, of 437.5 grains troy each, or only 1.26 ounces less than 1000 avoirdupois ounces: so that rain water, at the same temperature, will weigh pretty nearly 1000 ounces. The specific gravity of water is always supposed = 1.000, and it is made the measure of the specific gravity of every other body.

Ice.

When water is cooled down to 32°, it assumes the form of ice. If this process goes on very slowly, the ice assumes the form of crystalline needles, crossing each other at angles either of 60° or 120°, as Mr de Mairan has remarked; and it has been often observed in large crystals of determinate figures. Ice, while kept at a temperature considerably below 32°, is very hard, and may be pounded into the finest dust. It is elastic. Its specific gravity is less than that of water.

Steam.

When water is heated to the temperature of 212°, it boils, and is gradually converted into steam. Steam is an invisible fluid like air, but of a less specific gravity. It occupies about 1200 times the space that water does. Its elasticity is so great, that it produces the most violent explosions when confined. It is upon this principle that the steam-engine has been constructed.

Boiling point of water

The phenomena of boiling are owing entirely to the rapid formation of steam at the bottom of the vessel. The boiling point of water varies according to the pressure of the atmosphere. In a vacuum water boils at 90°; and when water is confined in Papin's digester, it may be almost heated red hot without boiling. The

Book II.

Impregnated with various salts.

mixture of various salts with water affect its boiling point considerably. Mr Achard made a number of experiments on that subject; the result of which may be seen in the following Tables *.

CLASS I. *Salts which do not affect the Boiling Point.*

Sulphat of copper.

CLASS II. *Salts which raiſe the Boiling Point.*

A saturated solution of	Muriat of soda	Raises the boiling point	10.35°
	Sulphat of soda		5.6
	Sulphat of potass		0.9
	Nitrat of potass		3.5
	Boracic acid		2.2
	Carbonat of soda		2.35

This augmentation varies with the quantity of salt dissolved. In general, it is the greater the nearer the solution approaches to saturation.

CLASS III. *Salts which lower the Boiling Point.*

Borax,	In a small quantity, lowers the boiling point	1.350°
	Saturated solution of, ...	0.22
Sulphat of magnesia,	In a small quantity, . .	2.47
	Saturated solution of, .	1.1
Alum,	A very small quantity of, ...	0.0
	A greater quantity, ...	0.7
	A saturated solution of, ...	0.0
Sulphat of lime	in any proportion,	2.02
Sulphat of zinc,		0.45
Sulphat of iron,		0.22
Acetite of lead,		1.24

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* *Trans. Berlin*, 1785.

CLASS IV.

Muriat of ammonia,	Small quantity of, lowers the boiling point	0.45°
	Saturated solution of, raises do.	9.79
Carbonat of potass,	Small quantity of, lowers do.	0.45
	Saturated solution of, raises do.	11.2

Water compressible.

Water was once supposed to be incompressible; but the contrary has been demonstrated by Mr Canton. The Abbé Mongez made a number of experiments, long after that philosopher, on the same subject, and obtained similar results.

Opinion about its nature.

Water was believed by the ancients to be one of the four elements of which every other body is composed; and, according to Hippocrates, it was the substance which nourishes and supports plants and animals. That water was an unchangeable element continued to be believed till the time of Van Helmont, who made plants grow for a long time in pure water: from which experiment it was concluded, that water was convertible into all the substances found in vegetables. Mr Boyle having digested pure water in a glass vessel hermetically sealed for above a year, obtained a quantity of earthy scales; and concluded, in consequence, that he had converted it partly into earth*. He obtained the same earth by distilling water in a tall glass vessel over a slow fire†. Margraff repeated the experiment with the same result, and accordingly drew the same conclusion. But the opinion of these philosophers was never very generally received. The last person who embraced it was probably Mr Wasclton, who published his experiments on the subject in the Journal de Phy-

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* Shaw's *Boyle*, iii. 417.

† Ibid. i. 267.

sique for 1780. Mr Lavoisier had proved, as early as 1773, that the glass vessels in which the distillation was performed lost a weight exactly equal to the earth obtained. Hence it follows irresistibly, that the appearance of the earth, which was silica, proceeded from the decomposition of the vessels; for glass contains a large proportion of silica. It has been since shown by Dr Priestley, that water always decomposes glass when applied to its surface for a long time in a high temperature.

History of the discovery of its composition.

Water is now known to be an oxide of hydrogen, or a compound of oxygen and hydrogen. As this discovery has almost entirely altered the appearance of the science of chemistry, by furnishing an explanation of a vast number of phenomena which were formerly inexplicable; it will be worth while to give a particular account of the different steps which gradually led to it.

The first person probably who attempted to discover what was produced by burning hydrogen gas was Scheele. He concluded, that during the combustion oxygen and hydrogen combined, and that the product was caloric.

In 1776 Macquer, assisted by Sigaud de la Fond, set fire to a bottle full of hydrogen gas, and placed a saucer above the flame, in order to see whether any fuliginous smoke would be produced. The saucer remained perfectly clean; but it was moistened with drops of a clear liquid, which they found to be pure water *.

Next year Bucquet and Lavoisier exploded oxygen and hydrogen gas, and made an attempt to discover what was the product; about the nature of which they had formed different conjectures. Bucquet had supposed that it would be carbonic acid gas; Lavoisier, on

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* Macquer's *Dictionary*, art. *Gas, inflammable.*

the contrary, suspected that it would be sulphuric or sulphurous acid. What the product was they did not discover; but they proved that no carbonic acid gas was formed, and consequently that Mr Bucquet's hypothesis was ill founded *.

In the beginning of the year 1781, Mr Warltire, at the request of Dr Priestley, fired a mixture of these two gases contained in a copper vessel; and observed, that after the experiment the weight of the whole was diminished. Dr Priestley had previously, in the presence of Mr Warltire, performed the same experiment in a glass vessel. This vessel became moist in the inside, and was covered with a sooty substance †, which Dr Priestley afterwards supposed to be a part of the mercury used in filling the vessel ‡.

In the summer of 1781, Mr Henry Cavendish, who had been informed of the experiments of Priestley and Warltire, set fire to 500,000 grain measures of hydrogen gas, mixed with about $2\frac{1}{2}$ times that quantity of common air. By this process he obtained 135 grains of pure water. He also exploded 19,500 grain measures of oxygen gas with 37,000 of hydrogen gas, and obtained 30 grains of water, containing in it a little nitric acid. From these experiments he concluded that water is a compound.—Mr Cavendish must therefore be considered as the real discoverer of the composition of water. He was the first who ascertained that water is produced by firing oxygen and hydrogen gas, and the first who drew the proper conclusion from that fact. Mr Watt, indeed, had also drawn the proper conclu-

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* *Mem Par.* 1781, p. 470.

† Priestley, v. 395.

‡ *Phil. Trans.* lxxiv. 332.

sion from the experiments of Dr Priestley and Mr Warltire, and had even performed a number of experiments himself to ascertain the fact, before Mr Cavendish had communicated his; but he had been deterred from publishing his theory by some experiments of Dr Priestley, which appeared contrary to it *. He has therefore a claim to the merit of the discovery; a claim, however, which does not affect Mr Cavendish, who knew nothing of the theory and experiments of that ingenious philosopher.

Meanwhile, in the winter 1781-2, Mr Lavoisier, who had suspected, that when oxygen and hydrogen gas are exploded, sulphuric or sulphurous acid is produced, made an experiment in order to ascertain the fact, at which Mr Gingembre assisted. They filled a bottle, capable of holding six pints (French), with hydrogen gas, to which they set fire, and then corked the bottle, after pouring into it 2 oz. (French) of lime water. Through the cork there passed a copper tube, by means of which a stream of oxygen gas was introduced to support the flame. Though this experiment was repeated three times, and instead of lime water a weak solution of alkali and pure water were substituted, they could not observe any product whatever †. This result astonished Mr Lavoisier exceedingly: he resolved, therefore, to repeat the experiment on a larger scale, and if possible with more accuracy. By means of pipes furnished with stop-cocks, he put it in his power to supply both gases as they should be wanted, that he might be enabled to continue the burning as long as he thought proper.

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* *Phil. Trans.* lxxv. 330.

† *Mem. Paris*, 1781, p. 470.

The experiment was made by Lavoisier and La Place on the 24th of June 1783, in the presence of Messrs le Roi, Vandermonde, several other academicians, and Sir Charles Blagden, who informed them that Mr Cavendish had already performed it, and that he had obtained water *. They continued the inflammation till all their stock of gases was wasted, and obtained about 295 grains of water, which, after the most rigid examination, appeared to be perfectly pure. From this experiment Lavoisier concluded, that water is composed of oxygen and hydrogen. Mr Monge soon after performed the same experiment, and obtained a similar result: and it was repeated again by Lavoisier and Meusnier on a scale sufficiently large to put the fact beyond doubt †.

Proofs of the composition of water.

The proof that water is a compound of oxygen and hydrogen is, that when these two gases, mixed in proper proportions, are fired, they almost wholly disappear, and there is found in their place a quantity of pure water, as nearly equal to them in weight as can be expected in experiments of that delicate nature. The hydrogen gas is made to pass slowly from the glass jar in which it is contained, by means of a tube furnished with a stop-cock into a glass globe filled with oxygen gas. It is set on fire at the extremity of the tube, either by means of electricity or by a little phosphorus, and it continues to burn slowly till the whole of it is consumed New portions of oxygen gas are introduced occasionally from another glass jar, by means of a tube furnished with a stop-cock. The water, as it is formed, is condensed in the glass globe. A great num-

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* *Mem. Par.* 1781, p. 472.

† Ibid. p. 474.

Book II.

ber of precautions are necessary to ensure the purity of the gases, and to measure their weight and the nature of the gas which remains after combustion. But for these I refer to the account of the experiments themselves, which have been published by the French chemists in the Memoirs of the Academy of Sciences. The experiment on which the greatest dependence may be put was made in the year 1790 by Seguin, Fourcroy, and Vauquelin *. The weight of the gases employed in this experiment was,

	Grains Troy.
Hydrogen gas.	862.178
Oxygen gas	5296.659
Azotic gas	151.402 †
Total	6310.239

The water obtained amounted to 5943.798 grains troy, or 12 oz. 7 dwts. and 15.798 grains. It exhibited no mark of acidity, and appeared in every respect to be pure water. Its specific gravity was to that of distilled water as 18671 to 18670; or nearly as 1.000053 to 1.

The residuum of gas in the vessel after combustion amounted to 382.465 grains troy; and, on being examined, was found to consist of the following quantities of gases:

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* See *Ann. de Chim.* viii. 225.

† The presence of this gas was owing partly to the impurity of the oxygen gas employed; partly to the unavoidable admission of common air.

	Grains Troy.
Azotic gas	170.258
Carbonic acid gas	23.306
Oxygen gas	188.371
Hydrogen gas	0.530
Total	382.465

	Grains Troy.
Now the weight of the whole gases employed was	6310.239
That of the water obtained, and of the residuum	6326.263
Or	16.024

grains more than had been employed. This approaches as near an equality as can be expected in experiments of this nature. The small surplus of azotic gas found after the combustion cannot be accounted for, unless we suppose some common air to have gained admission during the process.

As sufficient precautions had been taken to prevent the introduction of carbonic acid gas, the quantity found in the residuum must have been formed during the process. There must therefore have been a small quantity of carbon introduced. Now zinc often contains carbon, and hydrogen has the property of dissolving carbon; probably, then, the carbon was introduced in this manner. The carbonic acid found in the residuum amounted to 23.306 grains, which, according to Lavoisier's calculation, is composed of 8.958 grains of carbon and 14.348 grains of oxygen.

Subtracting these 8.958 grains of carbon, and the 0.530 of a grain of hydrogen, which remained in the vessel, from the total of hydrogen introduced, there will remain 852.690 grains for the hydrogen that disappeared.

Subtracting the 14.348 grains of oxygen which entered into the composition of the carbonic acid, and the residuum of oxygen, which amounted to 188.371 grains, the quantity of oxygen that disappeared will amount to 5093.940 grains.

	Grains Troy.
Hydrogen that disappeared	852.690
Oxygen	5093.940
Total ...	5946.630
Quantity of water obtained ...	5943.798
Which is less than the gases consumed by	2.832

It is impossible to account for the exact coincidence of the water condensed with the weight of the gases consumed, unless we suppose it to be composed of these bodies.

Dr Priestley, however, who made a great many experiments on this subject, drew from them a very different conclusion; and thought he had proved, that during the combustion the two gases combine, and that the combination is nitric acid. This theory was adopted, or rather it was suggested, by Mr Keir, who has supported it with a great deal of ingenuity *.

Let us examine these experiments of Dr Priestley †, and see whether they warrant the conclusions he has drawn from them. The gases were exploded in vessels of copper. He found that the quantity of water ob-

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* Keir's *Dictionary*, art. *Nitrous Acid.*

† *Phil. Trans.* 1788.

tained was always *less* than that of the gases which he had used. He obtained also a considerable quantity of nitric acid. In the experiment made on the largest quantity of the gases, and from which he draws his conclusions, the quantity of liquid obtained amounted to 442 grains. This liquid was examined by Mr Keir. It was of a green colour; 72 grains of brown oxide of copper were deposited in it, and it contained a solution of nitrat of copper (copper combined with nitric acid). Mr Keir analysed this liquor: It consisted of pure water and nitrat of copper: and Mr Keir concluded that the nitric acid formed amounted to $\frac{1}{20}$ of the oxygen gas employed. Here then a quantity of oxygen and hydrogen gas has disappeared: What has become of them? They have combined, says Dr Priestley, and formed nitric acid. This nitric acid is only $\frac{1}{20}$ of their weight. Dr Priestley supposes, however, that it contains the whole oxygen and hydrogen that existed in these gases, and that all the rest of the weight of these gases was owing to a quantity of water which they had held in solution. Oxygen gas, then (for we shall neglect the hydrogen, which Dr Priestley was not able to bring into view at all) is composed of one part of oxygen and 19 of water. Where is the proof of this? Dr Priestley informs us, that he ascertained by experiment that half the weight of carbonic acid gas was pure water. Supposing the experiment accurate, surely it cannot be concluded from it that oxygen gas consists of $\frac{19}{20}$ parts, or almost wholly of water. It is impossible, therefore, from Dr Priestley's experiments, allowing his ingenious suppositions and conjectures their utmost force, to account for the disappearing of the two gases, or the appearance of the water, without admitting that this liquid is actually composed of oxygen and hydrogen. If we add to this, that oxygen gas can scarcely be procured absolutely free from some admixture of azot, and that his oxygen was always obtained either from red oxide of lead, or from black oxide of manganese, or red oxide of mercury, all of which substances yield a considerable proportion of azot; if we add, that it has been proved beyond the possibility of doubt, and to Dr Priestley's own satisfaction, that nitric acid is composed of oxygen and azot—we shall find it no difficult matter to explain the origin of that acid in Dr Priestley's experiments: and if we recollect that in Seguin's experiment, upon a much larger scale than Dr Priestley's, no nitric acid at all was formed, it will be impossible for us to believe that the compound formed by oxygen and hydrogen is nitric acid. Thus Dr Priestley's experiments rather confirm than destroy the theory of the composition of water. We obtain from them, however, one curious piece of information, that the presence of copper increases the quantity of nitric acid formed.

The proof for the composition of water, derived from the combustion of hydrogen gas, is rendered still stronger by reversing the experiment. When electric explosions are made to pass through water, part of it is decomposed and converted into oxygen gas and hydrogen gas. Messrs Van Troostwyk and Dieman, assisted by Mr Cuthbertson, filled a small glass tube, $\frac{1}{8}$ of an inch in diameter and 12 inches long, with distilled water. One end of this tube was sealed hermetically; but at the same time a small gold wire had been passed thro' it. Another wire passed through the open end of the tube, and could be fixed at greater or smaller distances from the first wire. By means of these wires, they made a great number of electrical explosions pass through the water. Bubbles of air appeared at every explosion, and collected at the top of the tube. When electric sparks were passed through this air, it exploded and disappeared almost completely. It must therefore have consisted of a mixture of oxygen and hydrogen gas, and this gas must have been formed by the decomposition of the water; for they had taken care to deprive the water before-hand of all its air, and they used every precaution to prevent the access of atmospherical air; and, besides, the quantity of gas produced did not diminish, but rather increase, by continuing to operate a number of times upon the same water, which could not have been the case had it been merely air dissolved in water: nor would atmospherical air have exploded and left only a very small residuum, not more than $\frac{1}{80}$ part. They had tàken care also to prove that the electric spark did not contribute to form hydrogen gas; for on passing it through sulphuric and nitric acids, the product was not hydrogen, but oxygen gas*.

These experiments have been since repeated by Dr Pearson, assisted by Mr Cuthbertson. He produced, by means of electricity, quantities of gas from water, amounting to 56.5488 cubes of $\frac{1}{10}$ of an inch each; on nitrous gas being added to which, it suffered a diminution of bulk, and nitrous acid appeared to have been formed. It must therefore have contained oxygen gas. When oxygen gas was added to the remainder, and an electric spark passed through it, a diminution took place precisely as when oxygen and hydrogen gas are

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* *Jour. de Phys.* xxxv. 369.

mixed: It must therefore have contained hydrogen. When an electric spark was passed through the gas thus produced from water, the gas disappeared, being no doubt converted into water *.

Such are the proofs by which the component parts of water have been ascertained. If we consider them attentively, and compare them with a vast number of other chemical phenomena, all of which tend to confirm and establish them, we must allow, I think, that scarcely any physical fact whatever can be produced, which is supported by more complete evidence. There are indeed some galvanic phenomena which scarcely seem compatible with it; but the nature of this singular power is still too imperfectly understood to warrant even a conjecture concerning it.

Water absorbs air

Water has the property of absorbing atmospheric air; and it always contains a portion of it when it has been exposed to the atmosphere. The greater part of this air is driven off by boiling: but, from the experiments of Dr Priestley, it appears, that the whole of it is not separated; nor can it be completely separated by any method at present known. Water owes its agreeable taste to the presence of air; hence the insipidity of boiled water.

And oxygen gas;

Water absorbs oxygen gas in preference to air, and nearly in the same proportion, as was first ascertained by Scheele.

Water is not altered by being made to pass through a red hot porcelain tube.

Its action on bodies.

It has no action on any of the simple combustibles while cold; nor does it combine with any of them. It

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* Nicholson's *Journal*, i. 242.

is not altered by sulphur nor azot, even at a red heat; but it is decomposed by charcoal at that temperature. The action of phosphorus on it in a red heat has not been tried.

Several of the metals are not altered by it; others decompose it, and are converted into oxides. But the action of metals on it has been already described.

Combination and affinity of water.

Water dissolves the alkalies and alkaline earths; the other earthy bodies are insoluble in it. It combines also with acids and with a vast number of substances: all bodies, indeed, which are soluble in water, form a chemical union with it.

Its affinity for other bodies is doubtless various, tho' we have no method of ascertaining this difference, except in those bodies which have no affinity, or but a very small affinity for each other; and it is only in a few even of these that this difference can be ascertained. Oxide of azot, for instance, separates common air from water, and sulphurated hydrogen or carbonic acid gas separates oxide of azot. Hence we see that the affinities of these bodies for water are in the following order:

Carbonic acid gas,
Sulphurated hydrogen,
Oxide of azot,
Air.

All gases in their usual state contain combined with them a quantity of water, which often amounts to a considerable proportion of their weight. Part of this water may be abstracted by exposing the gases to substances which have a strong affinity for water, as dry potass; but part adheres with a great deal of obstinacy, and perhaps cannot be removed by any method in our power.

SECT. III.

OF THE OXIDES OF AZOT.

Azot and oxygen form two different oxides, both of which were discovered by Dr Priestley. They can only be exhibited in the state of a gas: hence the first of them has been called *gaseous oxide of azot;* the second, *nitrous gas.*

I. *Oxide of Azot.*

Method of procuring oxide of azot.

Oxide of azot may be procured by the following process: Take any quantity of *nitrat of ammonia* (a salt composed of nitric acid and ammonia) in crystals, and expose it in a retort, by means of a lamp, to a heat not under 340°, nor above 500°. It melts rapidly, and is decomposed, emitting a great quantity of gas, which issues from the mouth of the retort, and may be received in glass jars in the usual manner. The gas which comes over is *oxide of azot.* This process was first pointed out by Berthollet; but it was much simplified by Mr Davy.

Its discovery.

The oxide of azot was discovered by Dr Priestley about the year 1776, and called by him *dephlogisticated nitrous gas.* The associated Dutch chemists examined it in 1793, and demonstrated it to be a compound of azot and oxygen *. But for a full investigation of its

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* *Jour. de Phys.* xlii. 323.

properties, we are indebted to Mr Davy, who published an excellent dissertation on it in the year 1800. He has given it the name of *nitrous oxide* *.

Its properties.

The oxide of azot, thus obtained, has all the mechanical properties of air: but it is much heavier than air; its specific gravity, according to Davy, being 0.00197. It is to common air nearly as 5 to 3 †.

It is capable of supporting combustion even better than common air; almost as well indeed as oxygen gas. A candle burns in it with a brilliant flame and a crackling noise. No combustible, however, burns in it, unless it be previously brought to a state of ignition.

Dr Priestley and the Dutch chemists had concluded that it cannot be respired; but they did not examine it in a state of purity ‡. Mr Davy ascertained that it may be breathed for several minutes without any bad effects. The feelings produced by breathing it bear a strong resemblance to intoxication; but they are not followed by that languor and debility which is a constant attendant of intoxication §. It cannot be brea-

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* *Researches, chiefly concerning nitrous oxide.*

† Davy's *Researches*, p. 94.

‡ Dr Priestley indeed found, in one instance, that a mouse breathed it five minutes without uneasiness. In this experiment he seems to have obtained it nearly pure.—Priestley, ii. 84.

§ Mr Davy describes the effects it had upon him as follows: "Having previously closed my nostrils and exhausted my lungs, I breathed four quarts of nitrous oxide from and into a silk bag. The first feelings were similar to those produced in the last experiment (giddiness); but in less than half a minute, the respiration being continued, they diminished gradually, and were succeeded by a sensation analagous to gentle pressure on all the muscles, attended by an highly pleasurable thrilling, particularly in the chest and the extremities. The objects around me became dazzling, and my hearing more acute. Towards the last inspirathed longer than about four minutes, without the loss of voluntary motion altogether. When animals are confined in it, they give no signs of uneasiness for some moments; but they soon become restless, and, if not removed in a very few minutes, die altogether. Hence we see that, though this gas be respirable, it is much less so than common air or oxygen gas*.

Component parts.

From the experiments of the Duch chemists, as corrected by those of Davy, it follows, that this oxide is composed of

63 azot
37 oxygen
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100

Absorbed by water.

This gaseous oxide is absorbed pretty rapidly by water, as Dr Priestley ascertained, especially when agitated. Water absorbs 0.54 parts of its bulk of this gas, or 0.27 of its weight. It acquires a sweetish taste; but its other properties do not differ perceptibly from common water. The whole of the gas is expelled unaltered by boiling the water†. When this gas combines with the water, it expels the common air which was formerly dissolved in the water. Hence the resi-

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tions, the thrilling increased, the sense of muscular power became greater, and at last an irresistible propensity to action was indulged in; I recollect but indistinctly what followed; I know that my motions were various and violent.

"These effects very soon ceased after respiration. In ten minutes I had recovered my natural state of mind. The thrilling in the extremities continued longer than the other sensations."—Davy's *Researches*, p. 457. The gas has been breathed by a very great number of persons, and almost every one has observed the same things. On some few, indeed, it has no effect whatever, and on others the effects are always painful.

* Davy's *Researches*, p. 94.

† Priestley, ii. 81.

duum of common air, which always appears when gaseous oxide of azot is exposed to a sufficient quantity of water*.

This gas is not altered by exposure to light, nor to any heat below ignition; but when made to pass thro' a red hot porcelain tube, or when electric sparks are made to traverse this gas, it is decomposed, and converted into *nitric acid* and *common air*†.

There is no action between this gas and air, or oxygen gas.

Action of combustibles on it.

Sulphur, at the common temperature of the air, is not altered by this gas. If it be introduced into it while burning with a blue flame, it is immediately extinguished; but if introduced while burning with a white flame, it continues to burn for some time with great brilliancy, and with a fine red flame. The products are sulphuric acid and azot. When about the half of the oxide of azot is decomposed, the sulphur is extinguished‡.

Phosphorus may be melted and sublimed in this gas without alteration; it may be even touched with a red hot wire without undergoing combustion; but when touched with a wire heated to whiteness, it burns, or rather detonates, with prodigious violence. The products are azotic gas, phosphoric acid, and nitric acid: a part of the oxide remains undecomposed§.

Charcoal, confined in gaseous oxide of azot, may be kindled by means of a burning-glass. It continues to burn with great brilliancy, till about the half of the gas is consumed. The products are carbonic acid gas and azotic gas ||.

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* Davy, p. 89.

† Priestley, ii. 91. and Davy, ibid. p. 279.

‡ Davy, ibid. p. 303.

§ Ibid.

|| Ibid. 311.

Hydrogen gas and oxide of azot detonate violently with a red flame, when a strong red heat is applied, or when the electric spark is made to pass through the mixture. When the proportion of hydrogen is nearly equal to that of the oxide, the products are water and azot; when the proportion of hydrogen is small, nitric acid is also formed*.

Sulphurated, phosphorated, and carbonated hydrogen gas likewise burn when mixed with oxide of azot, and exposed to a strong red heat. The products differ, according to the proportions of the gases mixed.

Iron wire burns in gaseous oxide of azot with the same brilliancy as in oxygen gas. The iron is converted into black oxide; part of the oxide of azot is decomposed, its azot is evolved, while its oxygen combines with the iron†. Zinc also may be oxidated in this gas‡. Its effect upon the other metals has not been tried.

Combines with alkalies and forms *azotites.*

Oxide of azot is capable of combining with alkalies, and forming salts of a very peculiar nature; for the discovery of which we are indebted to the sagacity of Mr Davy. No combination takes place when the alkalies are exposed to oxide of azot in the gaseous state. But if it come into contact with them at the instant of its formation, it combines with them very readily. As these combinations have not yet received a name, we may call them *azotites,* till some better appellation be thought of§.

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* Priestley, ii. 83. and Davy, p. 286.

† Priestley, ii. 86.

‡ Davy, p. 317.

§ Mr Davy has proposed to call them *nitroxis;* but this name is exceptionable, not only because it is contrary to the idiom of the English lan-

Azotite of potass may be formed by the following process: Nitrous gas (a substance which will be described immediately), by confining in it crystallized sulphite of potass*, is gradually deprived of a portion of its oxygen, and converted into oxide of azot. If very finely pulverised sulphite of potass, mixed with potass, be exposed for a great length of time in a sufficient quantity of nitrous gas, it is changed almost completely into sulphat of potass, while the oxide of azot, as it is evolved, combines with the pure potass. Consequently the salt is converted into a mixture of sulphat of potass and azotite of potass. The sulphat may be separated by solution, evaporation, and crystallization in a low temperature.

Azotite of potass is obtained in irregular crystals. It is composed of about three parts of alkali and one part of oxide of azot. It is soluble in water. Its taste is caustic, and it has a peculiar pungency. It converts vegetable blues into green. Pulverized charcoal, mixed with it, and inflamed, burns with slight scintillations. When projected into zinc in fusion, a slight inflammation takes place. All acids, even carbonic, seem capable of expelling the oxide of azot from the potass†. The other properties of this salt have not been examined.

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guage, but because the term *nitrous oxide* (from which it is derived) cannot be applied to oxide of azot without the risk of confounding it with *nitrous gas*, to which that name has been already assigned.

* Potass combined with sulphurous acid. This salt has a strong affinity for oxygen. It absorbs it from nitrous gas, and is converted into *sulphat of potass*. Hence the change of nitrous gas to gaseous oxide of azot.

† Davy, p. 262.

Azotite of soda may be formed in the same manner, and seems to agree nearly in its properties with azotite of potass. The oxide of azot is disengaged from it by a heat of between 400° and 500°. Its taste is more acrid than that of azotite of potass, and it seems to contain less oxide of azot[*].

Mr Davy did not succeed in combining oxide of azot with ammonia and earths; but he has rendered it probable that these azotites may be formed.

Much is still wanting to render the history of this singular substance complete. Mr Davy has laid open a very interesting field of investigation, which promises, if pursued far enough, to throw much light upon the nature of combustion; an operation more intimately connected with azot and its compounds than is at present supposed.

II. *Nitrous Gas.*

Method of obtaining nitrous gas.

NITROUS gas, called by the French chemists *nitrous oxide*, may be obtained by the following process: Put copper or mercury into a glass retort, and pour over it somewhat diluted nitrous acid. The metal is rapidly dissolved with a strong effervescence, and a great quantity of gas issues from the mouth of the retort, which may be received in glass jars. This gas is *nitrous gas*.

Discovery.

It was obtained accidentally by Dr Hales; but its nature and properties were investigated by Priestley, in one of the first excursions made by that illustrious philosopher into the then unbeaten tracts of pneumatic chemistry. As the phenomena exhibited by this oxide

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[*] Davy p. 268.

are intimately connected with the most important investigations in chemistry, its properties were examined with great care, and occupied the attention of almost every chemist of eminence.

Its properties.

When pure it is invisible like common air, of which it possesses the mechanical properties. Its specific gravity, according to Kirwan, is 0.001458 [*]; according to Davy, 0.001343 [†]. This last is most to be depended on, because Mr Davy's experiment was susceptible of greater precision than that of Mr Kirwan. Nitrous gas then is to common air nearly as 34 to 31.

Nitrous gas is exceedingly noxious to animals, producing instant suffocation whenever they attempt to breathe it.

Supports combustion.

The greater number of combustible bodies refuse to burn in it: A taper, for instance, is extinguished the moment it is plunged into nitrous gas; the same thing happens to sulphur, even though previously burning with a white flame. It is capable however of supporting the combustion of several bodies, as has been ascertained by the experiments of Priestley and Davy. When Homberg's pyrophorus [‡] is introduced into nitrous gas it takes fire spontaneously, just as it does in common air. Phosphorus, too, when introduced into this gas in a state of inflammation, burns with as much splendor as in oxygen gas [§].

Decomposes air.

When nitrous gas and common air are mixed together, the mixture instantly assumes a yellow colour,

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[*] *On Phlogiston*, p. 28.

[†] *Researches*, p. 6.

[‡] This substance will be described hereafter. The combustible part of it is charcoal and sulphur.

[§] Davy, p. 134.

heat is evolved, and the bulk of the two gases diminishes considerably; slowly, if the experiment be made over mercury; but rapidly, if it be made over water. When the diminution has reached its maximum, the mixture becomes perfectly transparent. The yellow colour is owing to a quantity of nitrous acid which is formed, and the diminution of bulk to the gradual absorption and condensation of this acid. What remains after this absorption is only azotic gas. The cause of this remarkable phenomenon is obvious. The nitrous gas combines with the oxygen of the air, and forms nitrous acid, which is condensed; while the azot of the air remains behind in the form of a gas. Hence with equal quantities of nitrous gas and air the diminution of bulk is always proportional to the quantity of oxygen present in the air. Hence it informs us of the proportion of that substance in any particular air. The same phenomenon takes place when oxygen gas and nitrous gas are mixed; but the condensation is much more considerable. Indeed it would be complete, provided the two gases were perfectly pure, and mixed in the proper proportions.

Its composition.

This conversion of nitrous gas into nitrous acid, by combining it with oxygen, is a demonstration that it is composed of the same ingredients with nitrous acid; that is, of azot and oxygen; but the proportion of its oxygen is much smaller. It follows from the experiments of Mr Davy* that it is composed of

45 azot
55 oxygen

100

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* *Researches*, p. 126.

Hence it contains more oxygen than oxide of azot. The quantity of oxygen in common air, oxide of azot, and nitrous gas, as far as it has been possible to estimate it, is therefore as in the following Table.

	Oxygen.
Air	0.23
Oxide of azot	0.367
Nitrous gas	0.56

Hence it follows that

Azot. Oxygen. Air.
$1 + 0.324 = 1.324$ Oxygen. Oxide of Azot.
$1.324 + 0.265 = 1.589$ Oxygen. Nitrous gas.
$1.589 + 0.459 = 2.043$

When electric sparks are made to pass through nitrous gas, it is decomposed and converted into nitrous acid and azotic gas*.

Nitrous gas is readily absorbed by water. From an experiment of Mr Davy, it appears that 100 cubic inches of water at the common temperature, and previously freed from air, absorb 11.8 cubic inches of nitrous gas, or nearly one-tenth, as Dr Priestley had ascertained. This solution has no particular taste, and does not redden blue vegetable colours. The gas is expelled again by boiling the water†; it separates likewise when the water is frozen‡.

Its action on combustibles.

Nitrous gas is decomposed by phosphorus and charcoal at a very high temperature, and probably also by sulphur. These substances are converted into acids by combining with the oxygen of the gas while its azot is evolved.

Hydrogen gas mixed with it acquires the property of

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* Priestley, ii. 22.

† Davy, p. 143.

‡ Priestley, i. 407.

burning with a green flame. A mixture of these two gases does not take fire when electric sparks are made to pass through it; but according to Fourcroy, it detonates when made to pass through a red hot porcelain tube; water is formed, and azotic gas evolved *.

Nitrous gas has no action whatever on azotic gas, even when assisted by heat.

Several of the metals have the property of decomposing it, especially when assisted by heat. This is the case particularly with iron. Dr Priestley confined a portion of nitrous gas for some time, in contact with a number of iron nails; the gas was converted into oxide of azot; in consequence, doubtless, of the iron abstracting part of its oxygen †. It was in this manner that oxide of azot was discovered by that philosopher. When the iron is heated to redness by means of a burning-glass, the decomposition is complete, the whole of the oxygen is abstracted from the nitrous gas, and only azotic gas remains behind ‡.

Absorbed by green sulphat of iron.

Dr Priestley ascertained that nitrous gas is absorbed by the green sulphat of iron; a property which is employed successfully to ascertain its purity. All that is necessary is, to expose a given portion of nitrous gas in a close vessel to the action of the green sulphat; the quantity of gas which remains unabsorbed gives the proportion of foreign bodies with which it is mixed. Mr Davy has proved, that all the salts containing the green oxide of iron possess the same property, and that they all absorb nitrous gas unaltered. The greatest part of it may even be expelled again by the application of heat. Several other metallic salts possess the same properties §.

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* Fourcroy, ii. 91. † Priestley, ii. 54. ‡ Ibid. p. 38. § Davy, p. 179.

Converted into oxide of azot.

The following bodies have the property of converting nitrous gas into gaseous oxide of azot:

- Alkaline sulphites,
- Hydrogenated sulphurets,
- Muriat of tin,
- Sulphurated hydrogen gas,
- Iron or zinc filings moistened with water.

During the action of the two last ammonia is also formed †.

Nitrous gas is absorbed by alkaline solutions; but it does not appear from the experiments hitherto made, that it is capable, like oxide of azot, of combining with alkalies and earths, and forming salts.

Metallic oxide.

Besides the oxides of the simple combustibles, there is another class, consisting of combinations of the metals with oxygen; but they have been already described under the head of the metals. The greater number of them differ from the oxides of the simple combustibles in this particular, that they cannot by combination with oxygen be converted into oxides. The greater number of the metallic oxides are unacidifiable; whereas all the oxides of the simple combustibles, except water, are acidifiable.

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† Priestley and Davy.

END OF THE FIRST VOLUME.

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Plate I. CHEMISTRY *End of Vol. I*

Fig. 1.

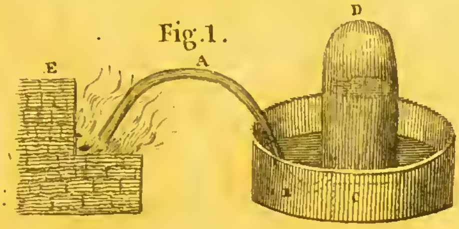
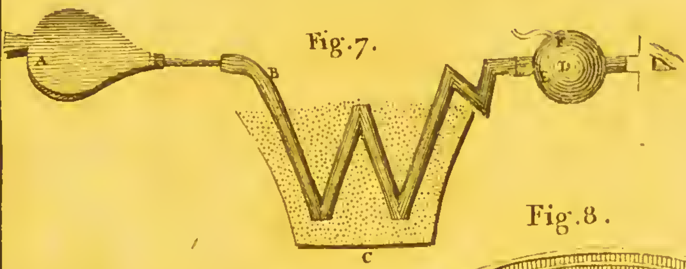


Fig. 3.

Fig. 2.

Fig. 7.



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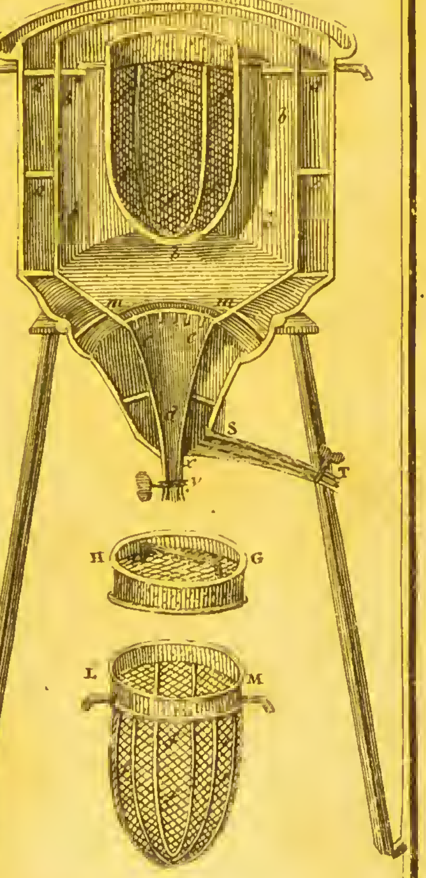

Fig. 4.

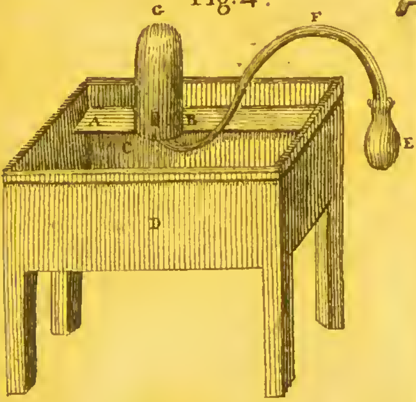

Fig. 5.

Fig. 6.

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