SYSTEM

OF

CHEMISTRY

IN FIVE VOLUMES.

By THOMAS THOMSON,

M.D. F.R.S.E.

THE FOURTH EDITION.

VOL. I.

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JOHN BARCLAY, M. D.

LECTURER ON ANATOMY.

SIR,

THE motives which induced me to prefix your name to the first Edition of this Work, still continue to operate with undiminished force. Your general knowledge, your particular views, and the intimate connection between Chemistry and that science of which you are so great a master, qualify you in a peculiar manner to judge of the merits of a Work which you originally suggested, and which you will receive as a pledge of that intimate friendship which we have so long enjoyed. I am,

DEAR SIR,

Your sincere Friend,

And humble Servant,

THE AUTHOR.

EDINBURGH,
April 20th, 1810.

PREFACE.

THE general attention which is at present paid to Chemistry in Britain cannot escape the most superficial observer. The sale of three large Editions of a Work so extensive as the present, within a year after the publication of each, is a decisive proof that the votaries of the science are numerous and daily increasing. Indeed, it possesses such attractive charms, and sheds so beneficial an influence over the arts and manufactures, that to be welcomed and cultivated it requires only to be known: and if we consider the number of eminent chemists at present in the British Empire, we cannot but indulge the most flattering hopes of the future progress of the science. Some years ago it was affirmed in a continental journal, and a chemist of eminence attached his name to the assertion, that Britain possessed scarcely a scientific chemist. The remark was prefixed to an account of a set of experiments on a subject of importance. In this account many interesting facts and observations are stated as new, though they had been almost all anticipated three years before by Dr Wollaston. The experiments of the British chemist must have been unknown to the continental philosopher, as he observes with regard to them the most profound silence; yet they had appeared in the Philosophical Transactions, the most celebrated work in England, or even in Europe.

At present it is not likely that any man, how partial soever to his own circle or his own country, would hazard the ridicule of such an assertion. We can reckon the names of not a few philosophers still worthy of the country of Bacon and of Newton, where Philosophical Chemistry first originated, who cultivate the science with assiduity and success, and who have already enriched it with the most important discoveries. Nor is it meant to depreciate the illustrious Chemists on the Continent; the science has been deeply indebted to their genius, and still requires their fostering care. Indeed, so important, so difficult, so vast, so infinite are the objects of Chemistry, that it can only be rapidly and successfully improved by the united exertions of all nations, tongues, and languages.

The object of this Work was to facilitate, as much as possible, the progress of Chemistry, by collecting into one body the numerous facts which lay scattered through a multiplicity of writings, by blending with them the history of their gradual development, and by accompanying the whole with exact references to the original works in which the discoveries have been registered. The avidity with which the work was received, and the private or public approbation of most of our most eminent Chemists, are flattering proofs that it was not considered as useless.

Several circumstances have retarded the appearance of this Edition much longer than was originally intended or expected. Meanwhile the science has been advancing in all its departments. A numerous band of philosophers are devoted to it in almost every part of

:urope; and new and important discoveries are the na- ural consequences of their enlightened exertions. No)ains have been spared by the Author to collect these mprovements as they made their appearance, and to ender this Edition as complete a register as possible f the present state of the science. Much curious ad- itional matter has been inserted in it, which was un- .nown at the publication of the last Edition. The dif- cult communication with the Continent, and the re- :nt discovery of several very important facts, have welled the Appendix to an unusual size.

IT was the intention of the Author to have collected l these alterations and improvements, and to have :inted them in a separate volume, for the sake of the ırchasers of the former Editions; but this plan has l :en abandoned with regret, as impracticable. The addi- t ons are so numerous, that, had they been thus collect- , they would have amounted to a size too nearly ap-] oaching that of the original work, and would have l en too expensive to answer the purpose of an Appen- ¢ x; nor would it have been possible, without perpe- t al repetitions, to have wrought them into any thing l :e a connected series.

MUCH pains have been taken to render every part of tl s Edition, and especially the numerous Tables which it :ontains, as correct as possible: But in a work of sı :h extent, and necessarily embracing such a vast va- ri :y of matter, errors, both from ignorance and inat- te tion, are perhaps unavoidable. The Author lay under cc siderable obligations to several of his friends, and lil :wise to different men of eminence with whom he was not personally acquainted, who took the trouble to send him lists of mistakes committed in the former Edition, and thus enabled him to correct errors which might otherwise have passed undiscovered by the Author himself. To some of the same gentlemen he is indebted for a variety of new and important chemical facts, which had not been previously published to the world.

THE last volume, in consequence of the great length of the Appendix, swelled out unexpectedly to such a size, that it was thought expedient, for the sake of uniformity in the bulk of the volumes, to place the Index at the end of the first rather than of the last volume, where it usually stands.

CONTENTS

OF

VOLUME FIRST.

SYSTEM

OF

CHEMISTRY.

Study of nature

A soon as man begins to think and to reason, the difere t objects which surround him on all sides naturally eng ge his attention. He cannot fail to be struck with thei number, diversity, and beauty; and naturally feels a d ire to be better acquainted with their properties and use. If he reflect also, that he himself is altogether depen ent upon these objects, not merely for his pleasures and omforts, but for his very existence, this desire must bec ne irresistible. Hence that curiosity, that eager thir for knowledge, which animates and distinguishes gen ous minds.

Divided into history and science.

N tural objects present themselves to our view in two diffe ent ways; for we may consider them, either as separ e individuals, or as connected together and depending pon each other. In the first case, we contemplate Nat e as in a state of rest, and consider objects merely as th y resemble one another, or as they differ from one anot er: in the second, we examine the mutual action of subs nces on each other, and the changes produced by that ction. The first of 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 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 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 are accompanied by *sensible* motions ; the second, all those which are not accompanied by *sensible* 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*; he 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 are *not* accompanied by *sensible* motions.

Its importance.

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

As a science, it is intimately connected with all the henomena of nature; the causes of rain, snow, hail, dew, wind, earthquakes, even the changes of the seasons, can ever be explored with any chance of success while we re ignorant of chemistry: and the vegetation of plants, nd some of the most important functions of animals, have ceived all their illustration from the same source. To study can give us more exalted ideas of the wisdom nd goodness of the Great First Cause than this, which hows us everywhere the most astonishing effects produced y the most simple though adequate means, and displays our view the great care which has everywhere been ken to secure the comfort and happiness of every living eature. As an art, it is intimately connected with all ur 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 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 consider-

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

The Alchymists.

a e eagerness by the Grecian ecclesiastics, to have passe from the Greeks to the Arabians, and by the Arabians t have been brought into the west of Europe. Those v o professed it gradually assumed the form of a sect, u ler the name of ALCHYMISTS; a term which is supp sed to be merely the word *chemist*, with the Arabian a icle *al* prefixed.

The alchymists laid it down as a principle, that all n tals are composed of the same ingredients, or that the s stances at least, which compose gold, exist in all meta s, contaminated indeed with various impurities, but cap le, by a proper purification, of being brought to a p fect state. The great object of their researches was to fi d out the means of producing this change, and conseq ently of converting the baser metals into gold. The s stance which possessed this wonderful property they c led *lapis philosophorum*, "the philosophers stone;" and n ny of them boasted that they were in possession of that g and instrument.

Their opinions

Chemistry, as the term was used by the alchymists, sign ied the art of making the philosophers stone. They a irmed that this art was above the reach of the human c pacity, and that it was made known by God to those l ppy sages only whom he peculiarly favoured. The f tunate few who were acquainted with the philosophers s ne called themselves *adepti*, "adepts;" that is, pers ns who had got possession of the secret. This secret t ey pretended they were not at liberty to reveal; affirmi g, that dire misfortune would fall upon that man's head o ventured to disclose it to any of the sons of men thout the clearest tokens of the divine authority.

In consequence of these notions, the alchymists made it 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 enigma which afterwards assumed a systematic form.

The alchymists seem to have been established in the west of Europe as early at least 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 precision, 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*.

And v
ting.

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 philoso-

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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*, which 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.

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.

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

phers stone; they all profess to communicate the method of making it; but their language is enigmatical, 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 the discoveries which they pretended to communicate. This laid the unwary open to the tricks of a set of impostors, who went about the world, affirming 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 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.

Universal medicine. 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 unparalleled degree of celebrity, and attracted the attention of all Europe. 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 Salzburg in the 47th year of his age.

The character of this extraordinary man is universally known. That he was an impostor, and boasted

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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.

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 the patient observers of Nature 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 thorougly 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 era 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 always distinguished by the name of the Stahlian Theory.

Its progress,

Ever since the days of Stahl, chemistry has been cultivated 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 Work, therefore, will 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 FIRST.

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.

Definition.

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.

Division.

The simple substances at present known amount to about 48, and naturally divide themselves into two classes. The bodies belonging to the first class can be confined in proper vessels, and of course exhibited in a separate state. Those which belong to the second class are of two subtile a nature to be confined by any of the vessels which we possess. They cannot, therefore, be exhibited in a separate state; and their existence is in rred merely from certain phenomena which the first cl s of bodies and their compounds exhibit in particula circumstances. Hence it is obviously necessary to be acquainted with the properties of the first set of bodi before we can investigate the second. It will be exceedingly convenient to consider these two classes sepa ately. And for want of better terms we shall distingu h the first set by the title of *confinable bodies*, the seco d by that of *unconfinable bodies* *.

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* An apology may be deemed necessary for these two words, which ha not been hitherto used by any British writer. I employ them, beca e I am acquainted with no English word that expresses the idea wh h I wish to convey; namely, that we are able to confine the first set of b dies in vessels, but that the second cannot be confined in any vessel. All the terms that have been hitherto employed to characterize the two sets of bodies convey some hypothesis or other, which in a wo of this kind it is necessary as much as possible to avoid.

DIVISION I.

OF

CONFINABLE BODIES.

Division. THE confinable bodies, amounting at present to 46, may be arranged under the following heads:

1. Simple supporters of combustion,
2. Simple combustibles,
3. Simple incombustibles,
4. Metals.

These classes of bodies shall be treated of in their order in the four following Chapters.

CHAP. I.

OF SIMPLE SUPPORTERS OF COMBUSTION.

Definition.

THE term *supporter of combustion* I apply to those su stances which must be present before combustible bo dies will burn. Thus a candle will not burn unless it e supplied with a sufficient quantity of *common air*. *C mmon air*, then, is a *supporter* of combustion. But w are acquainted with several other substances besides co mon air, which answer the same purpose, and the ter *supporter* is applied to them all. By *simple sup- po ers* we understand such of those bodies as have not hi erto been decompounded.

ne *simple supporter* only is at present known, namely, OXYGEN; so that the first of our classes includes un er it only one substance; but a substance which acts so mportant a part in the phenomena of chemistry, th it is proper to become acquainted with it as early as ossible. It will form the subject of the following Se ion.

SECT. I.

OF OXYGEN.

Oxygen may be obtained by the following process:

Method of procuring oxygen.

Procure an iron bottle of the shape A (fig. 1.), and capable of holding rather more than an English pint. To the mouth of this bottle an iron tube bent like B (fig. 2.) is to be fitted by grinding. A gun barrel deprived of its butt-end answers the purpose very well. Into the bottle put any quantity of the black oxide of manganese * in powder; fix the iron tube into its mouth, and the joining must be air-tight; then put the bottle into a common fire, and surround it on all sides with burning coals. The extremity of the tube must be plunged under the surface of the water with which the vessel C (fig. 3.) is filled. This vessel may be of wood or of japanned tin-plate. It has a wooden shelf running along two of its sides, about three inches below the top, and an inch under the surface of the water. In one part of this shelf there is a slit, into which the extremity of the iron tube plunges. The heat of the fire expels the greatest part of the air contained in the bottle. It may be perceived bubbling up through

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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, from whom it may be easily procured.

Chap. I.

the water of the vessel C from the extremity of the iron tube. At first the air bubbles come over in torrents; but after having continued for some time they cease altogether. Meanwhile the bottle is becoming gradually hotter. When it is obscurely red the air-bubbles make their appearance again, and become more abundant as the heat increases. This is the signal for placing the glass jar D, open at the lower extremity, previously filled with water, so as to be exactly over the open end of the gun-barrel. The air bubbles ascend to the top of the glass jar D, and gradually displace 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 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. 4.) Another jar may then be filled with air in the same manner; and this process may be continued either till the manganese 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. All the airs obtained by this or any other process, or, to speak more properly, all the airs differing in their properties from the air of the atmosphere, have, in order to distinguish

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* For a more exact description of this and similar apparatus, the reader is referred to Lavoisier's *Elements of Chemistry*, and Priestley *on Airs*, and above all to Mr Watt's description of a *pneumatic apparatus* in Beddoes' *Considerations on Factitious Airs*.

Book I.
Division I.

them from it, been called *gases*; and this name we shall afterwards employ *.

Oxygen gas may be obtained likewise by the following process:

Another method.

D (in fig. 5.) 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 *pneumatico-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

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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. Macquer seems to have introduced the word into the language of modern chemistry.

e glass tube F, so closely that no air can escape except
rough the tube. This may be done either by grind-
g, or by covering the joining with a little glazier's
utty, and then laying over it slips of bladder or linen
ipped in glue or in a mixture of the white of eggs and
uicklime. The whole must be made fast with cord*.
he end of the tube F is then to be plunged into the
neumatic apparatus D, and the jar G, previously filled
ith water, to be placed over it on the shelf. The
hole apparatus being fixed in that situation, the glass
essel E is to be heated by means of a lamp or a candle.
quantity of oxygen gas rushes along the tube F, and
ills the jar G. As soon as the jar is filled, it may be
lid to another part of the shelf, and other jars substi-
uted in its place, till as much gas has been obtained as
s wanted. The last of these methods of obtaining
xygen gas was discovered by Scheele†, the first by
r Priestley‡.

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[*] This process, by which the joinings of vessels are made air-tight, is called *luting*, and the substances 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 linseed oil. Bees wax, melted with about one-eighth part of turpentine, 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 *Air and Fire*, p. 43. Engl. Trans.

[‡] Priestley *on Air*, ii. 154.

Discovered by Priestley and Scheele.

The gas which we have obtained by the above processes was discovered by Dr Priestley on the 1st of August 1774, and called by him *dephlogisticated air*. Mr Scheele of Sweden discovered it before 1777, 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.

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 phial filled with oxygen gas, it burns with such splendour 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 cannot live without air, and by Mayow that they cannot breathe the same air for any length of time without suffocation. Dr Priestley and several other philosophers have shown 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.

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[*] Scheele *on Air and Fire*, p. 34. Engl. Trans.

	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 repeat-d 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

Ie then put in two together; the one died in 20 mi-iutes, but the other lived an hour longer.

4. It has been ascertained by experiments, which hall be afterwards related, that atmospherical air conains 21 parts in the hundred (in bulk) of oxygen gas; nd that no substance will burn in common air previusly deprived of all the oxygen gas which it contains. 3ut combustibles burn with great splendour in oxygen ;as, or in other gases to which oxygen gas has been dded. Oxygen gas, then, is absolutely necessary for ombustion.

Exists in the atmosphere.

5. It has been proved also, by many experiments,

Book I. Division I.

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. Oxygen gas is somewhat heavier than common air. If the specific gravity of common air be reckoned 1·000, that of oxygen gas, as determined by Mr Kirwan, is 1·103*. With this result the statement of Lavosier † agrees exactly. But Mr Davy found it a little heavier; and Fourcroy, Vauquelin, and Seguin, found it a little lighter. Its specific gravity, according to Mr Davy's experiments, is 1·127‡; according

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* *On Phlogiston*, p. 25.

† *Elements*, Appendix. See also Kirwan *on phlogiston*, p. 37. of Nicholson's translation

‡ Davy's *Researches*, p. 8. Mr Davy's oxygen gas was procured from oxide of manganese. It is possible that it contained a little *carbonic acid gas*. The tests used would not have excluded that body. This would explain its greater specific gravity.

to the French chemists, 1·087*. At the temperature of 60°, and when the barometer stands at 30 inches, 100 cubic inches of common air weigh very nearly 31 grains†. 100 inches of oxygen gas, at the same temperature and pressure, weigh, according to Kirwan and Lavoisier, 34 grains; according to Mr Davy, 34·74 grains; and according to Fourcroy, Vauquelin, and Seguin, 33·69 grains.

Combination with water.

8. Oxygen gas is not *sensibly* absorbed by water, though jarfuls of it be left in contact with that liquid. It has been ascertained, however, that water does in reality absorb a small portion of it, though not enough to occasion any perceptible diminution in the bulk of the gas. When water is freed from all air by boiling, and the action of the air pump, Dr Henry ascertained, that 100 cubic inches of it will imbibe 3·55 inches of oxygen gas‡. By forcing oxygen gas into a bottle of water by means of strong pressure, the water may be made to absorb about half its bulk of that gas, and to retain it in solution. This experiment was first made by Mr Paul, a celebrated preparer of mineral waters, now settled in London. Water thus impregnated does not sensibly differ from common water either in taste or smell, yet it has been found a valuable remedy in several diseases§.

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[*] *Ann. de Chim.* ix. 34.

[†] Sir John Shuckburgh Evelyn, as quoted by Kirwan *on phlogiston*, p. 23.

[‡] *Phil. Trans.* 1803, p. 174.

[§] See Dr Odier's observations on it in the 8th and 10th vols of the *Bibliotheque Britannique;* and the Appendix to Mr Paul's little publication on his *Artificial Mineral Waters*.

Affinity explained.

9. Oxygen is capable of combining with a great number of bodies, and of forming compounds. As the combination of substances with each other is of the utmost importance in chemistry, before we proceed 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

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

Chap. I.

this last term is now employed in preference, because the other two are rather general. All substances which 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 it is said that 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 was universally adopted, and has contributed very much to the rapid progress of chemistry.

We shall see as we proceed the order which substances follow in their affinity for oxygen.

CHAP. II.

OF 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 four in number; namely, **Hydrogen**, **Carbon**, **Phosphorus**, and **Sulphur**. The metals might indeed be classed among combustible bodies; but the greater number of their properties are so different from those of the four 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.

Number.

SECT. I.

OF HYDROGEN.

HYDROGEN, the first of the simple combustibles, may be procured by the following process.

How procured.

Into a retort having an opening at A* (fig. 7.), put one part of iron filings; then shut the opening A with a cork, through which a hole has been previously drilled by means of a round file, and the bent funnel B passed through it. Care must be taken that the funnel and cork fit the retort so as to be air-tight. Plunge the beak of the retort C under water; then pour through the bent funnel two parts of sulphuric acid previously diluted with four times its bulk of water. Immediately the mixture begins to boil or *effervesce* with violence, and air-bubbles rush abundantly from the beak of the retort. Allow them to escape for a little, till you suppose that the common air which previously filled the retort has been displaced by the newly generated air. Then place an inverted jar on the pneumatic shelf over the beak of the retort. The bubbles rise in abundance and soon fill the jar. The gass obtained by this process is called *hydrogen gas*. It was formerly called *inflammable air*, and by some chemists *phlogiston*.

It may be procured also in great abundance and purity, by causing the steam of water to pass through a

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* Such retorts are called *tubulated* by chemists.

red hot iron tube. This gas being sometimes emitted in considerable quantities from the surface of the earth in mines, had occasionally attracted the notice of observers*, and indeed was the dread of miners under the name of *fire damp*. Mayow†, Boyle‡, and Hales, procured it in considerable quantities, and noted a few of its mechanical properties. Its combustibility was known about the beginning of the 18th century, and was often exhibited as a curiosity§. 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.

Discovery.

Its properties.

1. Hydrogen gas, like *air*, is invisible and elastic, and capable of indefinite compression and dilatation. When prepared by the first process it has a disagreeable smell, similar to the odour evolved when two flint stones are rubbed against each other. This smell must be ascribed to some foreign body held in solution by the gas; for the hydrogen procured by passing steam through red hot iron tubes has no smell.

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* See an instance related in *Phil. Trans.* Abr. i. 169.

† *Tractatus quinque*, p. 163.

‡ Shaw's *Boyle*, iii. 21.

§ Cramer's *Elementa Docimasiæ*, i. 45. This book was published in 1739.—Wasserberg relates a story of an accidental explosion which terrified Professor Jacquin's operator. Wasserberg's *Institutiones Chemiæ*, i. 184.

|| *Phil. Trans.* 1766, vol. lvi p. 141.

Weight.

2. It is the lightest gaseous body with which we are acquainted. If the specific gravity of common air be reckoned 1·000, the specific gravity of hydrogen gas, as determined by Mr Kirwan, will be 0.0843 *. Mr Lavoisier states it as only 0·0756 †, while Messrs Fourcroy, Vauquelin, and Seguin ‡, make it 0.0887. Mr Kirwan's estimate appears to me the most correct. At the temperature of 60°, while the barometer stands at 30 inches, 100 cubic inches of hydrogen gas weigh, according to Kirwan, 2·613 grains troy; according to Lavoisier, 2·372 grains; and according to Fourcroy, Vauquelin, and Seguin, 2·75 grains. It is very nearly 12 times lighter than common air.

Action on combustibles.

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

On animals.

4. When animals are obliged to breathe it, they soon die. A mouse put into a jar of it by Dr Gilby of Birmingham lived 30 seconds without inconvenience; but in 1 minute 33 seconds it was dead. Dr Beddoes kept a rabbit in it 7 minutes; it was much distressed and weakened, but recovered §. Scheele found that he could make 20 inspirations of it without much inconvenience ||; but Fontana, who repeated the experiment, affirmed that this was owing to the quantity of common air contained in the lungs when he began to breathe; for on expiring as strongly as possible before

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* On *Phlogiston*, p. 26.

† *Elements*. Appendix.

‡ *Ann. de Chim.* ix. 294.

§ Beddoes *on Factitious Airs*, p. 31, 32.

|| Scheele *on Air and Fire*, p. 60.

Book I. Division I.

drawing in the hydrogen gas, he could only make three respirations, and even these three produced extreme feebleness and oppression about the breast*. The assertion of Scheele was fully verified by Pilatre de Rozier† and Mr Watt‡.

The ingenious Mr Davy, professor of chemistry in the Royal Institution, 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.

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[*] *Jour. de Phys.* xv. 99.

[†] He breathed hydrogen gas six or seven times from a bladder without inconvenience. To demonstrate that it was really hydrogen gas which he was breathing, he made a strong inspiration, and expired the air slowly through a long tube. On bringing a lighted taper to the end of the tube, the gas took fire, and continued to burn for some time. It was objected to him, that the gas which he breathed was diluted with common air. To show that this was not the case, he mixed together one part of common air and nine parts of hydrogen gas; and having drawn the mixture into his lungs, he threw it out the same way. On applying a taper to the tube, the whole of the gas exploded in his mouth, and almost stunned him. At first he thought that the whole of his teeth had been driven out; but fortunately he received no injury whatever. See *Jour. de Phys.* xxviii. 425.

[‡] Beddoes *on the Use and Production of Factitious Airs*, p. 110.

[§] Davy's *Researches*, p. 400.

[‖] Ibid. p. 466.

Combustible.

5. 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 yellowish white colour; but if the gas hold 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 †. A red hot iron likewise sets fire to hydrogen gas. From my experiments it follows, that the temperature at which the gas takes fire is about 1000°.

Explodes with oxygen gas, and forms water.

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 be 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 2·05 parts 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. This important experiment was made by Scheele §; but for want of a proper apparatus he was not able to draw the proper consequences. Mr Cavendish made the experiment in dry glass vessels with all that precision

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† Hydrogen always holds in solution a certain portion of the metal by means of which it was produced. This affects the colour of its flame very much at first; but when the gas is kept, most of the metallic matter is deposited.

‡ *Ann. de Chim.* ix. 41.

§ Scheele *on Air and Fire*, p. 57.; and Crell's *Annals*, iii. 101. Eng. Trans.

Book I.
Division I.

and sagacity which characterise his philosophical labours, and ascertained, that after the combustion there was always deposited a quantity of water equal in weight to the two gases which disappeared. Hence he concluded that the two gases had combined and formed this water. This inference was amply confirmed by the subsequent experiments of Lavoisier and his friends*. Water, then, is a compound of oxygen and hydrogen, united in the proportion of $85\frac{2}{3}$ parts by weight of oxygen, and $14\frac{1}{3}$ of hydrogen†.

When 4 measures of hydrogen gas are mixed with 10 measures of common air, the mixture detonates with equal violence; and if the experiment be made in glass tubes, 8 measures only will remain after the combustion. 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 hydrogen gas to be examined are mixed in 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 four parts of hydrogen gas and ten parts

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* The history of this great discovery, and the objections which have been made to it, will be given in the Section which treats of Water, where they will be better understood than they can be at present. It ought never to be forgotten, that Newton had long before, with a sagacity almost greater than human, conjectured, from the great refracting power of water, that it *contains a combustible substance.*

† Fourcroy, Vauquelin, and Seguin, *Ann. de Chim.* ix. 45.

of air is diminished after the explosion to eight parts, the hydrogen gas may be considered as pure; if only to nine, 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[*]. The glass tube used for similar experiments is usually called by foreign chemists *Volta's eudiometer*.

Not altered by water.

6. 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 shown, that it undergoes no change, provided sufficient care be taken to exclude every other gas.

Nor absorbed.

7. Hydrogen gas is not sensibly absorbed by water, though left for some time in contact with it. When water is previously deprived of all its air by boiling, 100 cubic inches of it imbibe 1·53 inches of hydrogen gas at the temperature of 60°[||]. By artificial pressure, water may be made to absorb about the third part of its bulk of that gas. The taste of the water is not sensibly altered. Mr Paul, who first formed this compound, informs us, that it is useful in inflammatory fevers and in nervous complaints; but it is injurious in dropsy[¶].

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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.

[||] Henry, *Phil. Trans.* 1803, p. 274.

[¶] *Phil. Mag.* xv. 93.

Such are the properties of hydrogen gas; one of the most remarkable and best known of the simple bodies, though its discovery cannot be dated farther back than 40 years.

SECT. II.

OF CARBON AND THE 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 nearly the same from whatever wood it has been obtained, provided it be exposed for an hour in a covered crucible to the heat of a forge[†].

Its properties.

1. Charcoal is insoluble in water. It is not affected (provided that all air and moisture be excluded) by the most violent heat which can be applied, excepting only that it is rendered much harder and more brilliant[‡].

It is an excellent conductor of electricity, and possesses besides a number of singular properties, which render it of considerable importance. It is much less

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[†] Unless that precaution be attended to, the properties of charcoal differ considerably.

[‡] This property was well known to the older chemists. See Hoffmann's *Observationes Physico-Chymicæ Selectiores*, p. 298.

liable to putrefy or rot than wood, and is not therefore so apt 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 putrefy, it takes away the 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[*].

2. New-made charcoal absorbs moisture with avidity. Messrs Allen and Pepys found, that when left for a day in the open air, it increased in weight about 12½ *per cent*. The greatest part of this increase was owing to moisture which it emitted again copiously when exposed under mercury to the heat of 214°[†].

Absorbs water, air, and oxygen.

3. 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 the air was disengaged. This air, on being examined, was found to contain a much smaller quantity of oxygen than atmospherical air does. He

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[*] See upon the properties of charcoal the experiments of Lowitz, Crell's *Annals*, ii. 165. Engl. Trans. and of Kels, ibid. iii. 270.

[†] Allen and Pepys on the quantity of carbon in carbonic acid. *Phil. Trans.* 1807.

Book I.
Division I.

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[†].

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, and then introduced it into a glass jar full of air. Seventeen cubic inches of charcoal absorbed, in five hours, 48 cubic inches of air, or 2·8 times its bulk[‡]. This absorption, though much more considerable than could have been expected from former experiments, has been confirmed by Morozzo, who has lately published a new set of experiments on the absorption of gases by charcoal. The instrument he employed was very simple; a glass tube open at one end and furnished with a steel stopcock at the other; to the stopcock was fitted another stopcock, having in it a cavity into which the red-hot charcoal was placed. When the charcoal was put into its cavity, and the stopcocks adjusted by turning the key, the gas which filled the tube was brought into

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

[†] *Jour. de Phys.* 1783.

[‡] *Ann. de Chim.* xxxii. 3.

ontact with the charcoal. The tube was of such a ize, that at the temperature of 57° it held a volume of ir weighing 4·5 grains, and the charcoal used was of beech-wood, and weighed about 36 grains. The result of his experiments was as follows :—

The absorption of common air amounted to 0·41 of the whole; that of hydrogen gas to 0·17. The effects of charcoal, when exposed in this manner to pure oxygen gas, if we believe Morozzo, are very remarkable indeed. On allowing the two bodies to remain in contact for several days, the whole of the oxygen was absorbed. Other experimenters had obtained an absorption not exceeding $\frac{1}{3}$ of the gas*. The charcoal by absorbing the gases acquired weight, and it gave out only a small quantity of air when plunged under water.

From the experiments of Sennebier, it was concluded that charcoal, when exposed to the atmosphere, absorbs oxygen gas in preference to *azote*, as the other portion of common air is called†. But Rouppe and Van Noorden have shown, that this happens only when the charcoal is hot: cold charcoal, they found, absorbed atmospheric air unaltered.

Morozzo observed, that the absorbent power of the charcoal varied according to the wood from which it was procured. The charcoal of beech and box-wood absorbed most air; the charcoal of willow and poplar was a little inferior; that of hazel and vine-twigs,

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* Nicholson's *Jour.* ix. 255. and x. 12.

† *Jour. de Phys.* xxx. 309.

still worse; and the charcoal from *cork*, which is extremely light, absorbed least of all*.

Converted by combustion into carbonic acid gas.

4. When charcoal is heated to about 802°†, or when it is made nearly red hot, and then plunged into oxygen gas, it takes fire; and, provided it has been previously freed from the earths and salts which it generally contains, or if we employ *lamp black*, which is charcoal nearly pure, it burns without leaving any residuum. But the air in which the combustion has been carried on has altered its properties very considerably, for it has become so noxious to animals that they cannot breathe it without death. If small pieces of dry charcoal be placed upon a pedestal, in a glass jar filled with oxygen gas, and standing over mercury, they may be kindled by means of a burning glass, and consumed. The bulk of the gas is not sensibly altered by this combustion, but its properties are greatly changed. A great part of it will be found converted into a new gas quite different from oxygen. This new gas is easily detected by letting up *lime-water* into the jar: the lime water becomes milky, and absorbs and condenses all the new-formed gas. This new gas has received the name of *carbonic acid*. Mr Lavoisier ascertained, by a very laborious set of experiments, that it is precisely equal in weight to the charcoal and oxy-

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* Nicholson, *Ibid.* and *Jour. de Phys.* lvii. 467. The increase of weight of charcoal had been observed also by Dr Watson. See his *Essays*, iii. 42.

† I estimated this temperature by ascertaining the time at which charcoal ceased to burn on an iron plate which had been heated to redness, and measuring the rate of cooling by Sir Isaac Newton's method, to be described hereafter.

n which disappeared during the combustion. Hence concluded, that carbonic acid is a compound of char- al and oxygen, and that the combustion of charcoal nothing else than its combination with oxygen[*]. Ir Lavoisier concluded from his experiments, that very 28 parts of charcoal, during their combustion, nited with 72 parts of oxygen, and that carbonic acid composed of these two bodies combined in that pro- ortion. The experiment is of difficult execution; yet t has been made by other philosophers with nearly he same result. The mean of five experiments made with great care by Messrs Allen and Pepys, gives for the constituents of carbonic acid,

charcoal	28·6
oxygen	71·4
	100·0[†]

This result differs so little from that obtained by Lavoisier, that in the present state of chemistry we may adopt the numbers of that illustrious philosopher as sufficiently precise.

When considerable quantities of charcoal are consumed in oxygen gas, some time after the commencement of the combustion a quantity of water deposites itself and trickles down the inside of the glass. This happens however dry the oxygen was, and however well the charcoal was prepared: but after the combustion has continued for a certain time the water is taken up again and disappears[‡]. This deposition of water

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[*] *Mem. Par.* 1781, p. 448.

[†] *Phil. Trans.* 1807.

[‡] Berthollet's *Statique Chimique*, ii. 42.

induced Mr Lavoisier to conclude that charcoal is not a simple substance, but that it is a compound of at least two bodies, both of which, during the combustion of charcoal, unite to oxygen, and form, the one *water*, and the other *carbonic* acid. The first we know to be *hydrogen;* the second Lavoisier called *carbon.* Charcoal then, according to Lavoisier, is a compound of hydrogen and carbon. He even estimated the hydrogen in common charcoal as $\frac{1}{8}$th of the whole. The subsequent experiments of other chemists, especially those of Priestley, Cruikshanks, and Berthollet junior, have amply confirmed this deduction of Lavoisier. Charcoal, then, is not pure carbon; but as the greatest part of it consists of that body, we may consider it as capable of giving us some idea of its properties. We are acquainted with carbon, however, in a state apparently very different: in that state it constitutes the *diamond.*

Properties of the diamond.

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

6. 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

594 by the Florentine academicians, in the presence f Cosmo III. Grand Duke of Tuscany. By means f a burning-glass they consumed several diamonds. rancis I. Emperor of Germany, afterwards witnessed ne destruction of several more in the heat of a furnace. 'hese experiments were repeated by Darcet, Rouelle, Iacquer, Cadet, and Lavoisier; who proved that the iamond was not merely evaporated, but actually urnt, and that if air was excluded it underwent no hange*.

Mr Lavoisier prosecuted these experiments with his isual precision; burnt diamonds in close vessels by neans of powerful burning glasses; ascertained, that luring their combustion carbonic acid gas is formed; ind that in this respect there is a striking analogy beween them and charcoal, as well as in the affinity of oth when heated in close vessels†. A very high temerature is not necessary for the combustion of the dianond. Sir George Mackenzie ascertained that they burn in a muffle‡ when heated to the temperature of 14° of Wedgewood's pyrometer; a heat considerably less than is necessary to melt silver§. When raised to this temperature they waste pretty fast, burning with a low flame, and increasing somewhat in bulk; their surface too is often covered with a crust of charcoal, especially when they are consumed in close vessels by means of burning glasses‖.

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

† Lavoisier's *Opuscules*, ii. as quoted by Macquer. *Dict.* i. 337.

‡ A *muffle* is a kind of small earthen-ware oven, open at one end, and fitted into a furnace.

§ Nicholson's *Quarto Jour.* iv. 104.

‖ Macquer and Lavoisier. Macquer's *Dict.* Ibid.

In 1785, Guyton-Morveau found that the diamond is combustible when dropped into melted nitre; that it burns without leaving any residuum, and in a manner analagous to charcoal *. Mr Smithson Tennant repeated this experiment with precision in 1797. Into a tube of gold he put 120 grains of nitre, and 2·5 grains of diamond, and kept the mixture in a red heat for half an hour. The diamond was consumed by the oxygen, which red hot nitre always gives out. The carbonic acid formed was taken up by means of lime, and afterwards separated from the lime and measured. It occupied the bulk in one experiment of 10·3 ounces of water, and in another of 10·1: the mean is equal to 19·36 inches of carbonic acid, which have been ascertained to weigh nearly 9 grains. But 9 grains of carbonic acid, by Lavoisier's experiments, contain almost exactly 2·5 grains of carbon, which was the original weight of the diamond †. Thus Mr Tennant ascertained, that the whole of the diamond, like charcoal, is converted by combustion into carbonic acid gas.

And is converted into carbonic acid.

As the proportion of carbonic acid formed by the combustion of diamond, is very nearly the same according to Tennant's experiment, as what would have been yielded by the same weight of good charcoal; it ought to follow, that diamond and charcoal consist both of exactly the same constituents. But when we consider the very different properties of the two substances, we feel a strong repugnance to embrace this conclusion.

The experiments of Lavoisier were repeated in 1800 by Morveau, who consumed various diamonds in glass

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* *Encyc. Method. Chim.* i. 742.

† *Ph. Trans,* 1797, p. 123.

globes filled with oxygen gas, by exposing them to the focus of the large burning glass of Tschirnhaus. He found that one part of diamond, during its combustion, combines with 4·55 parts of oxygen, and the carbonic acid gas formed amounts to 5·55 parts. Consequently carbonic acid gas is composed of one part of diamond and 4·55 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[*]	

This experiment cannot be reconciled with that of Mr Tennant. Were it to be depended on, it would demonstrate that charcoal and diamond are essentially different; since the first requires only 2·57 times its weight of oxygen to convert it into carbonic acid, while the last requires 4·55 times its weight to undergo the same change. This difference could be explained only by supposing that charcoal already contains a considerable proportion of oxygen, which is wanting in diamond. But as several circumstances, in the experiment of Guyton-Morveau, rendered its precision questionable, it became requisite to repeat it, before the conclusions founded upon it could be admitted as established. This was done with every requisite precaution by Messrs Allen and Pepys in the year 1807; and we have every reason to confide in the accuracy of the results which they obtained. They found that diamond when burnt required the same weight of oxygen, and formed the

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[*] *Ann. de Chim.* xxxi. 99.

same quantity of carbonic acid as well burnt charcoal[*]. Some inaccuracy, therefore, must have crept into Morveau's experiment. As far as experiment has gone, the constituents of diamond and charcoal are absolutely the same. Now as the presence of hydrogen has been demonstrated in the latter, we must admit it also in the former; a conclusion which corresponds with the previous deductions of Biot, founded on the power of the diamond to refract light. At the same time, it must be admitted that considerable obscurity still hangs over this subject. The properties of diamond and charcoal are different in almost every respect; if their composition be the same, it is impossible to explain upon what that difference depends.

Such are the facts that have been ascertained respecting the combination of carbon with oxygen. Let us now examine the compounds which it forms with hydrogen.

Heavy inflammable airs.

7. When charcoal is exposed to a strong heat in an iron retort, there is disengaged from it a gas which has the property of burning with a blue flame, and which is considerably heavier than hydrogen gas; hence it received the name of *heavy inflammable* air. A gas possessed of similar properties is obtained by causing steam to pass through a tube filled with red-hot charcoal; by passing spirit of wine, ether, or camphor, through red-hot tubes; by distilling oils, wood, bones, or indeed almost any animal or vegetable body whatever. These heavy inflammable airs were occasionally collected by Dr Priestley, but they were first particu-

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[*] *Phil. Trans.* 1807.

larly examined by Mr Lavoisier, Dr Higgins, and Dr Austin, who ascertained, that when they are mixed with oxygen gas and burnt, the products are only *water* and *carbonic acid*. Hence it was concluded, that they are composed of carbon and hydrogen; and the term *carbureted hydrogen* gases, indicating their constituents, was applied to them. These gases, in consequence of the experiments of Dr Priestley, have lately attracted the attention of chemists; and many important additions have been made to our knowledge of them, chiefly by the Dutch chemists, by Mr Cruikshanks, Mr Berthollet, and Dr William Henry. But notwithstanding the merit and sagacity of these philosophers, the nature of the gases is still involved in considerable obscurity, owing in a great measure to our uncertainty of the proportion of carbon in carbonic acid. The opinion of Dr Henry and Mr Dalton, that there are only three species of *heavy inflammable air*, and that all the variety which we obtain is produced by mixtures of these in various proportions, seems to me much more probable than the opinion of Berthollet, that their number is indefinite. Let us endeavour to state the facts respecting these three species of gas as distinctly as possible.

Three species of heavy inflammable air.

8. There is a gas which rises spontaneously in hot weather from marshes and stagnant water, and which may be easily collected in considerable quantities; this gas was examined by Dr Priestley, and more lately by Mr Cruikshanks and Mr Dalton. It is invisible and elastic, like common air, and it burns with more brilliancy than hydrogen gas. Its specific gravity, according to Cruickshanks, is 0.67774; that of common air being 1·000. One hundred cubic inches of it, at

1. Carbureted hydrogen.

60°, weigh 21 grains *. When mixed with oxygen gas and fired by electricity, it explodes, and leaves a residue more bulky than the original mixture; but lime-water absorbs the greatest part of it. The substances formed during this combustion are carbonic acid and water. Hence it is obvious, that the gas is composed of carbon and hydrogen. It is therefore entitled to the name of *carbureted hydrogen.* But after the carbonic acid has been removed (supposing it had been mixed with oxygen in the exact proportion to consume the whole of that body), Mr Dalton has ascertained, that there always remains a residue amounting to about $\frac{1}{5}$th of the gas from stagnant water originally used. This residue possesses the properties of the gas called *azote* †, which we shall examine in a subsequent chapter. The gas from stagnant waters, then, is a mixture of four parts of carbureted hydrogen, and one part of azote. Dr Henry has ascertained, that if the azote be supposed separated, the carbureted hydrogen requires for combustion twice its bulk of oxygen gas; and there is produced a quantity of carbonic acid just equal in bulk to the carbureted hydrogen ‡. Hence it is easy to determine its constituents.

Its composition.

One hundred inches of it require 200 inches of oxygen gas, 100 of which form carbonic acid; and the remaining 100 must enter into the composition of the water formed, and of course combine with a quantity of hydrogen equal in bulk to 200 inches. Now 100 inches of carbonic acid contain 13·02 grains of carbon, and 200

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* Nicholson's 4to *Jour.* v. 8.

† Henry, Nicholson's *Jour.* xi. 68.

‡ Ibid.

hes of hydrogen weigh 5·2 grains. This would give the gas composed of nearly

28½ hydrogen
71½ carbon
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100

result which accords pretty nearly with the weight the gas, as ascertained by Cruikshanks. One hun-ed inches of carbureted hydrogen (freed from azote) ight to weigh, according to him, 18·6 grains; and the nstituents, as stated above, weigh 18·22 grains.

Gas from acetate of potash;

The gas obtained by distilling *acetate of potash**, ems to be the same very nearly with the carbureted drogen above described. It was this gas that was bjected to experiment by Drs Austin and Higgins.

From pit-coal.

When common pit-coal is distilled in close vessels, vast quantity of inflammable air is evolved, which s rather an unpleasant smell, burns with a fine yel-wish white flame like oil, and yields a very bright ght. This gas has been substituted for oil in lamps, d has been used successfully to light up rooms†. It

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* A salt described in a subsequent part of this Work.

† Many successive exhibitions of it were made at the Lyceum in Lon-n in 1804, and it had been publicly proposed in France for the same rposes about the year 1801; but the real discoverer of the use of the s was Mr Murdoch of Birmingham. Dr William Henry has publish- the following detail of the discovery:

"In the year 1792, at which time Mr Murdoch resided at Redruth in rnwal, as Boulton and Watt's principal agent and manager of engines that county, he commenced a series of experiments upon the quantity l quality of the gases contained in different substances. In the course these he remarked, that the gas obtained by distillation from coal, t, wood, and other inflammable substances, burnt with great brillianappears from the experiments of Dr Henry, that this gas is composed of the same constituents as the gas from stagnant waters, excepting only a small portion of

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cy upon being set fire to; and it occurred to him, that by confining and conducting it through tubes, it might be employed as an economical substitute for lamps and candles. The distillation was performed in iron retorts, and the gas conducted through tinned iron and copper tubes to the distance of 70 feet. At this termination, as well as at intermediate points, the gas was set fire to, as it passed through apertures of different diameters and forms, purposely varied with a view of ascertaining which would answer best. In some the gas issued through a number of small holes, like the head of a watering pan; in others it was thrown out in thin long sheets; and again in others in circular ones, upon the principle of Argand's lamp. Bags of leather and of varnished silk, bladders, and vessels of tinned iron, were filled with the gas, which was set fire to, and carried about from room to room, with a view of ascertaining how far it could be made to answer the purpose of a moveable or transferable light. Trials were likewise made of the different quantities and qualities of gas produced by coals of various descriptions, such as the Swansea, Haverfordwest, Newcastle, Shropshire, Staffordshire, and some kinds of Scotch coals.

'Mr Murdoch's constant occupations prevented his giving farther attention to the subject at that time; but he again availed himself of a moment of leisure to repeat his experiments upon coal and peat at Old Cumnock, in Ayrshire, in 1797; and it may be proper to notice that both these, and the former ones, were exhibited to numerous spectators, who, if necessary, can attest them. In 1798, he constructed an apparatus at Soho Foundry, which was applied during many successive nights to the lighting of the building; when the experiments upon different apertures were repeated and extended upon a large scale. Various methods were also practised of washing and purifying the air, to get rid of the smoke and smell. These experiments were continued, with occasional interruptions, until the epoch of the peace in the spring of 1802, when the illumination of the Soho manufactory afforded an opportunity of making a public display of the new lights; and they were made to constitute a principal feature in that exhibition. I do not know exactly at what time the first trials were made or published in France. The first notice we received of them here, was in a letter from a friend at t o other inflammable gases with which he supposes it n xed*.

Chap. II.

Expanded by electricity.

One of the most remarkable properties of carbureted h drogen gas is, that when electric shocks are passed th ough it for some time, it is permanently dilated to a out twice its natural bulk. Dr Austin, who bestowe considerable pains on this gas, directed his particul attention to the changes produced in it by electricit. He found, that by repeatedly passing electric e plosions through a small quantity of carbureted hyd ogen gas, it was permanently dilated to more than t ice its original bulk. He rightly concluded, that t s remarkable expansion could only be owing to the e olution of hydrogen gas. On burning air thus exp nded, he found that it required a greater quantity of o ygen than the same quantity of gas not dilated by e ctricity: An addition therefore had been made to th combustible matter; for the quantity of oxygen n cessary to complete the combustion of any body is a ways proportional to the quantity of that body. He

Austin's theory of the composition of carbon.

F is, dated the 8th of Nov. 1801; in which he desires me to inform M Murdoch, that a person had lighted up his house and gardens with th gas obtained from wood and coal, and had it in contemplation to li t up the city of Paris.

After mentioning the above, I think it is proper to state also, that i the ovens constructed upon Lord Dundonald's plan, at Calcutts in S opshire, for the purpose of saving the tar, &c. which escapes during th coaking of coal, it has been usual for a number of years past to set fi to the large current of gas as it flies off, and thus procure a bright il mination. This however was not known to Mr Murdoch, and was n er seen by him "—Nicholson's *Jour.* xi. 73.

The gases supposed mixed, are the two species described in the subs uent part of this Section.

Phil. Trans. lxxx. 51.

concluded from his experiments, that he had decomposed the carbon which was united to the hydrogen gas; and that carbon is composed of hydrogen and *azote*[*], some of which he 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 carbureted hydrogen gas were owing merely to the decomposition of carbon, no such increase ought to take place, but rather the contrary; for the carbon, which is itself a combustible substance, is resolved into two ingredients, hydrogen and azote, only the first of which burnt on the addition of oxygen and the application of heat. Dr Austin's experiments were repeated by Dr William Henry with his usual ingenuity and precision[†]. He found that the dilatation which Dr Austin describes actually took place; but that it could not be carried beyond a

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[*] His theory was, that carbureted hydrogen gas is composed of hydrogen and azote, and charcoal, of azote and carbureted 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 carbureted hydrogen gas, he actually decomposed it by melting sulphur in it: the sulphur combined with the hydrogen gas, and a quantity of charcoal 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.* 1797, Part ii. and Nicholson's quarto *Jour.* ii. 241.

certain degree, a little more than twice the original bulk of the gas, as had been previously remarked by Dr Austin himself. Upon burning separately, by means of oxygen, two equal portions of carbureted 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.

Expansion occasioned by water.

Dr 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 carbureted hydrogen gas of as much water as possible, by making it pass over very dry potash, 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 carbureted hydrogen gas. 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 azote which Dr Austin found in his dilated gas, it evidently proceeded from the admission of some atmospheric air, about 79 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 shown that air in such a situation always becomes impregnated with azote*.

Such are the properties of carbureted hydrogen gas. Mr Watt, who first pointed out the effects of this gas when respired, seems to have been the philosopher who gave it the name of *hydro-carbonate*†; a name very commonly used by British writers. Dr Henry has lately changed it into *hydro-carburet*. The term thus altered appears unexceptionable, and may be used with propriety to distinguish this species from the other compounds of hydrogen and carbon.

9. Supercarbureted hydrogen, or olefiant gas.

9. When four parts of sulphuric acid and one part of alcohol are mixed together in a retort, the mixture becomes very hot, and assumes a brown colour. By applying the heat of a lamp to the vessel while its beak is plunged under water, we soon cause it to boil, and a gas is disengaged in abundance. This gas was first particularly examined by a society of Dutch chemists‡, and called by them *olefiant gas*; but perhaps the term *super-carbureted hydrogen*, which is more systematic, might be applied to it with propriety. It has been since analysed by Berthollet and Dr William Henry.

Properties.

This gas possesses the mechanical properties of common air; but it has a disagreeable odour, owing perhaps to some oily matter which it holds in solution. It does not support combustion, and is equally noxious to

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* The increase of the combustible matter in Dr Austin's experiment was doubtless owing to the oxidizement of a part of the mercury at the expence of the water.

† See his letters in Beddoes's work on *Factitious Airs*.

‡ Messrs Bondt, Dieman, Van Troostwyk, and Lauwerenburg. Their memoir is published in the *Journal de Physique*, xlv. 178

nimals with the last described species. Its specific ravity, according to the Dutch chemists, is 0·905, hat of air being 1·000. Therefore at the temperature f 60°, barometer 30 inches, 100 cubic inches of it veigh 28·18 grains troy. When this gas is kindled, t burns with a dense white flame, and with very great plendour; the combustion continuing a very considerable time. When mixed with oxygen gas, and urnt in close vessels by means of electricity, it detonates; the products of this combustion are water and arbonic acid. Hence we learn, that the constituents of the gas are hydrogen and carbon. From the experiments of Mr Dalton, it appears that 100 inches of olefiant gas, in order to be completely consumed, must be mixed with 300 inches of oxygen. There is formed a quantity of carbonic acid equal to 200 inches. 200 inches of the oxygen gas were employed in forming this gas. The remaining 100 must have united with hydrogen, and formed water; and we know that they must have united with a quantity of hydrogen equal to 200 inches in bulk. 200 inches of carbonic acid contain 26·04 grains of carbon, and 200 inches of hydrogen weigh 5·2 grains. Hence it follows, that 100 inches of olefiant gas are composed of

Composition.

26·04	carbon
5·2	hydrogen
31·24	

A quantity rather exceeding the weight of 100 inches. Olefiant gas, then, is composed of

83	carbon
17	hydrogen

Book I.
Division I.

The proportion of carbon is almost double what exists in the last described species. Hence the reason of applying to it the name of super-carbureted hydrogen; the term indicates the superior proportion of carbon. The constituents are:

	Hydrogen.	Carbon.
Carbureted hydrogen,	100	250·8
Super-carbureted hydrogen,	100	488·2

The preceding analysis by no means agrees with that of Berthollet, who informs us that he ascertained by his trials that super-carbureted hydrogen gas was composed of one part hydrogen and three parts carbon; but as he does not give us the data upon which this conclusion was founded, it is impossible to ascertain the cause of the difference between his statement and that deduced from Mr Dalton's experiments[*].

Mr Berthollet relates a very curious experiment which had not been observed by the Dutch chemists: When four measures of olefiant gas and three measures of oxygen gas are fired together by electricity, the mixture dilates so much as to occupy the bulk of 11 measures, and a quantity of charry matter is deposited. The dilated gas is still susceptible of detonation when mixed with more oxygen[†]. Berthollet supposes, that the effect of the first detonation was to form a combination of the two gases, which still retained the gaseous form; but it is difficult to conceive how such a combination could be produced by combustion, and yet remain combustible.

One of the most characterestic properties of this gas

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[*] *Statique Chimique* ii. 68.

[†] Ibid, p. 71.

Action of oxymuriatic acid.

is the rapid diminution of bulk, and the formation of an opal coloured oil when it is mixed with the gas called *oxymuriatic acid* *. It was this property which induced the Dutch chemists to give to super-carbureted hydrogen the name of *olefiant gas*. They found, that when the two gases were mixed together in the proportion of three measures olefiant gas, and four measures oxymuriatic, the two gases disappear completely: but the proportions which Dr William Henry found to produce this effect, were somewhat different; namely, five measures of olefiant gas, and six measures of oxymuriatic. This rapid absorption and formation of oil enables us to detect the presence of olefiant gas in gaseous mixtures with considerable facility. Dr Henry has applied it very ingeniously to the analysis of a variety of mixed inflammable gases †.

3. Carbonic oxide.

10. When a mixture of equal parts of iron filings and chalk, both made previously as dry as possible, are exposed to a red heat in an iron retort, there is disengaged a great quantity of gas, consisting partly of carbonic acid, and partly of a species of heavy inflammable air. When the carbonic acid is separated by means of lime-water, the inflammable gas is obtained in a state of great purity. It was first procured by Dr Priestley; but for our knowledge of its constituents and its properties, we are indebted to the ingenious experiments of Mr Cruikshanks. Clement and Desormes, Morveau and Berthollet, examined it also soon after with equal address and success. The name *carbonic*

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* This gas will be described in the next Chapter.

† Nicholson's *Jour.* xi. 65.

oxide gas has been given it by chemists, and Cruikshanks has rendered it probable that it is a compound of oxygen and carbon; the account of its properties belongs therefore to a subsequent part of this Work: but I consider it as necessary to give a short detail of them in this place, because it has been so often confounded with the other two species, from which, however, it is exceedingly distinct.

This gas possesses the mechanical properties of air. Its specific gravity, according to Cruikshanks, is 0·956, that of air being 1·000; hence 100 inches of it weigh, under the medium pressure and temperature, 29·64 grains troy.

Properties.

It burns with a deep blue flame, and gives out but little light. When mixed with oxygen gas it detonates, though not loudly; eight measures of it require for combustion about $3\frac{1}{2}$ of oxygen gas. When 100 cubic inches of it are mixed with 40 inches of oxygen gas, the whole is consumed, and 92 inches of carbonic acid are formed*. Now 100 of carbonic oxide and 40 of oxygen weigh 43·6 grains, and 92 of carbonic acid weigh 42·78 grains. From this near coincidence between the weight of the substances consumed and the product, Cruikshanks drew his conclusion that the gas contained no hydrogen; and in this opinion the greater number of chemists have acquiesced. Supposing it correct, it will be easy for us to assign the constituents of the gas; the carbonic acid produced contains very nearly 11·72 grains of carbon, the remainder of the weight is oxygen; from which if we subtract the weight of the 40 inches of

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* Cruikshanks, Nicholson's 4to *Jour.* v. 8.

oxygen used for the combustion, we have a remainder of nearly 18$\frac{2}{3}$, which must be the oxygen that previously existed in the gas. Hence, according to this statement, carbonic oxide is composed of about

Composition.

39	carbon
61	oxygen
100	

Berthollet does not acquiesce in this analysis. According to him, the gas contains hydrogen as a constituent, and is a triple compound of oxygen, carbon, and hydrogen. That it often contains hydrogen is probable; but the experiments of Henry have made it probable, that it is only accidentally and not essentially present: for when subjected to the action of electric explosions, it does not expand as all gases do, hitherto tried, which contain hydrogen as a constituent[*].

Hydro-carbonates.

11. These three species of gas have been long confounded in this country, under the name of *hydro-carbonates*. The first and last species are not sensibly absorbed by water; but 100 inches of water absorb about 11 inches of olefiant gas, or nearly $\frac{1}{9}$ of its bulk[†]. They are all exceedingly noxious to animals, occasioning almost instantaneous fainting, feebleness, and death. The last species is easily recognized by the deep blue flame with which it burns: the flame of the two first species is white, but the second is vastly more brilliant than the first. From the late experiments of Dr Henry, there is reason to consider it as probable, that

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[*] Nicholson's *Jour.* xi. 72.

[†] Henry, on the authority of Dalton, *Nicholson*, xi. 70.

all the other species of *heavy inflammable gas* are nothing else than mixtures of these three and of hydrogen gas. The following are the most remarkable of these.

Gas from moist charcoal.

12. When steam is made to pass through red hot charcoal, confined in a porcelain or metal tube, a great quantity of gas is obtained. When the steam passes so rapidly that a portion of it comes over in the state of water, the gas obtained is a mixture of carbonic acid and heavy inflammable air; but when the steam passes so slowly as to be wholly decomposed by the charcoal, the gas which issues from the tube is almost all inflammable. Dr Priestley first procured gas in this manner, and pointed out the effect of different proportions of steam[*]. The process was repeated with great care by Lavoisier, during the course of his experiments to determine the constituents of carbonic acid[†]; and Mr Watt pointed it out as the readiest way of procuring *hydro-carbonate* for the purposes of pneumatic medicine[‡]. This is the gas, accordingly, which has been commonly employed when the effects of carbureted hydrogen on the animal system were investigated. Cruikshanks examined it during his experiments on carbonic oxide[§], and it has been lately subjected to analysis by Dr Henry[||].

This gas burns with a deep blue flame like carbonic oxide, and is equally injurious to life. From the experiments which we have on this gas, it cannot be doubted that it varies considerably at different times,

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[*] Priestley, i. 284.

[†] Mem. Par. 1781, p. 458.

[‡] Beddoes and Watt, on *Factitious Airs*.

[§] Nicholson's 4to. *Jour.* v. 6.

[||] Nicholson's *Jour.* xi. p. 66.

ccording to the proportion of water and the degrees of
eat employed. The difference of its specific gravity,
consider as a demonstration of this. Lavoisier and
Ieusnier found it 0·279, that of air being 1·000 *;
vhile Cruikshanks got it as high as 0·468, or al-
ost double†. According to the former, 100 cu-
ic inches weigh 8·66 grains; according to the lat-
r, they weigh 14·50 grains. The gas examined by
Ienry seems to have been a little lighter than the gas
f Mr Cruikshanks. Dr Henry considers this gas as
mixture of hydrogen gas with carbonic oxide, and
erhaps a little carbureted hydrogen. The results ob-
ined by him by combustion, accord very well with
is notion; he found that 100 measures of this gas,
hen detonated with 60 of oxygen, left 35 measures
f carbonic acid. Let us suppose that these 35 inches
f carbonic acid were formed by the union of oxygen
d carbonic oxide: they weigh 16·27 grains, and are
omposed of 11·15 grains carbonic oxide, and 5·12
xygen, which would make 37 inches of carbonic oxide
d 15 of oxygen. Supposing these 37 measures to
ave existed in the gas before the combustion, there
ill remain to be accounted for 63 inches, which, if
e suppose it hydrogen, would require 31 inches of
xygen; but 45 inches of oxygen have been consumed.
ur supposition, then, does not tally exactly with the
henomena: to make them accord, it would be neces-
ry to suppose the gas from moist charcoal a mixture
somewhat less carbonic oxide and hydrogen, and to
ake up the 100 by supposing a quantity of carbure-

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[*] Mem. Par. 1781, p. 458.

[†] Nicholson's 4to *Jour.* v. 8.

ted hydrogen present. But in the present state of uncertainty, it is unnecessary to proceed any farther with the investigation.

Gas from wood.

13. The gas obtained by the distillation of wood burns with a much whiter flame than that from charcoal: yet Dr Henry found, that 100 measures of gas from oak required only 54 measures of oxygen to saturate it, and produced 33 measures of carbonic acid. This result induces him to consider it as a mixture of the same gases as the last, but in different proportions.

Gas from peat.

The gas from dried peat differs considerably in its properties, according to the qualities of the peat, and the mode employed in procuring it. I have obtained no less than four kinds, and Dr Henry procured and examined another altogether different. Its specific gravity varies from 0.813 to 0·608. It burns sometimes with a white, sometimes with a blue flame; 100 cubic inches of the heaviest kind consume 100 inches of oxygen, and form 80 inches of carbonic acid; 100 inches of the lightest kind consume 160 inches of oxygen, and form 60 inches of carbonic acid gas *. It is probably a mixture of two different gases, and its different properties are most likely owing to a variation in their proportions. One of these gases I conceive to be carbonic oxide; but I think I have shown that the other is a gas not yet obtained or examined in a separate state. If this last gas shall be found to contain oxygen as a constituent, which is not unlikely, it will constitute a triple compound, to which the name of *oxy-carbureted hydrogen* may be applied.

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* See my experiments on it in Nicholson's *Jour.* xvi. 241.

Pitcoal.

The gas obtained by distilling coal burns with great br liancy. Dr Henry considers it as a mixture of carb eted hydrogen with some carbonic oxide and olefia t gas.

Oils and spirits.

The gases obtained from oil and wax by distillation ar carbureted hydrogen gas; but the first contains $\frac{1}{8}$ of its bulk, and the other $\frac{1}{4}$ its bulk of olefiant gas. The ol ant gas is present also in the gases obtained by pa sing camphor, ether, or alcohol, through hot tubes *.

SECT. III.

OF PHOSPHORUS.

Method of preparing phosphorus.

P OSPHORUS, the third of the simple combustibles, may be procured by the following process: Let a quantity of ones be burnt, or, as it is termed in chemistry, *calcin l*, till they cease to smoke, or to give out any odour, an let them afterwards be reduced to a fine powder. Pu 100 parts of this powder into a bason of porcelain or oneware, dilute it with four times its weight of wa r, and then add gradually (stirring the mixture aft every addition) 40 parts of sulphuric acid. The mi ure becomes hot, and a vast number of air-bubbles are xtricated †. Leave the mixture in this state for 24 ours; taking care to stir it well every now and

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* Henry, ibid.

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

then with a glass or porcelain rod to enable the acid to act upon the powder*.

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, nitrate of lead†, dissolved in water, is to be poured slowly; a white powder immediately falls to the bottom: the nitrate 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. 5. *b.*) The retort is to be put into a furnace, and the beak of it plunged into a vessel of water, so as to be just under the surface. Heat is now to be applied gradually till the retort be heated to whiteness. 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

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* Fourcroy and Vauquelin, *Mem. de l' Inst.* ii. 282.

† A salt to be described in a subsequent part of this Work. It answers better than acetate of lead, as was first pointed out by Giobert, and more lately by Mr Hume. See Giobert's process, *Ann. de Chim.* xii. 15. and *Phil. Mag.* xx. 160.

th appearance of melted wax, and which congeals unde the water*. This substance is *phosphorus*.

History of its discovery.

t was accidentally discovered by Brandt, a chemist of Hamburgh, in the year 1669†, as he was attemptin to extract from human urine a liquid capable of cc verting silver into gold. He showed a specimen of it to Kunkel, a German chemist of considerable er nence, who mentioned the fact as a piece of news to ne Kraft, a friend of his at Dresden. Kraft imm liately repaired to Hamburgh, and purchased the se et from Brandt for 200 dollars, exacting from him at he same time a promise not to reveal it to any other pe son. Soon after, he exhibited his phosphorus publi y in Britain and France, expecting doubtless that it w ild make his fortune. Kunkel, who had mentioned to Kraft his intention of getting possession of the proce , being vexed at the treacherous conduct of his fr nd, attempted to discover it himself; and about the ye r 1674 he succeeded, though he only knew from B ndt that urine was the substance from which phospl orus had been procured‡. Accordingly he is always re koned, and deservedly too, as one of the discoverers of phosphorus.

Boyle likewise discovered phosphorus. Leibnitz inde d affirms, that Kraft taught Boyle the whole pro-

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The theory of this process will be explained afterwards.

Homberg, *Mem. Par.* 1692. An account of it is published in the *Pl osophical Transactions* for 1681, first by Sturmius, and then by Dr Sl :.

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

cess, 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 only 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 his assistant 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 far communicating his process. Hellot, Dufay, Geoffroy, and Duhamel, saw him execute it with success; and Hellot published a very full account of it in the Memoirs of the French Academy for 1737.

It consisted in evaporating putrid urine to dryness, heating the inspissated residue to redness, washing it with water to extract the salts, drying it, and then raising it gradually in stone-ware retorts to the greatest intensity of heat. It was disgustingly tedious, very expensive, and yielded but a small quantity of produce. The celebrated Margraf, who informs us that he had

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

[†] See Hoffman's experiments on it, published in 1722 in his *Observat. Phys. Chym. Select.* p. 304.

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

d voted himself at a very early period to the investiga-
ti n of phosphorus, soon after published a much more
e: peditious and productive process; for the first hint
o which he was indebted to Henkel. It consisted in
n xing a salt consisting chiefly of lead with the inspis-
sa ed urine. He even found that urine contained a pe-
cu iar salt*, which yielded phosphorus when heated
w h charcoal †.

n the year 1769, Gahn, a Swedish chemist, disco-
ve ed that phosphorus is contained in bones ‡; and
S eele §, very soon after, invented a process for ob-
ta ning it from them. Phosphorus is now generally
p: ocured in that manner. The process described in the
b ginning of this Section is that of Fourcroy and Vau-
q elin. The usual process followed by manufacturers
o phosphorus is an improvement on that of Scheele.

oon after the discovery of phosphorus, many
e: periments on it were made by Slare and Boyle.
H ffman published a dissertation on it, containing some
cu ious facts, in 1722; but Margraf was the first who
in estigated its effects upon other bodies, and the na-
tu e of the combinations which it forms. The subject
w s resumed by Pelletier, and continued with much in-
d stry and success. Lavoisier's experiments were still

Known at that time by the name of *fusible salt of urine*, now called
ph hate of ammonia.

Miscel. Berolin, 1740, vi. 54.; and *Mem. Acad. Berlin*, 1746, p. 84;
an Margraf's *Opusc.* i. 30.

Bergman's *Notes on Scheffer.*

Crell, in his life of Scheele, informs us, that Scheele himself was the
di overer of the fact. This, he says, appears clearly from a printed let-
te of Scheele to Gahn, who was before looked upon as the discoverer.
Se Crell's *Annals*, English Trans. i. 17.

more important, and constitute indeed a memorable era in chemical science.

Its properties.

1. Phosphorus, when pure, is semi-transparent, and of a yellowish colour; but when kept some time in water, it becomes opaque externally, 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 mean specific gravity is 1·770.

2. It melts at the temperature of 99°[*]. Care must be taken to keep phosphorus under water when melted; for it is so combustible, that it cannot easily 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 then squeezing it through a piece of clean shamois 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.

3. When phosphorus is exposed to the atmosphere, 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

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

[†] Ibid. p. 381.

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

Soluble in oxygen gas.

4. 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 white colour, which gradually changes to a dark brown.

Converted by combustion

5. When heated to 148°, phosphorus takes fire and 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 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

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

† This acid shall be afterwards described.

‡ The term *phlogiston* was applied by Stahl and his followers to a substance which, according to them, exists in all combustible bodies, and separates during combustion. A sketch of their theory will be given in the next Section, in which we shall treat of sulphur, on which the hypothesis was founded.

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 *.

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 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;

But it was observed by Margraf, that phosphoric acid is heavier than the phosphorus from which it was produced; and Boyle had long before shown 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 La-

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* Stahl's *Three Hundred Experiments*.

† Margraf's *Opusc.* i. 56.

v sier published those celebrated experiments which t! ew so much light on the nature and composition of a ds*.

Which is phosphorus combined with oxygen

He exhausted a glass globe of air by means of an a -pump; and after weighing it accurately, he filled it v th oxygen gas, and introduced into it 100 grains of] osphorus. The globe was furnished with a stop-(ck, by which oxygen gas could be admitted at plea-: re. He set fire to the phosphorus by means of a l urning glass. The combustion was extremely rapid, companied by a bright flame and much heat. Large iantities of white flakes attached themselves to the ner surface of the globe, and rendered it opaque; and ese at last became so abundant, that notwithstanding ie constant supply of oxygen gas the phosphorus was xtinguished. The globe, after being allowed to cool, as again weighed before it was opened. The quantity f oxygen employed during the experiment was ascer-ained, and the phosphorus, which still remained un-hanged, accurately weighed. The white flakes, which vere nothing else than pure phosphoric acid, were ound exactly equal to the weights of the phosphorus ind oxygen which had disappeared during the pro-cess. Phosphoric acid therefore must have been form-ed by the combination of these two bodies; for the ab-solute weight of all the substances together was the ame after the process as before it†. It is impossible, hen, for phosphorus to be composed of phosphoric acid ind phlogiston, as phosphorus itself enters into the com-position of that acid.

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* *Mem. Par.* 1778 and 1780.

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

Thus the combustion of phosphorus, like that of hydrogen and carbon, 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.

From Lavoisier's experiment it follows, that 100 parts of phosphorus, during this combustion, unite with 154 parts oxygen. So that a grain of phosphorus condenses no less than 4½ cubic inches of oxygen gas; and five grains are capable of depriving 102¼ cubic inches of air of all its oxygen gas.

Oxide of phosphorus.

6. Though pure phosphorus does not take fire till it be heated to 148°, it is nevertheless true, that we meet with phosphorus which burns at much lower temperatures. The heat of the hand often makes it burn vividly; nay, it sometimes takes fire when merely exposed to the atmosphere. In all these cases the phosphorus has undergone a change. It is believed at present, that this increase of combustibility is owing to a small quantity of oxygen with which the phosphorus has combined. Hence, in this state, it is distinguished by the name of *oxide of phosphorus*. When a little phosphorus is exposed in a long narrow glass tube to the heat of boiling water, it continues moderately luminous, and gradually rises up in the state of a white vapour, which lines the tubes. This vapour is the *oxide* of phosphorus. This oxide has the appearance of fine white flakes, which cohere together, and is more bulky than the original phosphorus. When slightly heated it takes fire, and burns brilliantly. Exposed to the air, it attracts moisture with avidity, and is con-

ve ed into an acid liquor*. When a little phosphorus is hus oxidized in a small tin box by heating it, the o de acquires the property of taking fire when exposed to he air. In this state it is often used to light candles u der the name of *phosphoric matches* ; the phosphorus b ng sometimes mixed with a little oil, sometimes with s phur.

When phosphorus is long acted on by water, it is c ered at last with a white crust, which is also consid ed as an oxide of phosphorus; but it differs consid rably from the oxide just described. It is brittle, less f sible, and much less combustible than phosphorus i elf†. Phosphorus, when newly prepared, usually ntains some of this last oxide of phosphorus mixed ith it; but it may be easily separated by plunging e mass into water heated to about 100°. The phos orus melts, while the oxide remains unchanged, and wims upon the surface of the melted phosphorus.

Phosphorized hydrogen gas.

7. When bits of phosphorus are kept for some hours hydrogen gas, part of the phosphorus is dissolved. his compound gas, to which Fourcroy and Vaque in, the discoverers of it, have given the name of *phos horized hydrogen gas*, has a slight smell of garlic. When bubbles of it are made to pass into oxygen gas, very brilliant bluish flame is produced, which per ades the whole vessel of oxygen gas. It is obvious hat this flame is the consequence of the combustion of he dissolved phosphorus‡.

Phosphoreted hydrogen gas.

When phosphorus is introduced into a glass jar of hydrogen gas standing over mercury, and then melted

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* Steinacher, *Ann. de Chim.* xlvii. 104.

† Ibid.

‡ Ibid. xxi. 220.

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 *phosphureted 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, 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 one of the most combustible substances 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. Scav. Etrang.* x.

[†] *Ann. de Chim.* x. 19.

[‡] Ibid. xxxv. 225.

ure water, when agitated in contact with this gas, dis olves at the temperature of between 50° and 60° ab ut the fourth part of its bulk of it*. The solutic is of a colour not unlike that of roll sulphur; it ha a very bitter and disagreeable taste, and a strong un leasant odour. When heated nearly to boiling, the w ole of the phosphureted hydrogen gas is driven off ur hanged, and the water remains behind in a state of pu ity. When exposed to the air, the phosphorus is gr dually deposited in the state of oxide; the hydrogen ga makes its escape; and at last nothing remains but p e water†.

When electric explosions are passed through this ga , its bulk is increased precisely as happens to carbu eted hydrogen. The water which it contains is deco posed, phosphoric acid formed, and hydrogen gas ev lved‡. We are neither acquainted with the specific gr vity, nor with the proportion of the constituents of th s gas.

Phosphuret of carbon.

8. Phosphorus is capable of combining with carb n. This compound, which has received the name o *phosphuret of carbon*, was first examined by Mr P oust, the celebrated professor of chemistry in S ain. It is the red substance which remains beh nd when new-made phosphorus is strained through s mois leather. In order to separate from it a small q antity of phosphorus which it contains in excess, it

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Such was the result obtained by Raymond. Dr Henry found that 1 inches of water took up only 2·14 inches of this gas at the temperatu of 60°. See *Phil. Trans.* 1803, p. 274.

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

Henry, Nicholson's quarto *Jour* ii. 247.

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[*].

Phosphurets.

9. Such are the properties of phosphorus, and the compounds which it forms with oxygen, hydrogen, and carbon. It is capable likewise of combining with many other bodies: the compounds produced are called *phosphurets*.

A poison.

10. 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[illegible]; that is, I suppose, in exciting the venereal appetite.

Composition.

11. Though nobody has hitherto succeeded in ascertaining the constituents of phosphorus, there is every reason to consider it as a compound. When acted upon by a powerful galvanic battery, Mr Davy found that it emitted hydrogen in considerable quantity. Hence it is not unlikely that hydrogen is one of its constituents. The other has not yet been observed in a separate state, but analogy renders it not improbable that it will be found to be of a metallic nature.

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

[†] Ibid. xxvii. 87.

[‡] Nicholson's *Journal*, iii. 85.

SECT. IV.

OF SULPHUR.

S LPHUR, distinguished also by the name of *brimstone*, w s known in the earliest ages. Considerable quantiti s of it are found native, especially in the neighbourh od of volcanoes, and it is procured in abundance by s bjecting the mineral called *pyrites* to distillation. The ancients used it in medicine, and its fumes were e ployed in bleaching wool*.

Properties.

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

It is a non-conductor of electricity, and of course bec mes electric by friction. Its specific gravity is 1·990.

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

Action of heat.

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

Flowers of sulphur.

When sulphur is heated to the temperature of about 70°, it rises up in the form of a fine powder, which

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* Pliny, lib. xxxv. c. 15.

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.*

When heated to the temperature of about 218° of Fahrenheit's thermometer, it melts and becomes as liquid as water. If this experiment be made in a thin glass vessel, of an egg shape, and having a narrow, mouth*, the vessel may be placed upon burning coals without much risk of breaking it. The strong heat soon causes the sulphur to boil, and converts it into a brown coloured vapour, which fills the vessel, and issues with considerable force out from its mouth.

Sulphur capable of crystallizing.

3. 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 *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. If the ex-

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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.

Chap. II.

pe ment be made in a glass vessel, or upon a flat plate of ron, the crystals will be perceived beginning to sh ot when the temperature sinks to 220°.

Converted by combustion into an acid.

. When sulphur is heated to the temperature of 560° in e open air, it takes fire spontaneously, and burns wi a pale blue flame, and at the same time emits a gr t quantity of fumes of a very strong suffocating od r. When set on fire, and then plunged into a jar fu of oxygen gas, it burns with a bright violet coloured ame, and at the same time emits a vast quantity of fu es. If the heat be continued long enough, the sulph r burns all away without leaving any ashes or *residu m*. If the fumes be collected, they are found to co sist entirely of *sulphuric acid*. By combustion, then, su hur is converted into an acid*. This fact was kn wn several centuries ago; but no intelligible explana on was given of it till the time of Stahl. That ch nist undertook the task, and founded on his experim its a theory so exceedingly ingenious, and supported y such a vast number of facts, that it was in a very sh t time adopted with admiration by the philosophic w ld, and contributed not a little to raise chemistry to th rank among the sciences from which the ridiculous p tensions of the early chemists had excluded it.

Stahl's explanation of this.

According to Stahl, there is only one substance in n re capable of combustion, which therefore he called PHLOGISTON; and all those bodies which can be set

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Acids are a class of compound bodies, to be afterwards described. Th y are distinguished by a sour taste, and by the property which they po ss of changing the blue colour of many vegetable infusions (of the flo rs of mallows, for instance, or red cabbage) to red.

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 show that sulphuric acid can be obtained by separating the phlogiston from sulphur, and that sulphur can be actually formed by combining together sulphuric acid and phlogiston. Both of these points Stahl undertook to demonstrate. If potash* and sulphur be mixed together and heated, they melt and form a brittle mass of a brown colour, consisting of the two substances combined together. Put this compound, previously reduced to powder, into a flat open vessel, and expose it to a gentle fire, the sulphur gradually disappears, and sulphuric acid is found in its place combined with the potash. In this case, said Stahl, the gentle heat dissipates the phlogiston and leaves the acid. To form the sulphur anew, it is only necessary to present to the acid a body containing phlogiston. Lamp black or charcoal is such a body: for it is combustible, and therefore, according to the theory of Stahl, contains phlogiston: when burnt, it leaves a very inconsiderable residuum,

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* The nature of *potash* shall afterwards be explained.

Chap. II.

and onsequently contains hardly any thing else than phl iston. He mixed together in a crucible the compou l consisting of sulphuric acid and potash, and one-four part by weight of pounded charcoal, covered the cruc le with another inverted over it, and applied a stro heat to it. He then allowed it to cool, and exami d its contents. The charcoal had disappeared, and ere only remained in the crucible a mixture of pota and sulphur combined together, and of a darker colo than usual from the residuum of the charcoal. No there were only three substances in the crucible at fi t, potash, sulphuric acid, and charcoal; two of thes have disappeared, and *sulphur* has been found in thei place. Sulphur then must have been formed by the mbination of these two. But charcoal consists of phl iston and a very small residuum, which is still foun in the crucible. The sulphur then must have bee formed by the combination of sulphuric acid and phl iston*. This simple and luminous explanation app red so satisfactory, that the composition of sulphur was ong considered as one of the best demonstrated trut in chemistry.

Unsatisfactory.

T ere are two facts, however, which Stahl either did not now, or did not sufficiently attend to, neither of whi is accounted for by his theory. The first is, that ulphur will not burn if air be completely excluded the second, that sulphuric acid is heavier than the sulp ur from which it was produced.

T account for these, or facts similar to these, suc-

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* S hl's *Opusc. Chymico-Physico-Med.* Anatomia sulphuris Comm. p. 74

ceeding 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 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 further diminution took place. On examining the sulphuret, it was found somewhat heavier

Real explanation by Lavoisier.

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

tl n when first introduced into the vessel, and the air
o the vessel wanted precisely the same weight. Now
tl s air had lost all its oxygen; consequently the whole
o that oxygen must have entered into the sulphuret.
P rt of the sulphur was converted into sulphuric acid;
a l as all the rest of the sulphuret was unchanged,
tl : whole of the increase of weight must have been
o ing to something which had entered into that part
o the sulphur which was converted into acid. This
s nething we know was oxygen. Sulphuric acid
t erefore must be composed of sulphur and oxygen;
f : as the original weight of the whole contents of the
v ssel remained exactly the same, there was not the
s nallest reason to suppose that any substance had left
t e sulphur.

It is impossible then that sulphur can be composed
o sulphuric acid and phlogiston, as Stahl supposed,
s ice sulphur itself enters as a part into the composi-
on of that acid. There must therefore have been
me want of accuracy in the experiment by which
ahl proved the composition of sulphur, or at least
me fallacy in his reasonings; for it is impossible that
iere can be two contradictory facts. Upon exami-
ing the potash and sulphur produced by Stahl's expe-
iment, we find them to be considerably lighter than
ie charcoal, sulphuric acid, and potash originally em-
loyed. Something therefore has made its escape during
ie application of the heat. And if the experiment be
onducted in a close vessel, with a pneumatic apparatus
ttached to it, a quantity of gas will be obtained exact-
y equal to the weight which the substances operated on
ave lost; and this weight considerably exceeds that of
ll the charcoal employed. This gas is *carbonic acid*

gas, which is composed of charcoal and oxygen. 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. In Stahl's first experiment, the change of sulphur into sulphuric acid was obviously owing to the absorption of oxygen from the air. Hence the reason why the mixture must be placed in an open vessel. The combustion of sulphur, then, is nothing else than the act of its combination with oxygen.

Constituents of sulphuric acid.

From the slow combustibility of sulphur, and the difficulty of condensing the acid fumes, it was not possible for Lavoisier to ascertain with how much it unites during its combustion in oxygen gas; but it may be converted into sulphuric acid by boiling it in a quantity of *nitric acid* *: and the proportion of oxygen with which it has united may be deduced from the increase of its weight. This experiment was first tried by Berthollet †; but his apparatus did not enable him to attain precision. Thenard ‡ and Chenevix § repeated it lately, and with proper precautions. According to the first, 100 parts of sulphur unite with 80; according to the last, with 62·6 of oxygen. But both of these chemists fell into a mistake in estimating the

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* This acid, called in common language *aqua fortis*, will be described hereafter.

† *Mem. Par.* 1781, p. 232.

‡ *Ann. de Chim.* xxxii. 66.

§ *Irish Trans.* 1802, p. 233.

quantity of sulphuric acid formed, which has been avoided in a late experiment on the same subject by Klaproth. The estimate of this eminent chemist, therefore, may be considered as approaching as nearly to precision as the present state of the science admits. According to him sulphuric acid is composed of

42·3 sulphur
57·7 oxygen

100·0

or 100 parts of sulphur combined with 136·5 of oxygen *.

Sulphurous acid.

4. But sulphur does not always unite with so great a quantity of oxygen: indeed it usually burns with a blue flame, and emits an exceedingly offensive smell. This smell is occasioned by the escape of a gas, which may be confined in proper vessels: it is *sulphurous acid*. By adding oxygen to it, we may convert it into sulphuric acid; a proof that it contains less oxygen than that acid. From a set of experiments which I made on sulphurous acid, it follows, that it consists of 82 parts of sulphuric acid united to 18 of sulphur. Hence its constituents must be

53 sulphur
47 oxygen

100

or 100 sulphur and 88·6 oxygen.

5. If sulphur be kept melted in an open vessel, it becomes gradually thick and viscid. When in this state,

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* Gehlen's *Jour.* v. 109.

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 sulphur soon recovers its original brittleness, but it retains its red colour. It is supposed at present, that sulphur, rendered viscid and red by a long fusion, has combined with a little oxygen; hence the term *oxide of sulphur* has been applied to it. This substance, when newly made, has a violet colour; it has a fibrous texture; its specific gravity is 2·325; it is tough, and has a straw colour when pounded. I found that 100 parts of it, when converted into sulphuric acid by means of nitric acid, became 220 parts, and therefore had united with 120 parts of oxygen. Hence it follows, that 107·3 parts would form 236 parts of sulphuric acid: but 100 parts of sulphur would form the same quantity of acid; therefore 107 parts of our oxide, by this reasoning, are composed of 100 sulphur and seven oxygen*.

Oxide of sulphur.

Lac sulphuris.

6. When sulphur is first obtained by precipitation from any liquid that holds it in solution, it is always of a white colour, which gradually changes to greenish yellow when the sulphur is exposed to the open air. If this white powder, or *lac sulphuris*, as it is called, be exposed to a low heat in a retort, it soon acquires the colour of common sulphur; and, at the same time, a quantity of water is deposited in the beak of the retort. On the other hand, when a little water is dropt

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* Nicholson's *Jour*. vi. 102.

into melted sulphur, the portion in contact with the water immediately assumes the white colour of *lac sulphuris*. If common sulphur be sublimed into a vessel filled with the vapour of water, we obtain *lac sulphuris* of the usual whiteness, instead of the common flowers of sulphur. These facts prove that *lac sulphuris* is a compound of sulphur and water. Hence we may conclude that greenish yellow is the natural colour of sulphur. Whiteness indicates the presence of water *.

Sulphureted hydrogen gas.

7. Sulphur unites very readily to hydrogen, and forms a compound known by the name of *sulphureted hydrogen gas*. That such a gas existed, and that it was inflammable, had been observed by Rouelle †; but its properties and composition were first investigated by Scheele in 1777, who must therefore be considered as the real discoverer of it ‡. Bergman, in 1778, detailed its properties at greater length §, having examined it probably after reading the experiments of Scheele. In 1786, Mr Kirwan published a copious and ingenious set of experiments on it **. The Dutch chemists examined it in 1792 ††, and in 1794 Berthollet, with his usual sagacity, still further developed its properties ‡‡; and since that time several important facts respecting it have been ascertained by Proust and Thenard.

This gas may be procured by the following process. Melt three parts of iron filings and two parts of sulphur in a close crucible, and continue the heat till the

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* Nicholson's *Jour.* vi. p. 102.

† Macquer's *Dict.* i. 520.

‡ Scheele *on Air and Fire*, p. 186. Engl. Trans.

§ See his Treatise on Hot Mineral Waters, *Opusc.* i. 233. and Engl. Trans. i. 290.

** *Phil. Trans.* 1786, p. 118.

†† *Ann. de Chim.* xiv. 294.

‡‡ *Ibid.* xxv. 233.

How prepared.

sulphur ceases to sublime. Let the mixture cool, reduce it 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. Sulphureted hydrogen gas is disengaged abundantly, and fills the glass jar *. This gas was first called *stinking sulphureous air*, then *hepatic air*, and after Gengembre had ascertained its composition it got the name of *sulphureted hydrogen*.

Its properties.

It is colourless, and possesses the mechanical properties of air. It has a strong fetid smell, not unlike that of rotten eggs. It does not support combustion, nor can animals breathe it without suffocation. Its specific gravity, according to the experiments of Kirwan, is 1·106, that of air being 1·000 †; but Thenard makes it as high as 1·231 ‡. 100 inches of it, according to Kirwan's estimate, at the temperature of 60°, barometer 30 inches, weigh 34·286 grains; but according to Thenard's estimate, they weigh 38·17 grains.

This gas is absorbed by water very rapidly. From the late experiments of Henry, we learn that 100 cubic inches of that liquid is capable, at the temperature of 50°, of absorbing 108 inches of sulphureted hydrogen §. The water thus impregnated is colourless, but it has the smell of gas, and a sweetish nauseous taste. It converts vegetable blue colours to red, and has many

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* Scheele, on *Air and Fire*, p. 186.

† *On Phlogiston*, p. 31.

‡ *Ann. de Chim.* xxxii. 267.

§ *Phil. Trans.* 1803, p. 274.

ther properties analagous to those of acids. When he liquid is exposed to the open air the gas gradually makes its escape.

Its constituents.

When sulphureted hydrogen gas is set on fire, it burns with a bluish red flame, and at the same time deposits a quantity of sulphur. When the electric park is passed through it, sulphur is deposited, but ts bulk is scarcely altered*. It deposits sulphur also when agitated with nitric acid, or when that acid is dropt into water impregnated with it†. When mixed with common air it burns rapidly, but does not explode. When mixed with its own bulk of oxygen gas, and fired by electricity, an explosion is produced, and no sulphur deposited; but the inside of the glass is moistened with water. The products in this case are sulphuric acid and water. It was experiments similar to this that induced Gengembre to conclude that this gas is composed of hydrogen and sulphur. He explained its formation by supposing that the sulphur, when united to iron, acquires a strong tendency to absorb oxygen. Accordingly it decomposes water, which is always present, and unites to its oxygen. By this means a part of the sulphur is converted into sulphuric acid, as had been observed by Scheele‡. The hydrogen of the water, at the instant of its evolution, coming in contact with the rest of the sulphur, dissolves a portion of it, and forms sulphureted hydrogen. The Dutch chemists have shown, that when carbureted hydrogen gas is passed through melted sulphur, the sul-

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* Austin, *Phil. Trans.* 1788, p. 385.

† Scheele, *on Air and Fire.* p. 190.

‡ *Ibid.* 192.

Book I. Division I.

phur is blackened (they supposed by the deposition of charcoal), and the gas assumes the properties of sulphureted hydrogen*. This demonstrates the presence of hydrogen in it, though neither they nor Kirwan succeeded in forming sulphureted hydrogen by passing hydrogen gas through melted sulphur†.

To ascertain the constituents of this gas, Thenard dissolved 100·7 cubic inches of it in water, and by means of an acid converted all the sulphur that they contained into sulphuric acid. The sulphuric acid obtained, according to his estimate, weighed very nearly 49·2 grains. Now if we suppose sulphuric acid composed of 100 sulphur and 136·5 oxygen, we obtain 20·8 grains for the sulphur contained in 100·7 inches of this gas: but 100·7 inches weigh, according to Thenard, 38·44 grains. The difference of the two weights must be ascribed to hydrogen; of course sulphureted hydrogen is composed of

20·8 sulphur
17·6 hydrogen

38·4

Hence 100 parts of hydrogen are combined in the gas with 118 parts of sulphur‡. If this analysis be precise, it follows, that 100 cubic inches of hydrogen gas, in order to be converted into sulphureted hydrogen, combine with about 3 grains of sulphur, and are converted into about 14 cubic inches: so that hydrogen

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* *Ann. de Chim.* xxi. 55.

† Gengembre says, that he succeeded in obtaining sulphureted hydrogen gas by heating sulphur in hydrogen gas by means of a burning glass.

‡ *Ann. de Chim.* xxxii. 267.

gas, by dissolving sulphur, is reduced to little more than $\frac{1}{7}$th of its original bulk*.

Dissolves phosphorus.

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 spunge are plunged into it, they continue luminous in the air for some time after†.

Action of sulphur on charcoal.

8. Sulphur acts with considerable energy upon charcoal when assisted by heat. The phenomena were first observed by Messrs Clement and Desormes, during a set of experiments on charcoal. The process which they followed was this: Fill a porcelain tube with charcoal, and make it pass through a furnace in such a way that one end shall be considerably elevated above the other. To the lower extremity lute a wide glass tube, of such a length and shape that its end can be plunged to the bottom of a bottle of water. To the elevated extremity lute another glass tube filled with small bits of sulphur, and secured at the further end, so that the sulphur may be pushed forward by means of a wire, without allowing the inside of the tube to communicate with the external air. Heat the porcelain tube, and consequently the charcoal which it contains, to redness,

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* It is necessary to remark, that in all probability hydrogen unites to at least two dozes of sulphur. Thenard's gas seems, from its specific gravity, to have contained more sulphur than Kirwan's.

† Fourcroy and Vauquelin, *Ann. de Chim.* xxi. 206.

and continue the heat till air-bubbles cease to come from the charcoal; then push the sulphur slowly, and piece after piece, into the porcelain tube. A substance passes through the glass tube, and condenses under the water of the bottle into a liquid*.

Supersulphureted hydrogen.

This liquid was obtained by Lampadius in 1796, while distilling a mixture of pyrites and charcoal, and described by him under the name of *alcohol of sulphur* †. From a late and more detailed set of experiments on it, he drew, as a conclusion, that it is a compound of sulphur and hydrogen ‡. But Clement and Desormes considered it as a compound of sulphur and charcoal; and inform us, that when it is exposed to evaporate in open vessels a portion of charcoal remains behind. The subject has been lately investigated with accuracy by Berthollet junior §. From his experiments it follows, that the opinion of Lampadius is correct, that the liquid in question is a compound of sulphur and hydrogen without any perceptible mixture of carbon, and that it contains a greater proportion of sulphur than sulphureted hydrogen. We may therefore give it the name of *supersulphureted hydrogen.*

Properties.

This liquid is transparent, and colourless when pure, but very frequently it has a greenish yellow tinge. Its taste is cooling and pungent, and its odour strong and peculiar. Its specific gravity is 1·3. It does not mix with water. When put into the receiver of an air pump, and the air exhausted, it rises in bubbles through the water and assumes the form of a gas. The same

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* *Ann. de Chim.* x[illegible]

[illegible] *nals*, 1796, ii. 136.

‡ Gehlen's *Jour.* [illegible]

[illegible] rcueil, i. 304.

cl nge takes place when it is introduced to the top of a arometer tube; but it is again condensed into a liq id when the tube is immersed under mercury.

This compound burns easily like spirit of wine and n ny other liquids. During the combustion it emits a s lphureous odour. When a little of it is put into a I ttle filled with oxygen gas, it gradually mixes with t oxygen, and asumes the gaseous form. If a burni g taper be applied to the mouth of the bottle, the ı ixture burns instantaneously, and with an explosion s violent as to endanger the vessel. It assumes the g seous form in the same way when placed in contact ith air. This mixture does not detonate when kindled, ıt burns quietly.

This liquid dissolves phosphorus readily. It dis lves likewise a small portion of sulphur; but has no tion whatever on charcoal*.

During the action of the sulphur on the charcoal a onsiderable portion of sulphureted hydrogen gas is also volved. Indeed it appears from the experiments of erthollet, junior, that the formation of the supersul ureted hydrogen, in a liquid state, depends upon the roper regulation of the heat, and upon the rapidity ith which the sulphur comes in contact with the char oal. When too much sulphur is passed through the arcoal, part of it escapes and condenses, but retains ı it a portion of hydrogen. The proportion of hydro en in the liquid which condenses, and likewise in the as formed, varies considerably according to circum ances.

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* Ann. de Chim. xlii. 136.

These experiments demonstrate that charcoal contains hydrogen as a constituent. The charcoal which remains in the tube after the process is unaltered in its appearance, but it retains a little sulphur, with which it is chemically combined. This sulphur may be burnt away by the application of heat in the open air. But the charcoal itself remains unconsumed, and does not burn without difficulty even when kept in a strong red heat.

By the application of a sufficiently strong and long continued heat to the charcoal while sulphur is made to come in contact with it, the whole disappears, and a gas passes over, which from the examination of Berthollet appears to be a triple compound of sulphur, carbon, and hydrogen*.

Sulphuret of phosphorus.

9. Sulphur and phosphorus readily combine with each other, as was first ascertained by Margraf†. Pelletier afterwards examined the combination with care‡. Some curious observations were published on the formation of this compound by Mr Accum§; and soon after the circumstances under which it takes place were explained with precision by Dr Briggs||.

All that is necessary is to mix the two substances together, and apply a degree of heat sufficient to melt them, as Pelletier first observed. The compound has a yellowish white colour, and a crystallized appearance¶. The combination may be obtained by heating the mixture in a glass tube, having its mouth properly

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* Mem. D'Arcueil, i 324.

† *Opusc.* i. 11.

‡ *Jour. de Phys.* xxxv. 382.

§ Nicholson, vi.

|| *Ibid.* vii. 58.

¶ Briggs, *Ibid.*

s ured from the air. The sulphuret of phosphorus,
t us prepared, is more combustible than phosphorus.
I it be set on fire by means of a hot wire, allowed to
b rn for a little, and then extinguished by excluding
t e air, the phosphorus, and perhaps the sulphur, is oxi-
d ted, and the mixture acquires the property of ta-
k ng fire spontaneously as soon as it comes in contact
w th air*.

The combination may be procured also by putting
t e two bodies into a retort, or flask, filled with water,
a d applying heat cautiously and slowly. They com-
b ne together gradually as soon as the phosphorus is
m elted. It is necessary to apply the heat cautiously,
b cause the sulphuret of phosphorus has the property
o decomposing water, as had been observed by Mar-
g af, and ascertained by Pelletier. The rate of decom-
p sition increases very rapidly with the temperature, a
p rtion of the two combustibles being converted into
a ds by uniting to the oxygen: the hydrogen at the
m oment of its evolution unites with sulphur and phos-
p orus, and forms sulphureted and phosphoreted gases.
T his evolution, at the boiling temperature, is so rapid
a to occasion violent explosions, as I accidentally ob-
s rved some years ago. Mr Accum has lately exami-
n d the circumstances attending this explosion, and found
t at the gas emitted burns spontaneously, and leaves
p osphoric and sulphuric acids. The sulphuret of phos-
p orus formed under water has a yellow colour. It
g es to the water in which it is kept an acid taste,
a d the smell of sulphureted hydrogen. It burns, ac-

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* Briggs, *Ibid.*

cording to Dr Briggs, at a temperature considerably lower than a similar compound made in the dry way. This induces him to conclude, that during the combination a little water is decomposed, and the oxygen expended in converting the sulphur and phosphorus into oxides.

The sulphuret of phosphorus may be distilled over without decomposition. Indeed it was by distillation that Margraf first obtained it. Sulphur and phosphorus, by combining, acquire a considerable tendency to liquidity; and this tendency is a maximum when the two bodies are combined in equal proportions. The following table exhibits the result of Pelletier's experiments on the temperatures at which the compound becomes solid when the substances are united in various proportions*:

8	Phosphorus	congeals at 77°
1	Sulphur	
8	Phosphorus	.... at 59°
2	Sulphur	
8	Phosphorus	.... at 50°
4	Sulphur	
8	Phosphorus	.... at 41°
8	Sulphur	
4	Phosphorus	.... at 54·5°
8	Sulphur	
$2\frac{2}{3}$	Phosphorus	.... at 99·5°
8	Sulphur	

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* *Ann. de Chim.* iv. 10.

Chap. II.

When the sulphur predominates, this compound may be called *phosphuret of sulphur*; when the phosphorus e ceeds, it may be called *sulphuret of phosphorus*.

10. From an experiment of Mr Clayfield made in 1 99, and lately described by Mr Davy*, and from simi ar experiments performed still more lately by Bertl llet junior†, there is reason to conclude that sulphur c tains hydrogen as a constituent. Mr Clayfield disti ed a mixture of three parts copper filings, and one p t powdered sulphur, both well dried, and obtained a uantity of sulphureted hydrogen gas. Berthollet disti ed sulphur mixed with copper, and with iron, and w h mercury, and obtained the same gas, especially w en mercury was used. Sulphur, then, is in all prob ility a compound. But as we are ignorant of the o er constituent of this substance, and as we do not k ow whether the hydrogen enters into the compositi n of sulphuric acid, we cannot venture as yet to place i n the class of compound combustibles.

* * *

Such are the properties of the simple combustibles, a l such the combinations which they form with oxyg n and with each other. Hydrogen, as far as we know a present, is really a simple body; but charcoal, phosp orus, and sulphur, are certainly compounds containing h drogen as a constituent. Whether this hydrogen enters i o the acid compounds which these three bodies form

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[*] On the *decomposition and composition of the fixed alkalies. Phil. T s.* 1808.

[†] *Mem. D'Arcueil*, i. 327.

with oxygen; or whether these acids consist merely of the other unknown constituent combined with oxygen, has not been determined. But the first of these suppositions is probable, though it would be difficult to ascertain its truth by actual experiment.

Hydrogen in a separate state can only be exhibited in the state of gas, and cannot therefore be compared with the rest in its properties. Carbon is always solid, and cannot be fused, far less volatilized, by any degree of heat which we can raise. Sulphur and phosphorus bear a striking resemblance to each other. They are both solid, both fusible by heat, both volatilizable, and both boil and assume the form of vapour when sufficiently heated.

Combinations with oxygen.

It is the combustibility of these bodies, and the strong tendency which they have to unite with oxygen, which constitutes their charateristic property. They are all capable of condensing a certain determinate portion of this principle; and when once they have combined with that portion, they cannot unite with any more. In chemical language, they are then said to be *saturated* with oxygen. Now the proportion of oxygen with which each is capable of uniting, is exceedingly different, as will appear from the following table:

100 hydrogen unites with	597·7 oxygen
100 carbon	257·0
100 phosphorus	154·0
100 sulphur	138·7

Affinity for oxygen.

This difference claims particular attention. Berthollet has ingeniously supposed that the affinity of one body for another is proportional to the quantity of it which it is capable of condensing. The phenomena of che-

Chap. II.

m try agree well with this supposition. But if we adm it, we must suppose the affinity of the simple comb tibles for oxygen to be in the order which we have fc owed in describing them. Hydrogen will have the g atest affinity, carbon will be next, then phosphorus; ai sulphur will have the weakest affinity of all.

Hydrogen when saturated with oxygen forms water; th other three combustibles form acids, the corrosive qu lities of which become stronger, the smaller the qu ntity of oxygen necessary to saturate the combustib . This fact is curious. Berthollet supposes that th properties of oxygen are disguised *best* when it is co nbined with those bases for which it has the stronges affinity, and that its predominant qualities begin to di play themselves as the affinity of the base diminishes. T is notion, which is ingenious enough, if applied to o ygen, would lead us to conclude, that when in a conde sed state it is of a *corrosive* nature, unless when its ac ion is checked by the body to which it is united. A n ion that accords well with the great activity of this i portant substance.

Hydrogen forms one compound;

Hydrogen combines only with oxygen in one proporti n; but all the rest are capable of uniting with vario doses of it.

Carbon, three;

Carbon is believed to be capable of uniting with three d es of it. The first compound is supposed to be a b ck powder resembling charcoal. It is rather hypoth tical at present. When ascertained it may be called *ca bonous oxide*. The second compound is *carbonic oxia* gas; the third *carbonic acid*.

Phosphorus, three;

Phosphorus when imperfectly burnt is convered into *ox le of phosphorus*. When left exposed to the open air, it gradually combines with oxygen, and is converted into an acid liquid called *phosphorous acid.* When set on fire, it combines with a maximum of oxygen, and is converted into white flakes, destitute of smell, called *phosphoric acid.*

Sulphur, three.

Sulphur, when kept long in a state of fusion, combines with a small dose of oxygen, and is converted into *oxide of sulphur.* When heated to 560° in the open air, it burns with a blue flame, combines with oxygen, and forms an acid which has a peculiarly suffocating odour, and is called *sulphurous acid.* When mixed with nitre and set on fire, it combines with a maximum of oxygen, and forms an acid without smell called *sulphuric acid.*

Combination of the combustibles with each other.

All the simple combustibles are capable of combining with each other. Chemists have agreed to give to all such combinations a name ending in *uret*, and derived from that ingredient which is supposed to characterize the compound. Thus we have *sulphuret of phosphorus*, of *carbon*, and of *hydrogen*; but the last compound being gaseous, is usually denominated *sulphureted hydrogen gas.* We have likewise *phosphuret of sulphur*, of *carbon*, and of *hydrogen*, or *phosphureted hydrogen gas.* We have also two species of *carbureted hydrogen gas.* All these compounds retain their combustibility.

CHAP. III.

OF SIMPLE INCOMBUSTIBLES.

Characters.

HE characteristic property of those substances which
erm simple incombustibles, is a strong tendency to
ite to oxygen; the combination is not accompanied
the emission of heat and light, and the compounds
med are capable of supporting combustion. Only
o substances possess this character; namely, *azote*
d *muriatic acid*. There are indeed two other incom-
stible bodies not hitherto decompounded; but they
not combine with oxygen at all: and at present ana-
gy leads us to place them among the compounds.

SECT. I.

OF AZOTE.

Method of procuring azotic gas.

I. AZOTE, called also NITROGEN, by some chemists, may be procured by the following process: 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 further diminution*. This residuum has obtained the appellation of *azotic gas*. There are other methods of obtaining it more speedily. If phosphorus, for instance, be substituted for the iron-filings and sulphur, the absorption is completed in less than 24 hours. The following method, first pointed out by Berthollet, furnishes very pure azotic gas, if the proper precautions be attended to. Very much diluted *aquafortis*, or *nitric acid* as it is called in chemistry, is poured upon a piece of muscular flesh, and a heat of about 100° applied. A considerable 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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* This experiment was first made by Dr Hales.

† See his thesis *De Aere Mephitico*, published in 1772.—" Sed aer salubris et purus respirationem animali non modo ex parte fit mephiticus, sed

Sch le procured it by the first mentioned process as earl as 1776, and proved that it was a distinct fluid*.

The air of the atmosphere contains about 0·79 par (in bulk) of azotic gas; almost all the rest of it is c ygen gas. Mr Lavoisier was the first philosopher wh published this analysis, and who made azotic gas kn vn as a component part of air. His experiments we published in 1773†. Scheele's Treatise on Air an Fire, in which his analysis is contained, was not pu ished till 1777.

Weight.

Azotic gas is invisible and elastic like common ai which it resembles in its mechanical properties. It as no smell. Its specific gravity, according to Kirw , is 0·985‡, that of air being 1·000. Lavoisier m tes it only 0·978§, and with this the statement of D y coincides exactly‖. According to Mr Kirwan, 1(cubic inches of it, at the temperature of 60°, baro eter 30 inches, weigh 30·535 grains; according to L oisier and Davy, they weigh 30·338 grains.

Destroys life,

It cannot be breathed by animals without suffocati . If obliged to respire it, they drop down dead al-

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et *liam indolis suæ mutationem inde patitur.* Postquam enim omnis aer n hiticus (*carbonic acid gas*) ex eo, ope lixivii caustici secretus et abducti fuerit, *qui tamen restat* nullo modo salubrior inde evadit; nam quamv nullam ex aqua calcis præcipitationem faciat haud minus quam antea et *mmam et vitam extinguit*," Page 17. When Hauxbee passed air through re hot metallic tubes, he must have obtained this gas; but at that time th difference between gases was ascribed to fumes held in solution. See P . *Trans.* Abr. v. 613.

† On *Air and Fire*, p. 7.

See his remarks on Scheele's works, *Mem. Par.* 1781, p. 397.

On *Phlogiston*, p. 27.

§ Lavoisier's *Elements*.

Researches, p. 565.

And prevents combustion.

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[†].

Absorption by water.

4. This gas is not sensibly absorbed by water; nor indeed are we acquainted with any liquid which has the property of condensing it. Dr Henry ascertained, that when water is previously deprived of all the air which it contains, 100 inches of it are capable of absorbing only 1·47 inches of azotic gas at the temperature of 60°[‡].

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[*] Hence the name *azote*, given it by the French chemists, which signifies "destructive to life."

[†] Nicholson's *Journal*, ii. 8.

[‡] *Phil. Trans.* 1803, p. 274.

I 1. When electric sparks are made to pass through common air confined in a small glass tube, or through a mixture of oxygen gas and azotic gas, the bulk of the air diminishes. This curious experiment was first made by Dr Priestley, who ascertained at the same time, that if a little of the blue infusion of *litmus* be let up into the tube it acquires a red colour *; hence it follows that an acid is generated. Mr Cavendish ascertained, that the diminution depends upon the proportion of oxygen and azote present; that when the two gases are mixed in the proper proportions they disappear altogether, being converted into *nitric acid*. Hence he inferred that nitric acid is formed by the combination of these two bodies. This important discovery was communicated to the Royal Society on the 2d June 17 5. The combination of the gases, and the formation of the acid, was much facilitated, he found, by introducing into the tube a solution of *potash* in water. This body united with the nitric acid as it was produced, and formed with it the salt called *nitre*. In Mr Cavendish's first experiments there was some uncertainty, both in the proportion of oxygen gas and of common air which produced the greatest diminution in a given time, and in the proportion of the two gases which disappeared by the action of the electricity. The experiment was twice repeated in the winter 1787-8 by Mr Gilpin, under the inspection of Mr Cavendish, and in the presence of several members of the Royal Society. The last of these experiments, which was conducted with every possible precaution to ensure ac-

Combines with oxygen,

And forms nitric acid.

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* Priestley on *Air*, ii. 248.

curacy, I shall consider as nearest the truth. It lasted rather more than a month. During the course of it there were absorbed 4090 measures of oxygen gas contaminated with $\frac{1}{12}$ part of azote, and 2588 measures of common air. Now if we suppose that common air contains 22 parts in the 100 of oxygen gas, and make the necessary corrections, we shall have 4532 measures of oxygen gas, and 2146 measures of azotic gas, or very nearly 2 measures of azotic gas to $4\frac{1}{4}$ of oxygen. 453·2 inches of oxygen weigh about 154 grains, and 214·6 measures of azote about 65 grains.

Proportion of its constituents.

According to this statement, we have nitric acid composed of 100 parts by weight of azote united to 236 of oxygen; or in the hundred parts

29·77 azote
70·23 oxygen

100·00 *

This result agrees almost exactly with the subsequent experiments of Mr Davy, according to which the constituents of nitric acid are

29·5 azote
70·5 oxygen

100·0 †

Two oxides of azote;

2. Nitric acid is a heavy liquid, usually of a yellow colour, which acts with great energy upon most substances, chiefly in consequence of the facility with which it yields a portion of its oxygen. If a little phosphorus or sulphur, for instance, be put into it, the acid

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* *Phil. Trans.* 1788, p. 266.

† *Researches*, p. 565.

1. Nitrous gas;

whe a little heated gives up oxygen to them, and convert them into acids precisely as if the two bodies were subj cted to combustion. In this case the nitric acid, by sing a portion of its oxygen, is changed into a spec s of gas called *nitrous gas*, which flies off and occasi s the effervescence which attends the action of nitri acid on these simple combustibles. Nitrous gas is p cured in greater abundance, as well as purity, by diss ving copper or silver in nitric acid. The gas may be ceived in a water trough in the usual way. It pos sses the curious property of combining with oxygen he instant it comes in contact with it, and of forming itric acid. Hence the yellow fumes which appear whe nitrous gas is mixed with common air. This com ination furnishes a sufficient proof that the constitue s of nitrous gas are azote and oxygen, and that it con ins less oxygen than nitric acid. It is therefore an *ide of azote*.

2. Gaseous oxide.

When iron filings are kept for some days in nitro gas, they deprive it of a portion of its oxygen, and onvert it into a gas which no longer becomes yellov when mixed with common air, but in which phosph us burns with great splendour, and is converted int phosphoric acid. This combustion and acidificatio is a proof that the new gas contains oxygen. Its for ation demonstrates that it contains azote, and that it l s less oxygen than nitrous gas. It is therefore an *oxi of azote* as well as the last described gas. The na *gaseous oxide of azote* has been given to it.

hus we learn that azote is capable of uniting with thr dozes of oxygen, and of forming two oxides and one acid. We shall find afterwards that there is still an her acid composed of the same ingredients.

III. The combinations of azote with simple combustibles are scarcely so numerous; but some of them are of great importance.

Combines with hydrogen.

1. When putrid urine, wool, shavings of horn, and many other animal substances, are subjected to distillation, among other products there is obtained a substance which has a very pungent odour, and which is well known under the names of *hartshorn* and *volatile alkali*[*]. It may be procured in greatest purity from the salt called *sal ammoniac.* Pound this salt, and put it into a flask together with thrice its weight of ground quicklime, and luting on a bent tube, plunge the extremity of it into a mercurial trough, and apply heat to the flask. A gas comes over, which is *hartshorn* in a state of purity; by chemists it is usually called *ammonia.* It is light, absorbed in great abundance by water, has a pungent taste, and gives a green colour to vegetable blues. When electric sparks are passed through this gas, its bulk is doubled, and it is converted into a mixture of hydrogen and azotic gases.

This was considered as a demonstration of its composition; but from the late experiments of Mr Davy, there is reason to conclude, that besides hydrogen and azote it contains also a portion of oxygen[†]. It is difficult to form ammonia by uniting its constituents artificially. However, Dr Austin succeeded in combining them.

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[*] The term *alkali* is applied in chemistry to a variety of substances which have the property of giving a green colour to vegetable blues.

[†] The details will be given when we come to treat of ammonia.

When they are in the gaseous state, the union does t take place; but when hydrogen, at the instant of its olution, comes in contact with azotic gas, ammonia is 'med. Dr Austin filled a jar with azotic gas, placed over mercury, and let up into it some moistened iron ngs. Now iron filings have the property of decom- sing water. They unite with its oxygen, and allow hydrogen to escape. There was suspended in the : a paper tinged blue with radish. In a day or two became green, and thus indicated the formation of amonia; for no gas but ammonia has the property of anging vegetable blues to green. When nitrous gas as substituted for azote, the ammonia was evolved ore speedily. The experiment succeeded also with mmon air, but more slowly [*]. When nitrous gas d sulphureted hydrogen are mixed, ammonia is form- , as Kirwan first observed [†]. In this case the de- mpositions and new combinations are more com- icated.

Dissolves charcoal,

2. No compound of azote and carbon is at present nown; but if we believe Fourcroy, azotic gas has the operty of dissolving a little charcoal. For according him, azotic gas, obtained from animal substances by erthollet's process, when confined long in jars, depo- tes on the sides of them a black matter, which has the roperties of charcoal [‡].

Phosphorus,

3. Phosphorus plunged into azotic gas is dissolved in small proportion. Its bulk is increased about $\frac{1}{40}$ [§],

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[*] *Phil. Trans.* 1788, p. 382.

[†] *Ibid.* p. 384.

[‡] Fourcroy, *Ann. de Chim.* i. 45.

[§] Berthollet.

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

And sulphur.

4. Fourcroy informs us, that when sulphur is melted in azotic gas, part of it is dissolved, and *sulphureted azotic gas* formed. This gas has a fetid odour. Its properties are still unknown [†]. It is said to have been lately discovered by Gimbernat in the waters of Aix-la-Chapelle [‡].

Attempts to decompose azote.

IV. As azote has never yet been decompounded, it must, 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 his 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;

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

[†] Fourcroy, i. 200.

[‡] *Jour. de Chim.* ii. 114.

and t even contributes by its affinity to produce that sep ation: The moment the air has combined with as mu ı phlogiston as it can receive, or, to use a chemical erm, the moment it is *saturated* with phlogiston, con ustion necessarily stops, because no more phlogiston an leave the combustible*: Air saturated with phl giston is azotic gas. This was a very ingenious the y, and, when Dr Priestley published it, exceeding plausible. A great number of the most eminent che ists accordingly embraced it: But it was soon after iscovered, that during combustion the quantity of air instead of increasing, as it ought to do if phlogiston be dded to it, actually diminishes both in bulk and we ht. There is no proof, therefore, that during combus on any substance whatever combines with air, but rat er the contrary. It was discovered also, that a qua tity of air combines with the burning substance durin combustion, as we have seen to be the case with sul hur, phosphorus, carbon, and hydrogen; and that thi air has the properties of oxygen gas. These disco eries entirely overthrew the evidence on which Dr Pr stley's theory was founded.

Supposed, 1. A compound of oxygen and phlogiston.

But erroneously.

Iore lately a new theory concerning the composition of zote has been proposed, and variously modified by di erent chemists. As this theory has occasioned a co troversy which has been maintained in Germany

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* This ingenious theory was first conceived by Dr Rutherford, as appe s from the following passage of his thesis. "Ex iisdem etiam deduce licet quod aer ille malignus (azotic gas) componitur ex *aere atmosp ico cum phlogisto unito et quasi saturato.* Atque idem confirmatur eo, qu d aer qui metallorum calcinationi jam inserviit, et phlogiston ab iis al puit, ejusdem plane sit indolis." *De Aëre Mephitico*, p. 20.

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 inside, 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 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 Westrumb drew the same conclusion from an experiment of his own; and hence inferred, 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,

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[*] Priestley *on Air*, ii. 407.

[†] Crell's *Annals*, 1785, i. 304.

[‡] *Ibid.* p. 499.

bo by reasoning and experiments, to prove the truth
of Westrumb's theory*. This paper drew the atten-
ti of the associated Dutch chemists, Deimann, Troost-
w h, and Lawerenburg ; and induced them to make
a ry complete set of experiments, an account of which
th published 1798†. Their experiments coincided
ex tly with those of Dr Priestley. No gas made its
ap earance except when the instruments employed were
of arthen ware, and of course capable of being pene-
tr ed by air. Wiegleb's method of making the ex-
pe ment was to lute the tube of a tobacco pipe to a re-
to containing some pure water. The tobacco pipe
w heated red hot by means of a charcoal fire ; and
th the water in the retort being made to boil, the
st m passed through the red hot pipe. The Dutch
ch mists found, that when instead of a tobacco pipe a
gl s or metallic tube was used, or when the tobacco
pi e was covered with a glass tube, no gas appeared,
u ess the tube was cracked : and that when gas was
ol ained, it was always the same with the air on the
o side of the tube ; that is to say, a mixture of carbo-
n acid and azotic gas, when the tube was heated in a
cl rcoal fire, and common air when the tube was with-
d wn from the fire. Thus their experiments coincided
p cisely with those of Dr Priestley, and led them to
th same conclusion. Mr Wiegleb attempted to an-
s r the objections of the Dutch chemists, and to esta-
bl h his own theory by new experiments ; but he has

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* *Ibid.* 1796, ii. 467.

† *Ann. de Chim.* xxvi. 310.

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 obtained 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 misled by some circumstance or other. His theory of course falls to the ground.

But without proof.

Its component parts unknown.

Thus as all the attempts to decompose azote 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

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[*] Crell's *Annals*, 1799, i. 45, &c. [†] *Ann. de Chim.* xxxiv. 3.
[‡] *Ibid.* xxxv. 23.

Chap. III.

for if it were possible to prove that azote 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 *.

SECT. II.

OF MURIATIC ACID.

Preparation.

MURIATIC acid, the second of the simple incombustibles, may be procured by the following process: Let a small pneumatic trough be procured, hollowed out of a single block of wood, about 14 inches long, 7 broad, and 6 deep. After it has been hollowed out to the depth of an inch, leave 3 inches by way of shelf on one side, and cut out the rest to the proper depth, giving the inside of the bottom a circular form. Fig. 8. represents a section of this trough. Two inches from each end cut a slit in the shelf to the depth

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* Nicholson's *Journal*, iv. 193.

Book I. Division I.

of an inch, and broad enough to admit the end of small glass tubes, or the points of small retorts. This trough is to be filled with mercury to the height of $\frac{1}{4}$ inch above the surface of the shelf. Small glass jars are to be procured of considerable thickness and strength, and suitable to the size of the trough. One of them being filled with mercury by plunging it into the trough, is to be placed on the shelf over one of the slits. It ought to be supported in its position; and the most convenient method of doing that is, to have a brass cylinder two inches high screwed into the edge of the trough just opposite to the border of the shelf. On the top of it is fixed two flat pieces of brass terminating each in a semicircle, moveable freely upon the brass cylinder, and forming together a brass arm terminating in a circle, the centre of which is just above the middle of the slit in the shelf, when turned so as to be parallel to the edge of the shelf. This circle is made to embrace the jar; being formed of two distinct pieces, its size may be increased or diminished at pleasure, and by means of a brass slider it is made to catch the jar firmly.

The apparatus being thus disposed, two or three ounces of common salt are to be put into a small retort, and an equal quantity of sulphuric acid added; the beak of the retort plunged below the surface of the mercury in the trough, and the heat of a lamp applied to the salt in its bottom. A violent effervescence takes place; and air bubbles rush in great numbers from its beak, and rise to the surface of the mercury in a visible white smoke, which has a peculiar odour. After allowing a number of them to escape, till it is supposed that the common air which previously existed in the retort has been displaced, plunge its beak into the slit in e shelf, over which the glass jar has been placed. Th air bubbles soon displace the mercury and fill the jar The gas thus obtained is called *muriatic acid gas*.

his substance in a state of solution in water was kn vn even to the alchymists; but in a gaseous state it wa first examined by Dr Priestley, in an early part of tha illustrious career in which he added so much to our kn vledge of gaseous bodies.

Properties.

. Muriatic acid gas is an invisible elastic fluid, reser bling common air in its mechanical properties. Its sp ific gravity, according to the experiments of Mr Ki wan, is 1·929, that of air being 1·000, at the tempera re of 60°, barometer 30 inches; 100 cubic inches of t weigh 59·8 grains. Its smell is pungent and pecu ar; and whenever it comes in contact with common ai it forms with it a visible white smoke. If a little of t be drawn into the mouth, it is found to taste exce ively *acid*; much more so than vinegar.

Does not support combustion nor ife.

. Animals are incapable of breathing it; and when pl nged into jars filled with it, they die instantaneously n convulsions. Neither will any combustible burn in t. It is remarkable, however, that it has a consid able effect upon the flame of combustible bodies; f if a burning taper be plunged into it, the flame, just b fore it goes out, may be observed to assume a green c our, and the same tinge appears the next time the t er is lighted *.

Tinges vegetable blues red.

3. If a little of the blue coloured liquid, which is obt ned by boiling red cabbage leaves and water in a tin ssel, be let up into a jar filled with muriatic acid

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* Priestley, ii. 293.

gas, it assumes a fine red colour. This change is considered by chemists as a characteristic property of *acids*.

Absorbed by water.

4. If a little water be let up into a jar filled with this gas, the whole gas disappears in an instant; the mercury ascends, fills the jar, and pushes the water to the very top. The reason of this is, that there exists a strong affinity between muriatic acid gas and water; and whenever they come in contact, they combine and form a liquid; or, which is the same thing, the water absorbs the gas. Hence the necessity of making experiments with this gas over mercury. In the water cistern not a particle of gas would be procured. Nay, the water of the trough would rush into the retort and fill it completely. It is this affinity between muriatic acid gas and water which occasions the white smoke that appears when the gas is mixed with common air. It absorbs the vapour of water which always exists in common air. The solution of muriatic acid gas in water is usually denominated simply *muriatic acid* by chemists.

In this state it appears to have been known to the alchymists; but Glauber was the first who extracted it from common salt by means of sulphuric acid. It was first called *spirit of salt*, afterwards *marine acid*, and now, pretty generally, *muriatic acid**. It is prepared for commercial purposes, by mixing together one part of common salt and seven or eight parts of clay, and distilling the mixture; or by distilling the usual proportion of common salt and sulphuric acid, and re-

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* From *muria*.

ceiving the product in a receiver containing water. For chemical purposes it may be procured pure in the following manner.

A hundred parts of dry common salt are put into a glass matrass, to which there is adapted a bent glass tube that passes into a small Wolf's bottle. From this bottle there passes also a glass tube into another larger bottle, containing a quantity of water equal in weight to the common salt employed. When the apparatus is properly secured by luting, 75 parts of sulphuric acid are poured into the common salt through a mouth of the matrass, furnished with a proper stopper. Heat is then applied. The sulphuric acid displaces the muriatic acid, which passes over and is condensed in the water of the large bottle, while any sulphuric acid that may be driven over by the heat is condensed in the smaller bottle, and thus does not injure the purity of the muriatic acid.

Proportion.

A cubic inch of water at the temperature of 60°, barometer 29·4°, absorbs 515 inches of muriatic acid gas, which is equivalent to 308 grains nearly. Hence water thus impregnated contains 0·548, or more than half its weight of muriatic acid, in the same state of purity as when gaseous. I caused a current of gas to pass through water till it refused to absorb any more. The specific gravity of the acid thus obtained was 1·203. If we suppose that the water in this experiment absorbed as much gas as in the last, it will follow from it, that six parts of water, by being saturated with this gas, expanded so as to occupy very nearly the bulk of 11 parts; but in all my trials the expansion was only to nine parts. This would indicate a specific gravity of 1·477; yet upon actually trying water thus saturated, its specific gravity was only 1·203. Is this difference owing to the gas that escapes during the taking of the specific gravity?

During the absorption of the gas, the water becomes hot. Ice also absorbs this gas, and is at the same time liquefied. The quantity of this gas absorbed by water diminishes as the heat of the water increases, and at a boiling heat water will not absorb any of it. When water impregnated with it is heated, the gas is again expelled unaltered. Hence muriatic acid gas may be procured by heating the common muriatic acid of commerce. It was by this process that Dr Priestley first obtained it.

Properties.

The acid thus obtained is colourless: it has a strong pungent smell similar to the gas, and when exposed to the air is constantly emitting visible white fumes. The muriatic acid of commerce is always of a pale yellow colour, owing to a small quantity of iron which it holds in solution.

Strength.

As muriatic acid can only be used conveniently when dissolved in water, it is of much consequence to know how much pure acid is contained in a given quantity of liquid muriatic acid of any particular density. Now the specific gravity of the strongest muriatic acid that can easily be procured and preserved is 1·196: it would be needless, therefore, to examine the purity of any muriatic acid of superior density. Mr Kirwan calculated that muriatic acid, of the density of 1·196, contains 0·2528 of pure acid: then, by means of experiments, he formed the following TABLE*:

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* Nicholson's quarto *Jour.* iii. 213. My experiments, as the reader will observe, are not reconcileable with this table.

100 Parts Sp. Gravity.	Real Acid.	100 Parts Sp. Gravity.	Real Acid.
1·196	25·28	1·1282	16·51
1·191	24·76	1·1244	15·99
1·187	24·25	1·1206	15·48
1·183	23·73	1·1168	14·96
1·179	23·22	1·1120	14·44
1·175	22·70	1·1078	13·93
1·171	22·18	1·1036	13·41
1·167	21·67	1·0984	12·90
1·163	21·15	1·0942	12·38
1·159	20·64	1·0910	11·86
1·155	20·12	1·0868	11·35
1·151	19·60	1·0826	10·83
1·147	19·09	1·0784	10·32
1·1414	18·57	1·0742	9·80
1·1396	18·06	1·0630	8·25
1·1358	17·54	1·0345	5·16
1·1320	17·02	1·0169	2·58

Combines with oxygen,

II. Muriatic acid is capable of combining with oxygen, and forms with it compounds which have a considerable analogy to the compounds of azote with the same principle.

And forms, 1. Oxymuriatic acid;

1. When muriatic acid is poured upon black oxide of manganese, an effervescence takes place; and by the assistance of heat a gas comes over, which may be received over water. Scheele, the discoverer of this gas, called it *dephlogisticated muriatic acid;* but it is now known by the name of *oxy-muriatic* acid. It has a green colour, a most detestable odour, and is very readily absorbed by water, to which it communicates its colour and properties. Berthollet filled a bottle with this impregnated water, fitted a bent tube to its mouth, connected it with a water trough, and exposed it to sun-

shine; the liquid gradually lost its colour, bubbles of gas separated, and were collected in a jar. The gas on examination was found to be oxygen, and the water was impregnated with common muriatic acid. This experiment demonstrates, that the constituents of oxymuriatic acid are oxygen and muriatic acid. By estimating the bulk of the oxygen that escaped, and the weight of the acid that remained, Berthollet concluded that oxymuriatic acid is composed of about

89	muriatic acid
11	oxygen
100	

But Mr Chenevix has more lately, from an experiment to be described hereafter, made the proportion of oxygen much higher. According to him the gas is composed of about

77·5	muriatic acid
22·5	oxygen
100·0	

2. Hyperoxymuriatic acid.

2. When a current of oxymuriatic acid is passed through water holding potash in solution, a number of flat shining crystals are at last deposited. They were first obtained by Dr Higgins, but first examined and analysed by Berthollet. These crystals are called *hyperoxymuriate of potash*. When this salt is exposed to a sufficiently strong heat, it gives more than $\frac{1}{3}$d its weight of oxygen gas: the residue is a compound of muriatic acid and potash. The acid in this salt, of course, contains much more oxygen than oxymuriatic acid. Ac-

rding to Chenevix, who has lately examined it, the nstituents are

34	muriatic acid
66	oxygen
100	

Action on simple combustibles.

III. The action of muriatic acid on the simple ombustibles has not been examined with much at-ntion.

1. Hydrogen, as far as we know at present, does not nite with muriatic acid.

2. Carbon is not supposed to combine with it. Charoal has the property of absorbing it very rapidly; but e change produced by the absorption has not been scertained.

3. Phosphorus, according to Dr Priestley's experiments, absorbs very little muriatic acid *.

Sulphuret.

4. Sulphur, according to Dr Priestley, imbibes it lowly †. When a current of oxymuriatic acid gas is assed over flowers of sulphur in a glass vessel, the ulphur is gradually converted into a fine red liquid, which I consider as a compound of muriatic acid and xide of sulphur; and which, therefore, may be termed

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* Priestley *on Air*, ii. 283. He affirms that the phosphorus smokes nd gives light in muriatic acid gas as in common air; but on repeatg the experiment I perceived no such effects. Priestley's gas, of course, ontained air.

† Ibid. He says sulphur imbibed 1-5th, and left a residue of 4-5ths flammable air, burning with a blue flame. This experiment requires epetition.

*sulphureted muriatic acid**. It weighs more than triple the sulphur employed.

It is perfectly liquid; its colour is a fine red, intermediate between scarlet and crimson. When streaks of it run down the inside of the phial, they appear green by transmitted light. Its specific gravity is 1·623.

When exposed to air it smokes very much. It is very volatile, disappearing very rapidly when exposed to a moderate heat.

Its smell has a strong resemblance to that of sea-plants, but is much stronger. The eyes, when exposed to its fumes, are soon filled with tears, and acquire the same painful feeling as when exposed to the smoke of wood or peat.

Its taste is strongly acid, hot, and bitter, affecting the throat with a painful tickling.

It converts vegetable blue papers to red; but the change takes place slowly, unless the paper be dipt into water; the paper is not corroded unless heat be applied.

If a drop of it be let fall into a glass of water, the

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* Berthollet Junior has lately repeated my experiments on this curious compound (*Mem. D'Arcueil*, i. 161.) He endeavours to prove that the sulphur is not in the state of an oxide, but that the liquor is a triple compound of oxygen, sulphur, and muriatic acid, and thinks that his experiments are inconsistent with mine, because he extracted the sulphur pure, and not in the state of an oxide. It is plain from this that he has never consulted my paper published in Nicholson's *Jour*. vi. 104. He would have seen that I always obtained the sulphur in the same state, and inferred the presence of oxygen from the formation of sulphuric acid whenever the liquid is decomposed. A fact confirmed by his own experiments.

surface of the water becomes immediately covered with a film of sulphur; a greenish red globule falls to the bottom, which remains for some time like a drop of oil, but at last is converted into yellow flakes. These flakes have an acid taste, which they do not lose, though allowed to remain in water for several days; they are very ductile, and continue so, though left exposed to the air.

When thrown into warm nitric acid, a very violent effervescence takes place, and the whole mixture is thrown, with a kind of explosion, out of the vessel. If the acid be cold, the effervescence is at first slow, but heat is very soon evolved, and the same effects produced. When the proportion of nitric acid is great, and the sulphuret dropt in very slowly, the effervescence continues moderate; nitrous gas and oxymuriatic gas being evolved.

It dissolves phosphorus cold with great facility. No effervescence takes place; the solution has a fine amber colour, and is permanent. When evaporated, the phosphorus remains behind with a little sulphur, and at last takes fire. When the solution is mixed with liquid potash, the whole becomes beautifully luminous, and phosphuret of sulphur is precipitated.

According to my analysis, it is composed of

44·00 oxide of sulphur
35·75 muriatic acid
20·25 loss

100·00 *

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* See Nicholson's *Jour.* vi. 104

IV. We are not acquainted with any combination of muriatic acid and azote; but when mixed with nitric acid it forms a compound possessed of very remarkable properties: it was formerly called *aqua regia*, but is now better known by the name of *nitro-muriatic acid*.

Action of electricity.

V. When electric explosions are made to pass through muriatic acid gas, its bulk is diminished, and hydrogen gas is evolved. At the same time, if the experiment be made over mercury, a quantity of muriate of mercury is formed. These changes continue to take place for a limited time only; after which electricity ceases to produce any farther change. They are always proportional to the moisture of the gas, and have been shown by Dr Henry to be owing to the decomposition of the water held in solution by the gas. The oxygen of the water combines with part of the acid, and forms oxymuriatic acid, while its hydrogen is set at liberty. Dr Henry has shown that 100 cubic inches of muriatic acid gas, after being made as dry as possible, by standing over quicklime or other bodies which absorb moisture, still contain 1·4 grains of water in solution: but this water may be completely decomposed and removed by means of electricity. Here then is a method of depriving this gas altogether of water *. When muriatic acid gas and carbureted hydrogen gas are mixed, electricity decomposes the water, and carbonic acid and hydrogen gas are evolved. After the water is completely decomposed, electricity produces no farther effect †.

Destroys putrid miasmata.

VI. Morveau first showed that muriatic acid, in the state of gas, neutralizes putrid miasmata, and by that

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* Nicholson's *Journal*, iv. 209.

† Henry. Ibid.

me ns destroys their bad effects. In 1773, the cathedr of Dijon was so infected by putrid exhalations, that it as deserted altogether after several unsuccessful atter pts to purify it. Application was made to Mr M veau, at that time professor of chemistry at Dijon, to e whether he knew any method of destroying these ex lations. Having poured two pounds of sulphuric aci on six pounds of common salt, contained in a glass cap ule, which had been placed on a few live coals in the niddle of the church, he withdrew precipitately, and sh all the doors. The muriatic acid gas soon filled the whole cathedral, and could even be perceived at the do . After twelve hours, the doors were thrown open, an a current of air made to pass through to remove the gas. This destroyed completely every putrid odo *.

UCH are the properties of the simple incombustible bo es. Like the combustibles, their predominant charac er is their affinity for oxygen. But they unite withou the phenomena of combustion ; hence the compo nds which they form with oxygen are supporters of ombustion. The quantity of oxygen which each is ca ble of condensing does not differ nearly so much as we bserve in the case of the combustibles.

Combination with oxygen.

100 muriatic acid condenses 194 oxygen
100 azote .... 236 oxygen

If e judge of the affinity by the power of condensatio it will follow, that azote has a stronger affinity for

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* Jour. de Phys. i. 436.

oxygen than muriatic acid. If the properties of the oxygen predominates most in those compounds in which the base has the least affinity for it, then, in that case, hyperoxymuriatic acid ought to be a better supporter of combustion, and to act with more energy, than nitric acid; which is the case.

Azote unites with three dozes.

Azote unites with three doses of oxygen at least, and forms,

1. Nitrous oxide
2. Nitric oxide
3. Nitric acid.

Muriatic acid, with two.

Muriatic acid unites with two, and forms,

1. Oxymuriatic acid
2. Hyperoxymuriatic acid.

The combinations of the simple incombustibles with the combustibles have not hitherto excited much of the attention of chemists.

Analogies, to be pointed out hereafter, lead us to suppose both azote and muriatic acid to be compounds; but till some fortunate experiment ascertain their component parts, we are under the necessity of considering them as simple.

CHAP. IV.

OF METALS.

Properties of metals.

I. 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 any 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 obaque, 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 moulds, 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 exceedingly various, more so indeed than that of any other class of bodies at present known. The greater number of them are heavier than any other known substances. This indeed, till very lately, was considered as a character be-

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* Davy *on the Decomposition of the Fixed Alkalies. Phil. Trans.* 1808.

longing to them all. But several very singular metals, discovered by Mr Davy, are not so heavy as water, and of course much lighter than most stony bodies. Platinum, the heaviest of the metals, is 23 times heavier than water; while the specific gravity of potasium is only 0·6, that of water being 1.

Conducting power.

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

Hardness.

6. None of the metals is 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 500lb. weight ; whereas a lead wire, of the same diameter, will not support above 29lb.

Combine with oxygen.

II. When metals are exposed to the action of heat and air, most of them lose their lustre, and are gradually converted into earthy-like powders of different colours and properties, according to the metal and the degree of heat employed. Several of them even take fire when exposed to a strong heat ; and after combustion the residuum is found to be the very same earthy-like substance.

Oxides or calces.

1. All metals, even the few that resist the action of heat and air, undergo a similar change when exposed to acids, especially the sulphuric, the nitric, and the muriatic, or a mixture of the two last. All metals, by these means, may be converted into powders, which have no resemblance to the metals from which they were obtained. These powders were formerly called *calces ;* but at present they are better known by the name of *oxides.* They are of various colours according to the metal and the treatment, and are frequently manufactured in large quantities to serve as paints.

Reduction.

2. When these oxides are mixed with charcoal pow-

ler, and heated in a crucible, they lose their earthy appearance, and are changed again into the metals from which they were produced. Oil, tallow, hydrogen gas, and other combustible bodies, may be often substituted for charcoal. By this operation, which is called the *reduction* of the oxides, the combustible is diminished, and indeed undergoes the very same change as when it is burnt. In the language of Stahl, it loses its *phlogiston*; and this induced him to conclude 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 Beccher, that there is another principle besides earth and phlogiston which enters into the composition of the metals. To this principle Beccher 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 oxide 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, 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.

Improved by Henkel,

And Bergman.

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 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 improvem nt in accuracy, chemistry is chiefly indebted to B rgman.

Refuted by Lavoisier.

But there were several phenomena of calcination w ich had all this time been unaccountably overlooke . The oxides are all considerably heavier than the m tals from which they are obtained. Boyle had obs ved this circumstance, and had ascribed it to a quanti y of *fire*, which according to him became fixed in the m tal during the process *. But succeeding chemists p d little attention to it, or to the action of air, till Mr L voisier published his celebrated experiments on calc ation, in the memoirs of the Paris Academy for 1 74. He put eight ounces of *tin* into a large glass r ort, the point of which was drawn out into a very s nder tube to admit of easy fusion. The retort was h ated slowly till the tin began to melt, and then seale hermetically. This heat was applied to expel some c the air from the retort; without which precaution i would have expanded and burst the vessel. The r ort, which was capable of containing 250 cubic inc es, was then weighed accurately, and placed again upo the fire. The tin soon melted, and a pellicle formed o its top, which was gradually converted into a grey p wder, that sunk by a little agitation to the bottom of t e liquid metal: in short, the tin was partly converted i to a *calx*. This process went on for three hours; a ter which the calcination stopped, and no further c ange could be produced on the metal. The retort w as then taken from the fire, and found to be precisely o the same weight as before the operation. It is evi-

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

dent then that no new substance had been introduced; and that therefore the increased weight of the 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 was 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 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

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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 1694, ascribed the increase of weight to the combination of the 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 IN FIXIS provenire videatur." *Ibid.* p. 29.

as ertained, that the residuum of the air, after calcinati has been performed in it, is always pure azotic gas: It ollows, therefore, that it is only the *oxygen* which cc abines with calces; and that a metallic calx is not a mple substance, but a compound.

Oxides composed of metals and oxygen.

Mr Lavoisier observed, that the weight of the oxide w always equal to that of the metal employed, together w h that of the oxygen absorbed. Hence he comcl ded, that the oxide is nothing else than a combinati of the metal with oxygen: that the metals, as far a we know, are simple substances; that what Stahl c isidered as the escape of phlogiston from metals was, i reality, their combination with oxygen; and that the r luction of metals, instead of restoring the lost phlog ton, consisted, in fact, in the separation of oxygen by n ans of some combustible which has a strong affinity f it. These conclusions were supported in the most i enious and satisfactory manner.

3. No metal can be converted into an oxide except s ne substance be present which contains oxygen; and ring the oxydizement a portion of that oxygen disa pears.

4. There are some metallic oxides which can be re ced by the application of heat in close vessels. Now enever they are reduced in that manner they yield ygen gas; and the weight of the oxygen, together th that of the metal obtained, is equal to the weight of t e original oxide. Thus when the oxide of mercury i heated in a retort, to which a pneumatic apparatus i attached, to the temperature of 1000°, it is converted i to pure mercury; and, at the same time, a quantity oxygen separates from it in a gaseous form. As t s process is performed in a close vessel, no new sub-

Book I.
Division I.

stance can enter: The oxide of mercury, then, is reduced to the metallic state without phlogiston. The weights of the metal and the oxygen gas are together equal to that of the oxide; 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 oygen*. Gold, platinum, silver, nickel, and even lead, may be reduced in the same way, and with the same evolution of oxygen gas. To them therefore the same reasoning applies. Several other oxides may be brought nearer the metallic state, though they cannot be completely reduced by heat; and this approach is accompanied by the escape of oxygen gas. Manganese, zinc, and probably also iron, are in this predicament.

5. All the oxides are reduced by means of combustible bodies; and during the combustion the combustible unites to oxygen. This is the reason that charcoal-powder is so efficacious in reducing them: and if they

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[*] This experiment was performed by Mr Bayen in 1774. This philosopher perceived, earlier than Lovoisier, 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 conclurer, 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 essuyé, *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 à l'examen." *Jour. de Phys.* 1774. pages 288, 295.

ar mixed with it, and heated in a proper vessel furni ed with a pneumatic apparatus, it will be easy to d cover what passes. During the reduction, a great de l of carbonic acid and carbonic oxide comes over. T ese, together with the metal, are equal to the weight o he oxide and the charcoal: they must therefore conta all the ingredients; and we know that they are co posed of carbon and oxygen. During the process, th n, the oxygen of the oxide combines with the charco l, and the metal remains behind. In the same mann , when oxide of iron is heated sufficiently, in cont t with hydrogen, the iron is reduced, and water f med, as was ascertained by the experiments of Dr P estley.

It cannot be doubted, therefore, that all the meta ic calces are composed of the entire metals combin with oxygen; and that calcination, like combusti , is merely the act of this combination. Metals, t n, in the present state of chemistry, must be considere as simple substances; for they have never yet been d ompounded.

Oxide and oxidizement explained.

The words *calx* and *calcination* being evidently imp per, because they convey false ideas, the words *oxide* a *oxidizement* *, which were invented by the French c emists, are substituted for them. A metallic *oxide* s nifies a metal united with oxygen; and *oxidizement* i plies the act of that union.

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* *Oxidation* was the word formerly used by British chemists. But th reasons assigned by Mr Chenevix in his *Remarks on the Chemical No-* m *lature*, page 163. have induced me to prefer the terms which he has th e substituted for it.

Metals combine with oxygen.

7. Metals, then, are all capable of combining with oxygen; and this combination is sometimes accompanied by combustion and sometimes not. The new compounds formed are called *metallic oxides*, and in some cases *metallic acids*. Like the two last classes of bodies, they are capable of combining with different doses of oxygen, and of forming different species of oxides or acids. These were formerly distinguished from each other by their colour. One of the oxides of iron, for instance, was called *black oxide*, another was termed *red oxide;* but it is now known that the same oxide is capable of assuming different colours according to circumstances. The mode of naming them from their colour, therefore, wants precision, and is apt to mislead; especially as there occur different examples of two distinct oxides of the same metal having the same colour.

Nomenclature of oxides.

As it is absolutely necessary to be able to distinguish the different oxides of the same metal from each other with perfect precision, and as the present chemical nomenclature is defective in this respect, I shall, till some better method be proposed, distinguish them from each other, by prefixing to the word *oxide* the first syllable of the Greek ordinal numerals. Thus the *protoxide* of a metal will denote the metal combined with a minimum of oxygen, or the *first oxide* which the metal is capable of forming; *deutoxide* will denote the second oxide of a metal, or the metal combined with two doses of oxygen.* When a metal has combined with as

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* The same explanation will apply to *tritoxide* (third oxide), *tetoxide* (fourth oxide), *pentoxide* (fifth oxide), *hectoxide* (sixth oxide), whenever they become necessary.

m h oxygen as possible, I shall denote the compound fo ned by the term *peroxide ;* indicating by it, that the m al is thoroughly oxidized †.

hus we have the term *oxide* to denote the combinati . of metals with oxygen in general ; the terms *proto de* and *peroxide* to denote the minimum and maxim n of oxidizement ; and the terms *deutoxide, tritoxide,* & to denote all the intermediate states which are capa le of being formed.

Combine with combustibles,

II. Metals are capable of combining with the simple co ibustibles. The compounds thus formed are denote by the simple combustible which enters into the co nbination, with the termination *uret* added to it. T us the combination of a metal with sulphur, phosph rus, or carbon, is called the *sulphuret, phosphuret,* or *ca buret* of the metal. The compounds formed by the m tals with the three combustibles just mentioned are u ally solid ; but when hydrogen unites with them, it st l retains its elastic state. These solutions of meta in hydrogen have been but slightly examined. T ey are usually distinguished by an epithet, indicati g the metal, prefixed to the word hydrogen. Thus *a enical hydrogen gas* means hydrogen holding arsenic in solution.

Etymologists will doubtless object to this term, that it is a heterog eous compound of a Greek and Latin word ; but this fault, if it be or , has been already committed very frequently in the formation of ch nical terms. My object was, not to prevent the objections of etymolo sts, but to employ a word perfectly precise, which could not mislead ar which was not unwieldy, nor unsuitable to the genius of the English la uage.

IV. The simple incombustibles, as far as is known at present, do not combine with the metals.

And with each other.

V. The metals, in general, unite very readily to one another, and form compounds, some of which are extremely useful in the manufacture of instruments and utensils. Thus *pewter* is a compound of lead and tin; *brass*, a compound of copper and zinc; *bell-metal*, a compound of copper and tin. These metallic compounds are called by chemists *alloys*, except when one of the combining metals is *mercury*. In that case the compound is called an *amalgam*. Thus the compound of mercury and gold is called the *amalgam of gold*.

Number of metals.

VI. The metals at present known, or concluded from analogy to exist, amount to about 40. But 12 of these, newly discovered by Mr Davy, and constituting the bases of the alkalies and earths, are still so imperfectly known, or possess such peculiar properties, that I shall defer giving an account of them till I come to treat of those bodies hitherto known by the names of *alkalies* and *earths*. In this chapter, then, we have to consider the properties of 28 metals. Of these only 7 were known to the ancients as metals, and no fewer than 17 have been discovered since the year 1730. Their number has multiplied exceedingly within these few years: but the more recently discovered metals, with a small number of exceptions, are so scarce as to be of comparatively small importance. Metals may be conveniently arranged under four classes: namely, 1. Malleable metals; 2. Brittle and easily fusible metals; 3. Brittle and difficultly fusible metals; 4. Refractory metals. Under which last name I comprehend all those metallic bodies which are only known at present in the state of combination; chemists not having succee ed hitherto in reducing them to the metallic state. Tl metals which belong to each of these heads will be se from the following Table:

Classification.

I. Malleable.

1. Gold.
2. Platinum.
3. Silver.
4. Mercury.
5. Palladium.
6. Rhodium.
7. Iridium.
8. Osmium.
9. Copper.
10. Iron.
11. Nickel.
12. Nicolanum.
13. Tin.
14. Lead.
15. Zinc.

II. Brittle and easily Fused.

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

III. Brittle and difficultly Fused.

1. Cobalt.
2. Manganese.
3. Chromium.
4. Molybdenum.
5. Uranium.
6. Tungsten.

IV. Refractory.

1. Titanium.
2. Columbium.
3. Cerium.

The metals of the first class were formerly called m *tals* by way of eminence, because they are possessed e her of malleability or ductility, or of both properties t gether: the rest were called *semimetals*, because they a brittle. But this distinction is now pretty general- l laid aside; and, as Bergman observes, it ought to be

Book I. Division I.

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 rest 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.

The different metals, in the order in which they have been enumerated, will occupy our attention in the following Sections.

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* Nickel and lead are reducible by mere heat, and of course entitled to the name of *noble metals* also.

CLASS I.

MALLEABLE METALS.

THE metals belonging to this Class, from their malleability, are of much more importance than the rest; all those known to the ancients belong to it, and five more which have been discovered by the moderns. Besides these five, I have included in this class three other recently discovered metals; the malleability of which has not been ascertained, but which may be inferred, perhaps, from the great analogy which they bear to the most perfect of the malleable metals.

SECT. I.

OF GOLD.

I. 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.

1. 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.

2. Its hardness is $6\frac{1}{2}$[†].

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[*] The fullest treatise on gold hitherto published is that by Dr Lewis in his *Philosophical Commerce of the Arts.* The account of gold in Wasserberg's *Institutiones Chemiæ*, vol. i. is, a great part of it at least, nearly a translation of Dr Lewis; but it contains likewise several discoveries of posterior date, chiefly made by Bergman. Mr Hatchett's *Experiments and Observations on the Alloys, Specific Gravity, and comparative wear of Gold*, published in the *Phil. Trans.* for 1803, are of the utmost importance, on account of the care with which they were made, and the many mistaken notions which they have enabled us to rectify.

[†] Mr Kirwan's method of denoting the different degrees of hardness by figures has been adopted in consequence of its brevity. Mr Kirwan's plan will be understood from his 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.

Its specific gravity is 19·3 *.

Malleability.

3. 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 only $\frac{1}{12}$ of that thickness. An ounce of gold upon silver wire is capable of being extended more than 1300 miles in length †.

Tenacity.

4. 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 0·078 inch in diameter is capable of supporting a weight of 150·07lbs. avoirdupois, without breaking ‡.

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.

The same meaning, however, is not affixed here to the figures; but a series of degrees of hardness is conceived, descending from steel to arsenic, each of which is denoted by arbitrary figures.

* The specific gravity of gold varies somewhat according to its state, that being heaviest which has been hammered or rolled. Dr Lewis informs us that he found, on many different trials, the specific gravity of pure gold, well hammered, between 19·300 and 19·400. The specific gravity of one mass which he specifies was 19·376, (*Philosophical Commerce of the Arts*, p. 41). Brisson found the specific gravity of another specimen of fine gold, hammered, 19·361. Mr Hatohett tried gold of 23 carats $3\frac{3}{4}$ grains, (or gold containing 1-96 of alloy); its specific gragravity was 19·277.

† See Shaw's *Boyle*, i. 404. and Lewis's *Philosoph. Commerce af the Arts*, p. 44.

‡ *Ann. de Chim.* xxv. 9.

Book I.
Division I.

Action of heat.

5. 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*. Gasto Claveus informs us that he put an ounce of pure gold in an earthen vessel, into that part of a glass-house furnace where the glass is kept constantly melted, and kept it in a state of fusion for two months, yet it did not lose the smallest portion of its weight[‡]. Kunkel relates a similar experiment attended with the same result[§]; neither did gold 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 a violent heat, 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 sensibly[**]; and Mr Lavoisier observed the very same thing when a piece of silver was held over gold melted

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

[†] Lewis's *Philosophical Commerce*, p. 67.

[‡] "Nec minimum de pondere decidisse conspexi" Gastonis Clavei *Apologia Argyropoeiæ et Chrysopoeæ adversus Thomam Erastum*, Theatrum Chemicum, ii. 17.

[§] Lewis, *Philosophical Commerce*, p. 70.

[||] Kirwan's *Mineralogy*, i. 92.

[¶] *Mem. Par.* 1702, p. 147.

[**] *Dictionaire de Chimie*, ii. 148.

by ı fire blown by oxygen gas, which produces a much gr ıter heat than common air *.

ıfter fusion, it is capable of assuming a crystalline fo n. Tillet and Mongez obtained it in short quadran- gı ır pyramidal crystals.

. Gold is not in the least altered by being kept ex- pc ɜd to the air ; it does not even lose its lustre. Nei- th : has water the smallest action upon it.

Oxides.

I. It is capable, however, of combining with oxy- ge , and even of undergoing combustion in particular ci umstances. The resulting compound is an *oxide of* gc *l*. Gold must be raised to a very high temperature be ɔre it is capable of abstracting oxygen from common ai It may be kept red hot almost any length of ti e without any such change. Homberg, however, ol erved, that when placed in the focus of Tschirnhaus's bı ning-glass, a little of it was converted into a purple cc ɔured oxide ; and the truth of his observations were c firmed by the subsequent experiments of Macquer w h the very same burning-glass †. But the portion o oxide formed in these trials is too small to admit of b ng examined. Electricity furnishes a method of oxi- d ing it in greater quantity.

[f a narrow slip of gold leaf be put, with both ends h ıging out a little, between two glass plates tied toge- tl r, and a strong electrical explosion be passed through it the gold leaf is missing in several places, and the g ss is tinged of a purple colour by the portion of the n tal which has been oxidized. This curious experi-

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* Kirwan's *Min.* ii. 92.

† *Dict.* ii. 152.

ment was first made by Dr Franklin[*]; it was confirmed in 1773 by Camus. The reality of the oxidizement 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 he 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 a purple coloured oxide of gold. This combustion, according to Van Marum, 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 combustion of gold is now easily affected by exposing gold-leaf to the action of the galvanic battery. I have made it burn with great brilliancy, and a green coloured flame, by exposing a gold wire to the action of a stream of oxygen and hydrogen gas mixed together and burning. Now in all cases of combustion the gold is oxidized. We are at present acquainted with two oxides of gold: the *protoxide* has a *purple* or violet, the *peroxide* a *yellow* colour.

Peroxide.

1. Of these the *peroxide* is most easily procured; it is therefore best known. It may be procured in the following manner: One part of nitric and four of muriatic acid are mixed together[†], and poured upon gold: an

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[*] Lewis's *Philosoph. Commerce*, p. 175. This work was published in 1763.

[†] 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*.

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 flies off in the state of *nitrous gas*. is the emission of this gas which causes the effervescence. The oxide of gold may be precipitated from e nitro-muriatic acid by pouring in a little potash dissolved in water, or even by lime water. It subsides owly, and has a yellowish brown colour, and sometimes, indeed, approaches to black. When carefully washed and dried, it is insoluble in water and tasteless. Bergman found that 100 parts of gold, when treated in this manner, weigh 110. Were we to suppose this estimate correct, but Bergman himself expresses his doubts of its accuracy, it would follow from it, that the peroxide of gold is composed of about

91 gold
9 oxygen

100*

When this oxide is moderately heated, it becomes purple. A stronger heat expels the whole of the oxygen, and reduces it to the metallic state.

Protoxide.

2. The properties of the *protoxide* of gold are but

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* Bergman's *Opusc.* ii. 201.

little known. It is formed when the metal is subjected to combustion, or to the action of electricity, and likewise by exposing the peroxide to the proper degree of heat, or even by placing it in the rays of the sun. Its colour is purple. Various preparations containing it are used in the arts.

The oxides of gold are still but imperfectly known; and all the attempts hitherto made to investigate them with more accuracy have been unsuccessful. Proust, in a dissertation which he has recently published, endeavours to show, that what has been called the *purple oxide* of gold, is in reality gold in the metallic state*. But his experiments do not appear to me satisfactory. From Proust's experiments compared with some of my own, it is probable that there are three oxides of gold, composed respectively of 100 parts gold combined with 8, 16, and 32 parts of oxygen. But from the great readiness with which they are decomposed and altered, it is extremely difficult to estimate their composition with precision.

III. Hitherto gold has been united artificially to none of the simple combustibles except phosphorus. Hydrogen and charcoal are said to precipitate it from its solutions in the metallic state.

Sulphuret.

1. Sulphur, even when assisted by heat, has no action on it whatever; nor is it ever found naturally combined with sulphur, as is the case with most of the other metals; yet it can scarcely be doubted that sulphur exercises some action on gold, though but a small

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* Nicholson's *Jour.* xiv. 238, and 324.

on : for when an *alkaline hydro-sulphuret*[*] is dropt in a solution of gold, a *black powder* falls to the botto , which is found to consist of gold and sulphur, m rely, as Proust informs us, in a state of mixture[†]; a . when potash, sulphur, and gold, are heated together, a . the mixture boiled in water, a considerable portion o gold is dissolved, as Stahl first discovered. Three p ts of sulphur, and three of potash, are sufficient to d solve one of gold. The solution has a yellow colour. hen an acid is dropt into it, the gold falls down, united t the sulphur in the state of a reddish powder, which comes gradually black[‡]. From the experiments of cholz, it seems to be composed of about one part of lphur to 4·5 of gold, or of about

82 gold
18 sulphur

100[§]

Phosphuret.

2. Margraf failed in his attempts to unite gold with hosphorus[||]; but Pelletier was fortunate enough to ucceed by melting together in a crucible half an ounce f 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

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[*] By this is understood a combination of sulphureted hydrogen and an alkali. These compounds will be described hereafter.

[†] Nicholson's *Jour.* xiv. 241.

[‡] Stahl's *Opusc. Chym.-Phys.-Med.* p. 606.

[§] Bucholz, *Beitrage zur erweiterung und Berichtigung der Chemie*, iii. 171.

[||] *Opusc.* i. 2.

[¶] Phosphoric acid evaporated to dryness, and then fused.

one of phosphorus *. He formed the same compound by dropping small pieces of phosphorus into gold in fusion †. By the application of a sufficient heat, the phosphorus is dissipated and the gold remains.

Action of incombustibles.

IV. Gold does not combine, as far as is known, with either of the simple incombustible bodies.

Alloys.

V. But gold combines readily with the greater number of the metals, and forms a variety of alloys.

This metal is so soft that it is seldom employed in a state of purity. It is almost always mixed with small quantities of copper and silver. Goldsmiths usually announce the purity of the gold which they sell in the following manner:—Pure gold they suppose divided into 24 parts called *carats*. Gold of 24 carats means pure gold; gold of 23 carats means an alloy of 23 parts gold, and one of some other metal; gold of 22 carats means an alloy of 22 parts of gold, and two of another metal. The number of carats mentioned, specifies the pure gold; and what that number wants of 24, indicates the quantity of alloy. Thus gold of 12 carats would be an alloy containing 12 parts gold, and 12 of some other metal. In this country the carat is divided into four grains; among the Germans into 12; and by the French it was formerly divided into 32 ‡.

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* *Ann. de Chim.* i. 71. † *Ibid.* xiii. 104.

‡ Lewis's *Philosoph. Commerce.* p. 115.

SECT. II.

OF PLATINUM.

G LD, the metal just described, was known in the ear est ages, and has been always in high estimation, on ccount of its scarcity, beauty, ductility, and indestr :tibility. But platinum, though perhaps inferior in w of these qualities, and certainly far superior in oth :s, was unknown in Europe, as a distinct metal, befor the year 1749 †.

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† 'ather Cortinovis, indeed, has attempted to prove that this metal wa he *electrum* of the ancients. See the *Chemical Annals of Brugnatelli*, 17 . That the *electrum* of the ancients was a metal, and a very valuable on is evident from many of the ancient writers, particularly Homer. Th 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.

iny gives us an account of it in his Natural History. He informs us th it was a composition of silver and gold; and that by candle-light it sh e with more splendour than silver. The ancients made cups, statues, an columns of it. Now, had it been our platinum, is it not rather extra 'dinary that no traces of a metal, which must have been pretty abunda , should be perceptible in any part of the old continent?

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

Omni auro inest argentum vario pondere,—Ubicunque quinta argen-

History of platinum.

I. It has hitherto been found only in America, in Choco in Peru, and in the mine of Santa Fe, near Carthagena. Vauquelin has lately discovered it in considerable quantity in the silver mines of Guadalcanal, in the province of Estremadura in Spain *. The workmen of the American mines must no doubt have been early acquainted with it; and indeed some of its properties are obscurely mentioned by some of the writers of the 16th century. Mr Charles Wood, assay-master in Jamaica, saw it in the West Indies about the year 1741. He gave some specimens of it to Dr Brownrigg, who presented it to the Royal Society in 1750. In 1748 it was noticed by Don Antonio de Ulloa, a Spanish mathematician, who, in 1735, had accompanied the French academicians to Peru in their voyage to measure a degree of the meridian. A paper on it was published by Mr Wood in the 44th volume of the Philosophical Transactions for 1749 and 1750. Dr Lewis began a set of experiments on it in 1749, the result of which was published in four papers in the Philosophical Transactions for 1754, and afterwards two other papers were

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ti 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 ſulgere tradit. Minervæ templum habet Lindos insulæ Rhodiorum in quo Helena sacravit calicem ex electro.—Electri natura est ad lusernarum lumina clarius argento splendere. Quod est nativum et venena deprehendit. Namque discurrunt in calicibus arcus çœlestibus similes cum igneo stridore, et gemina ratione prædicunt."—Lib. xxxiii. cap. iv.

* *Ann. de Chim.* lx. 317.

added[*]. These experiments demonstrate its peculiar nature and its remarkable properties. In 1752, Scheffer of Sweden published a dissertation on this metal, remarkable for its precision, if we consider the small quantity of ore on which he had to work, which was not more than 40 grains. The experiments of Lewis were repeated, and many curious additions made to them by Margraf in 1757[†]. These dissertations having been translated into French, drew the attention of the chemists of that country, and induced Macquer and Baumé[‡] to make a set of experiments on platinum, which were soon followed by the experiments of Buffon, Tillet, and Morveau[§]; Sickengen[||], Bergman[¶], Lavoisier[**], and more lately Mussin Puschkin[††], and Morveau[‡‡]; and several other chemists of eminence have added to our knowledge of this mineral.

Crude platina comes from America in small flat grains of a silvery lustre. In this state it is exceedingly impure, containing, either mechanically mixed, or chemically united, no less than nine other metals; but it may be reduced nearly to a state of purity by the following process. Dissolve the grains in diluted nitromuriatic acid with as little heat as possible. Decant the solution from the black matter which resists the action of the acid. Drop into it a solution of *sal ammo-*

Purification.

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[*] *Phil. Trans.* xlviii. 638, and l. 148. See also *Phil. Com.* p. 443, for a full detail of all the experiments on this metal made before 1763.

[†] *Mem. Berlin*, 1757, p. 31. and Margraf's *Opusc.* ii. 226.

[‡] *Mem. Par.* 1758, p. 119.

[§] *Jour. de Phys.* iii. 324.

[||] Macquer's *Dictionary*.

[¶] *Opusc.* ii. 166.

[**] *Ann. de Chim.* v. 137.

[††] *Ibid.* xxiv. 205.

[‡‡] *Ibid.* xxv. 3.

Book I. Division I.

niac[*]. An orange yellow-coloured precipitate falls to the bottom. Wash this precipitate; and when dry, expose it to a heat slowly raised to redness in a porcelain crucible. The powder which remains is platinum nearly pure. By redissolving it in nitro-muriatic acid, and repeating the whole process, it may be made still purer. When these grains are wrapt up in a thin plate of platinum, heated to redness, and cautiously hammered, they unite, and the whole may be formed into an ingot[†].

Properties.

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

2. Its hardness is 8. Its specific gravity, after being hammered, is 23·000; so that it is by far the heaviest body known[§].

3. 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

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[*] This salt will be described afterwards. It is a combination of *muriatic* acid and *ammonia*.

[†] *Phil. Mag.* xxi. 175.

[‡] 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. Authors differ considerably in their estimate of the specific gravity of this metal. Lewis did not obtain it heavier than gold; but his trials were made on impure specimens. Scheffer, from the specific gravity of the alloys made by Lewis, calculated the specific gravity of platinum at 21; but this theory was erroneous. Sickingen found it 21·061. I have a crucible whose specific gravity at first was near 22. Chabanau found the specific gravity of pure hammered platinum no less than 24.

properties it is probably inferior to gold, but it seems to surpass all the other metals.

4. Its tenacity is such, that a wire of platinum 0·078 inch in diameter is capable of supporting a weight of 274·31 lbs avoirdupois without breaking *.

5. It is one of the most infusible of all metals, and cannot be melted in any quantity at least, by the strongest artificial heat which can be produced. Macquer and Baumé 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.

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

Oxides.

II. It cannot be combined with oxygen and converted into an oxide by the strongest artificial heat of our furnaces. Platinum, indeed, in the state in which it is brought from America, may be partially oxidized 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 oxidized 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 in-

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* Morveau, *Ann. de Chim.* xxv. 7.

to a species of dust, which proved to be the oxide of platinum. By putting a platinum wire into the flame produced by the combustion of hydrogen gas mixed with oxygen, I caused it to burn with all the brilliancy of iron wire, and to emit sparks in abundance.

Peroxide.

1. To obtain the oxides of this metal, it is necessary to have recourse to the action of an acid. When the deep brown solution of platinum in nitro-muriatic acid is treated with lime water, a yellowish-brown powder falls. Dissolve this powder in nitric acid; evaporate to dryness, and apply a heat sufficient to drive off the acid. The brown powder which remains is the peroxide of platinum. It is tasteless and insoluble in water. When heated to redness, the oxygen is driven off, and the oxide reduced to the metallic state. One hundred and fifteen parts of oxide, by this treatment, leave 100 parts of metal. Hence the oxide is composed of

87 platinum
13 oxygen

100 *

Protoxide.

2. If the heat in this experiment be very cautiously raised, the oxide, before it is reduced, assumes a green colour. This change is occasioned by the separation of a portion of the oxygen. The green-coloured powder is, according to Chenevix, a protoxide of platinum. From his experiments, we learn that it is composed of

93 platinum
7 oxygen

100 †

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* Chenevix on Palladium, *Phil. Trans.* 1803.

† *Ibid.*

III. The action of the simple combustibles on this metal is not more remarkable than their action on gold.

1. Neither hydrogen nor carbon have been hitherto combined with it.

Phosphuret.

2. Phosphorus unites without difficulty, and forms a *phosphuret*. 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* 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 †.

Sulphuret.

3. Platinum cannot be made to unite to sulphur by heating them together ‡. In this respect it resembles gold. Yet there seems to be an affinity between the two substances; for when the metal is heated with a mixture of potash and sulphur, it is corroded and rendered partly soluble in water, as was proved by the experiments of Lewis § and Margraf ‖. And when sulphureted hydrogen gas is passed into a solution of platinum in an acid, the metal is thrown down in dark

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* *Ann. de Chim.* i. 71.

† *Ibid.* xiii. 105.

‡ Lewis, *Phil. Com.* p. 498.

§ *Ibid.* p. 499.

‖ *Opusc.* ii. 284.

brown flakes, apparently in combination with sulphur. Indeed, if we believe Mr Proust, a sulphuret of this metal occurs sometimes mixed with native platina *.

IV. Platinum, as far as is known, does not combine with the simple incombustibles.

Alloys.

V. It combines with most of the metals and forms alloys, which were first examined by Dr Lewis.

1. Gold.

1. Dr Lewis found that gold united with platinum when they were melted together in a strong heat. He employed only crude platina; but Vauquelin, Hatchett, and Klaproth, have since examined the properties of the alloy of pure platinum and gold †. To form the alloy, it is necessary to fuse the metals with a strong heat, otherwise the platinum is only dispersed through the gold. When gold is alloyed with this metal, its colour is remarkably injured; the alloy having the appearance of bell metal, or rather of tarnished silver. Dr Lewis found, that when the platinum amounted only to $\frac{1}{6}$th, the alloy had nothing of the colour of gold; even one forty-second part of platinum greatly injured the colour of the gold. The alloy formed by Mr Hatchett of nearly eleven parts of gold to one of platinum, had the colour of tarnished silver. It was very ductile and elastic. From Klaproth we learn, that if the platinum exceed $\frac{1}{17}$th of the gold, the colour of the alloy is much paler than gold; but if it be under $\frac{1}{17}$th, the colour of the gold is not sensibly altered. Neither

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* *Ann. de Chim.* xxxviii. 149. It is not unlikely that this ingenious chemist took for a sulphuret of platinum some one of the numerous metallic bodies that have been lately discovered in crude platina.

† Vauquelin, *Manuel de l'Essayeur*, p. 44.—Hatchett on the Alloys of Gold, &c. *Phil. Trans.* 1803.—Klaproth, *Journal de Chimie*, iv. 29,

is there any alteration in the ductility of the gold. Platinum may be alloyed with a considerable proportion of gold without sensibly altering its colour. Thus an alloy of one part of platinum with four parts of gold can scarcely be distinguished in appearance from pure platinum. The colour of gold does not become predominant till it constitutes eight-ninths of the alloy *.

From these facts it follows, that gold cannot be alloyed with $\frac{1}{10}$th of its weight of platinum, without easily detecting the fraud by the debasement of the colour; and Vauquelin has shown, that when the platinum does not exceed $\frac{1}{10}$th, it may be completely separated from gold by rolling out the alloy into thin plates, and digesting it in nitric acid. The platinum is taken up by the acid while the gold remains. But if the quantity of platinum exceeds $\frac{1}{10}$th, it cannot be separated completely by that method †.

SECT. III.

OF SILVER.

I. Silver seems to have been known almost as early as gold.

Properties.

1. It is a metal of a fine white colour with a shade of yellow, without either taste or smell; and in point

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* Klaproth, *Journal de Chimie*, iv. 29.

† *Manuel de l'Essayeur*, p. 48.

of brilliancy is perhaps inferior to none of the metallic bodies, if we except polished steel.

2. Its hardness is 7. When melted, its specific gravity is 10·474 *; when hammered, 10·510 †.

3. In malleability it is inferior to none of the metals, if we except gold. It may be beat out into leaves only $\frac{1}{100000}$ inch thick. Its ductility is equally remarkable: it may be drawn out into a wire much finer than a human hair; so fine indeed, that a single grain of silver may be extended about 400 feet in length.

4. Its tenacity is such, that a wire of silver 0·078 inch in diameter is capable of supporting a weight of 187·13lbs avoirdupois without breaking ‡.

5. Silver melts when it is heated completely red hot; and while melted its brilliancy is much increased. According to the calculation of Mortimer and Bergman, its fusing point is 1000° of Fahrenheit. Dr Kennedy ascertained, that the temperature at which it melts corresponds to 22° of Wedgewood's pyrometer §. If the heat be increased after the silver is melted, the liquid metal boils, and may be volatilized; but a very

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* Brisson and Hatchett. Fahrenheit found it 10·481. (*Phil. Trans.* 1724, vol. xxxiii. p. 114.) I found pure silver melted and slowly cooled of the specific gravity 10·3946; when hammered it became 10·4177; when rolled out into a plate it became 10·4812. Nicholson's *Jour.* xiv. 397.

† According to Brisson. Muschenbroeck found the specific gravity of hammered silver 10·500. Dr Lewis makes it no less than 10·980. (*Phil. Com.* p. 549.)

‡ *Ann. de Chim.* xxv. 9.

§ Sir James Hall, *Nicholson's Jour.* ix. 99.

strong and long-continued heat is necessary. Gasto Claveus kept an ounce of silver melted in a glass-house furnace for two months, and found, by weighing it, that it had sustained a loss of $\frac{1}{12}$ of its weight[*].

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.

II. Silver is not oxidized 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 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 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

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[*] *Theatrum Chem.* ii. 17.

[†] Junker's *Conspectus Chem.* i. 887.

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

[§] Macquer's *Dictionary*, ii. 571.

Book I.
Division I.

greenish white flame, and was dissipated into smoke. Before a stream of oxygen and hydrogen gas, it burns rapidly with a light green flame. By means of the galvanic battery it may be burnt with great brilliancy.

The oxide of silver, obtained by means of heat, is of a greenish or olive colour. When silver is dissolved in nitric acid, and precipitated by lime water, it falls to the bottom under the form of a powder of a dark olive brown colour. From the experiments of Klaproth we learn, that this oxide is composed of 100 parts of silver united to 12·8 of oxygen [*], or *per cent.* of about

89 silver
11 oxygen

100

which differs but little from the previous statements of Bergman [†] and Wenzel. But Proust, from an experiment, which however he thinks requires repetition, considers this oxide as a compound of 100 silver and 9½ oxygen [‡]. This oxide is tasteless and insoluble in water. When exposed to the light, part of its oxygen is separated, as Scheele first ascertained, and it is converted into a black powder, which contains but a very small portion of oxygen, and may be considered as silver reduced. By exposing the solution of silver in nitric acid to sunshine, the silver precipitates in the form of a flea-brown powder.

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[*] Beitrage, iii. 199.

[†] *Opusc.* iii. 391.

[‡] Nicholson's *Jour.* xv. 375.

The oxide now described, as far as we know at present, is the *peroxide* of silver; the protoxide, as Proust has discovered, may be formed by dissolving silver in nitric acid, and heating the solution in contact with a portion of the metal in the state of powder. Its colour resembles that of the peroxide; but its combination with nitric acid is much more soluble *.

Combination with combustibles.

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

Sulphuret.

1. 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; capable of being cut with a knife; often crystallized in 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. This compound frequently occurs native. It has a dark grey colour, a metallic lustre, and the softness, flexibility, and malleability of lead. Its specific gravity is about 7·2. According to the analysis of Klaproth, it is composed of

85	silver
15	sulphur
100 †	

Hence 100 parts of silver unite with about 17·6 parts of sulphur ‡.

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* Nicholson's *Jour*. xv. 376.

† Beitrage, i. 162.

‡ In Wenzel's trials, 100 parts of silver took up only 14·7 parts of sulphur. But probably the heat was too great. *Verwandtschaft*, p, 279, Grindel's edition.

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.

2. 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 silver, after the crucible is taken from the fire, a quantity of phosphorus is emitted the moment the metal congeals [‡].

IV. Silver does not combine with the simple incombustibles.

Alloys

V. Silver combines readily with the greater number of metallic bodies.

With gold,

1. When silver and gold are kept melted together, they combine, and form an alloy composed, as Homberg

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[*] *Ann. de Chim.* i. 142.

[†] Pelletier, *Ann. de Chim.* i. 73.

[‡] *Ann. de Chim.* xiii. 110.

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 melted with gold in almost any proportion; and if the proper precautions be employed, the two metals remain combined together.

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

With platinum.

2. When silver and platinum are 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. Indeed Dr Lewis found, that when the two metals were melted together, they

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* Muschenbroeck.

† Hatchett.

sputtered up as if there were a kind of repugnance between them. The difficulty of uniting them was noticed also by Scheffer *.

SECT. IV.

OF MERCURY.

I. 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.

1. 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.

2. Its specific gravity is 13·568 †.

When in a solid state its density is increased; its specific gravity, according to the experiments of Schulz,

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* Lewis's *Philosoph. Commerce*, p. 522.

† Cavendish and Brisson. The specific gravity varies considerably like that of all other metals. Fahrenheit found it 13·575. (Phil. Trans. 1724. vol. xxxiii. 114.) Mr Biddle found it 13·613 at the temperature of 50°. (Phil. Mag. xxx. 134).

being 14·391[*], according to the experiments of Mr Biddle 14·465[†].

Point of congelation.

3. 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 Hutchins[‡] at Hudson's Bay. The congelation of mercury was accidentally discovered by Professor Braun at Petersburgh in 1759. Taking the advantage of a very severe frost, he 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, he broke the bulb of the thermometer, 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 Hutchins

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[*] Gehlen's *Jour.* iv. 434.

[†] *Phil. Mag.* xxx. 134.

[‡] *Phil. Trans.* 1783, p. 303. See also Mr Cavendish's observations on Mr Hutchin's experiments in the same volume of the Transactions.

[§] The method of performing this experiment will be described in the Second Division of the first part of this Work.

was enabled to ascertain the real freezing point of the metal.

4. 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.

Boiling point.

5. Mercury boils when heated to 656°[*]. 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[†].

Oxides.

II. 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

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[*] Crichton, *Phil. Mag.* xiv. 49.

[†] Macquer's *Chemistry*.

the metal is converted into an oxide: by the last, into a black coloured oxide; and by the first, into a red coloured oxide. This metal does not seem to be capable of combustion; at least no method which I have hitherto tried to burn it has succeeded. It is the only metal I have hitherto had an opportunity of examining which may not, by peculiar management, be made to *burn*.

The oxides of mercury at present known are four in number.

Protoxide.

1. The protoxide 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*. It is a black powder without any of the metallic lustre, has a coppery taste, and is insoluble in water. According to the experiments of Fourcroy, it is composed of 96 parts of mercury and four of oxygen†. According to Messrs Braamcamp and Siquiera-Oliva, it is composed of 92·5 mercury and 7·5 oxygen‡. When this oxide is exposed to a strong heat, oxygen gas is emitted, and the mercury reduced to the metallic state. In a more moderate heat it combines with an additional dose of oxygen, and assumes a *red* colour.

This black oxide may be procured by shaking pure

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* This experiment was first made by Homberg in 1699. He attached a bottle holding some mercury to the clapper of a mill. Martyn's *Abridg. of the Par. Mem.* vol. i.

† *Jour. de Mines*, An. x. p. 283.

‡ *Ann. de Chim.* liv. 120.

mercury in oxygen gas or common air, or by triturating it with water[*].

2. When mercury is dissolved in nitric acid without the assistance of heat, and the acid is made to take up as much mercury as possible, it has been ascertained by the experiments of Mr Chenevix, that an oxide is formed, composed of 89·3 mercury and 10·7 oxygen[†]. In this case, 100 parts of mercury unite with about 12 of oxygen. This oxide cannot be separated completely from the acid which holds it in solution without undergoing a change in its composition; of course we are at present ignorant of its *colour* and other properties. Indeed it is believed by many to be the same with the black oxide just described under the name of *protoxide;* but as this has not been proved, and as experiments have given a different proportion of oxygen for each, it would be improper at present to confound them together. Besides, during the formation of the *red oxide* of mercury by heat, three stages may be observed: The metal first assumes the form of a black powder; this powder becomes afterwards *yellow*, and at last *red.* The yellow powder may be the very oxide which is formed by nitric acid in the above process.

Red oxide.

3. When mercury, or its protoxide, is exposed to a heat of about 600°, it combines with additional oxygen, assumes a red colour, and is converted into an oxide, which, in the present state of our knowledge, we must consider as a *tritoxide*. This oxide may be formed two different ways: 1. By putting a little mercury

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[*] See Wasserberg's *Institutiones Chemiæ*, ii. 26.

[†] *Phil. Trans.* 1802.

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 weeks, 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 *precipitate per se*. 2. When mercury is dissolved in nitric acid, evaporated to dryness, and then exposed to a graduated heat, it assumes a brilliant scarlet colour. The powder thus obtained was formerly called *red precipitate*, and possesses exactly the properties of the oxide obtained by the former process*.

This oxide has an acrid and disagreeable taste, possesses poisonous qualities, and acts as an escharotic when applied to any part of the skin. It is somewhat soluble in water. When triturated with mercury, it gives out part of its oxygen, and the mixture assumes various colours according to the proportion of the ingredients. When heated along with zinc or tin filings, it sets these metals on fire. According to Fourcroy, it is composed of 92 parts of mercury and eight of oxygen†. But the analysis of Mr Chenevix, to be

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[*] See a description of the method of manufacturing this oxide, by Payssé, *Ann. de Chim.* li. 202.

[†] *Jour. de Mines*, An. x. p. 283.

described hereafter, gives, for the proportion of its component parts, 85 parts of mercury and 15 parts of oxygen. Messrs Braamcamp and Siquiera-Oliva, on the other hand, found it a compound of 90 mercury and 10 oxygen*.

4. When a current of oxymuriatic gas is passed through water in which there is red oxide of mercury, the oxide gradually assumes a dark brown colour, and a portion of it is dissolved. This brown powder retains the form and crystalline appearance of the red oxide. It dissolves in nitric acid without effervescence; with muriatic acid it forms the very same compound as the red oxide; and from both it is thrown down in the state of a yellow powder by potash, as is the case with the red oxide when similarly dissolved. We have therefore no proof, except the new colour, to lead us to suppose that the brown powder is a different oxide from the red. Mr Chenevix, however, to whom we are indebted for all these facts, is rather inclined to consider them as distinct†. But Messrs Braamcamp and Siquiera-Oliva have rendered it extremely probable, that the dark colour is owing merely to the presence of a portion of muriatic acid, and not to any difference in the state of oxidizement‡.

Combination with combustibles.

III. Mercury does not combine with carbon nor hydrogen; but it unites readily with sulphur and with phosphorus.

Black sulphuret.

1. When two parts of sulphur and one of mercury are triturated together in a mortar, the mercury gradually

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[*] *Ann. de Chim.* liv. 118.

[†] *Phil. Trans.* 1802.

[‡] *Ann. de Chim.* liv. 129

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.

When this substance is heated, part of the sulphur is dissipated, and the compound assumes a deep violet colour.

Fourcroy had 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[*]. But the late experiments of Proust have shown that this is not the case[†]. Berthollet had conjectured that it contains sulphureted hydrogen; but Seguin has ascertained that this opinion is not well founded[‡]. Ethiops mineral, then, is merely a sulphuret of mercury. The union is probably less intimate, and the proportion of sulphur greater, than in *red sulphuret* of mercury.

Red sulphuret.

2. When ethiops mineral is 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

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[*] Fourcroy, v. 298.

[†] *Jour. de Phys.* liii. 92.

[‡] *Statique Chimique*, ii. 438.

vermilion [*]. It has been hitherto supposed a compound of the oxide of mercury and sulphur. But the experiments of Proust have demonstrated that the mercury which it contains is in the metallic state. According to that very accurate chemist, it is composed of 85 parts of mercury, and 15 of sulphur [†]. It is therefore a *sulphuret of mercury*.

This sulphuret of mercury has a scarlet colour, more or less beautiful, according to the mode of preparing it. Its specific gravity is about 10. It is tasteless, insoluble in water, and in muriatic acid, and not altered by exposure to the air. When heated sufficiently, it takes fire, and burns with a blue flame. When mixed with half its weight of iron filings, and distilled in a stone ware retort, the sulphur combines with the iron, and the mercury passes into the receiver, which ought to contain water. By this process mercury may be obtained in a state of purity. The use of this sulphuret of mercury as a paint is well known [‡].

Cinnaber 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 potash to moisten them, are triturated for

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

[†] *Jour. de Phys.* liii. 92.

[‡] See a description of the process of making it by Paysse, *Ann. de Chim.* li. 196, and by Tuckert, *ibid*, iv. 25.

some time in a porcelain cup by means of a glass pestle, ethiops mineral is produced. Add to this 160 grains of potash 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 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 jelly, 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 *.

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

Phosphuret.

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

IV. Mercury does not combine with the simple incombustibles.

Amalgams.

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

Of Gold.

1. The amalgam of gold is formed very readily, because there is a very strong affinity between the two

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* *Ann. de Chim.* xiii. 122.

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

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 heated till it begins to smoke. The proportions of the ingredients are not determinable, because they combine in any proportion. This amalgam is of a silvery whiteness. By squeezing it through leather, the excess of mercury may be separated, and a soft white amalgam obtained, which gradually becomes solid, and consists of about one part of mercury to two of gold. It melts at a moderate temperature; and in a heat below redness the mercury evaporates, and leaves the gold in a state of purity. It is much used in gilding. The amalgam 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*.

Platinum.

2. Dr Lewis attempted to form an amalgam of platinum, but succeeded only imperfectly, as was the case also with Scheffer†. 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

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* Gellert's *Metallurgic Chemistry*, 375, and Lewis, *Phil. Com.* p. 75.

† Lewis, *Phil. Com.* p. 508.

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 *.

The simplest and easiest way of combining platinum and mercury was pointed out by Muschin Pushkin. It consists in triturating with mercury the fine powder obtained by precipitating platinum from nitro-muriatic acid by sal ammoniac, and exposing the precipitate to a graduated heat. Some trituration is necessary to produce the commencement of combination; but when once it begins, it goes on rapidly. Small quantities of the platinum and mercury are to be added alternately till the proper portion of amalgam is procured. The excess of mercury is then separated by squeezing it through leather. The amalgam obtained is of a fine silvery whiteness, and does not tarnish by keeping. At first it is soft, but gradually acquires hardness. It adheres readily to the surface of glass, and converts it into a smooth mirror.

Silver.

3. The amalgam of silver is made in the same manner as that of gold, and with equal ease. It forms dendritical crystals, which, according to the Dijon acade-

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* *Ann. de Chim.* xxv. 12.—This was doubtless owing to the strong cohesion which exists between the particles of mercury. If you lay a large mass of platinum upon the surface of mercury, it sinks directly on account of its weight; but a small slip (a platinum wire, for instance) swims, being unable to overcome the cohesion of the mercury. However, if you plunge it to the bottom, it remains there in consequence of its superior weight. If heat be now applied to the bottom of the vessel, the wire comes again to the surface, being buoyed up by the hot mercury, to which it has begun to adhere. These facts explain the seeming anomaly observed by Morveau.

micians, contains 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 metals. 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. This amalgam is sometimes employed, like that of gold, to cover the surfaces of the inferior metals with a thin coat of silver.

SECT. V.

OF PALLADIUM.

This metallic body, recently discovered by Dr Wollaston in crude platina, has given birth to a very extraordinary controversy, which is not yet settled.

History.

In the month of April 1803, a printed paper was partially circulated in London, announcing, that a new metal called *palladium*, or *new silver*, was sold at Mr Forster's, Gerrard-street. Several of the properties of he metal were stated; but the name of the discoverer, and every thing which could lead to the knowledge of the substance from which it was obtained, were

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* Gellert's *Metallurgic Chemistry*, 142.

Book I.
Division I.

omitted. This unusual mode of proceeding led Mr Chenevix to suspect imposition on the part of the discoverer, and induced him to undertake a very laborious set of experiments to detect what he considered as a fraud. The result of his inquiries was published in the Philosophical Transactions for 1803. He concluded palladium to be a compound of platinum and mercury. He pointed out various methods of uniting the two metals together; but could not succeed in again decomposing them, or in reducing palladium to its constituents. The very extraordinary consequences that followed from these experiments and assertions of Chevenix, immediately attracted the attention of all chemists to the subject. Dr Wollaston and Mr Smithson Tennant very soon announced, that they considered Mr Chenevix as mistaken, as his experiments in their hands did not succeed. Dr Wollaston informed him, that he had detected small quantities of palladium in crude platina, and endeavoured to convince him that the palladium in his experiments had been derived from that source. Mr Chenevix, however, still persisted in his original opinion. Some months after, a letter was published by the unknown discoverer, denying the accuracy of Chenevix's experiments, affirming that palladium cannot be made artificially, and offering a reward of twenty guineas to any person who could produce twenty grains made either by means of the formula of Chenevix or any other. The money was actually deposited, but nobody appeared to lay claim to the reward.

In France some of Mr Chenevix's experiments were repeated by Morveau, who exhibited several of his results before the National Institute, and affirmed that they coincided in general with those of the British chemist. But Fourcroy and Vauquelin investigated the subject farther, and were led to conclude that mercury does not enter into the composition of palladium.

In Germany the investigation was taken up by Rose and Gehlen, and by Richter; but none of these chemists succeeded in forming palladium artificially. Neither were the attempts of Trommsdorf and Klaproth attended with better success. My own trials to obtain the results of Chenevix were not more fortunate.

This uniform failure led the generality of chemists to suspend their judgment, and even to suspect that Mr Chenevix had allowed himself to be deceived. This naturally induced him to resume the subject, to examine with more precision the mutual action of platinum and mercury, and to ascertain the circumstances upon which their union depends. These new experiments were sent to the Royal Society, and read at one of their meetings in January 1805. The week following Dr Wollaston read a paper on palladium, vindicating the conduct of the unknown discoverer, and assigning his reasons for believing that he had procured it from crude platina. He finished, by acknowledging that he himself was the discoverer; that he had separated it during a long continued series of experiments on crude platina; and that the occurrence of several anomalous circumstances had induced him to act as he did, that he might have leisure to examine and explain the whole of the phenomena, before he ventured to publish an account of them in his own name.

This avowal of Dr Wollaston entirely destroyed the presumption which had induced Chenevix to undertake his original experiments; namely, that palladium

Book I. Division I.

was an artificial alloy, and that the discoverer had fraudulently attempted to impose upon the public. We now know that it exists in crude platina, and that Dr Wollaston extracted it from that mineral. Of consequence, since palladium exists in a natural substance, since no one has succeeded in decomposing it, and since all other chemists have hitherto failed in forming it artificially by any of the methods pointed out by Chenevix, we are under the necessity of considering it as a distinct metal. Mr Chenevix indeed still persists in his original opinion, even since he has been informed of the real history of the discovery; but it cannot be expected that others will embrace his opinion till he succeeds in pointing out a method by which his experiments may be successfully repeated. At the same time it is but justice to say, that even if his conclusions should not be verified to their full extent, still the experiments of this ingenious chemist would be of great importance, by leading chemists to examine the mutual action of the metals on each other, and the compounds which they are capable of forming in various circumstances; investigations which may ultimately tend to diminish the number of simple metals, which seem at present likely to multiply almost without limit.

I. Dr Wollaston separated palladium from crude platina by the following process:

Dissolve crude platina in nitro-muriatic acid, and into the solution, previously freed from any excess of acid, drop a quantity of *prussiate of mercury* [*]. In a short time the liquid becomes muddy, and a pale yel-

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[*] A salt to be described in a subsequent part of this Work.

lowish white matter falls down. This precipitate, washed, dried, and exposed to a strong heat, leaves a white matter, which is palladium*. By heating it with sulphur and borax it may be obtained in the state of a metallic button, which will bear hammering or rolling.

Properties.

1. Palladium thus obtained is a white metal, which, when polished, bears a very close resemblance to platinum.

2. It is rather harder than wrought iron. Its specific gravity varies according to the state in which it is exhibited. When completely fused, Mr Chenevix found it 11·871; but some of the pieces exposed to sale were as low as 10·972. Dr Wollaston states it as varying from 11·3 to 11·8.

3. It seems to be as malleable as platinum itself. It possesses but little elasticity, breaks with a fibrous fracture, and appears of a crystallized texture.

4. It is not altered by exposure to the air. It requires a very violent heat to fuse it. Mr Chenevix succeeded in melting it, but was not in possession of the means of estimating the temperature.

Oxides.

II. When strongly heated its surface assumes a blue colour; but by increasing the temperature the original lustre is again restored. This blue colour is doubtless a commencement of oxidizement; but neither the properties of the oxides of this metal, nor the proportion of oxygen with which it combines, have been ascertained.

When sulphuric acid is boiled upon palladium, it acquires a fine red colour, and dissolves a portion of the metal. Nitric acid acts rather more powerfully, and forms with it a beautiful red-coloured solution. Mu-

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* Wollaston on the *Discovery of Palladium*, *Phil. Trans.* 1805.

riatic acid acts upon it also at a boiling heat, and becomes of a fine red; but nitro-muriatic acid dissolves it readily, and with violence, without the assistance of heat, and forms a beautiful red solution. When potash or lime water is dropt into these solutions, the oxide of palladium is precipitated of a fine orange colour, not in a pure state, but in combination with a portion of the dissolving acid and the precipitating substances.

III. The effect of hydrogen upon palladium has not been tried. Chenevix melted the metal in a charcoal crucible, but it was not in the least altered.

Sulphuret.

Palladium unites very readily to sulphur. When it is strongly heated, the addition of a little sulphur causes it to run into fusion immediately, and the sulphuret continues in a liquid state till it be only obscurely red hot. Sulphuret of palladium is rather paler than the pure metal, and is extremely brittle. By means of heat and air, the sulphur may be gradually dissipated, and the metal obtained in a state of purity.

IV. Azote has probably no effect upon it; but muriatic acid promotes its oxidizement, and forms a red solution with the oxide.

Alloys with

V. Mr Chenevix alloyed palladium with various metals. The following are the results which he obtained.

Gold,

1. " Equal parts of palladium and gold were melted together in a crucible. The colour of the alloy obtained was grey: its hardness about equal to that of wrought iron. It yielded to the hammer; but was less ductile than each metal separate, and broke by repeated percussions. Its fracture was coarse-grained, and bore marks of crystallization. Its specific gravity was 11·079.

Platinum,

2. " Equal parts of platinum and palladium ent

into fusion at a heat not much superior to that which was capable of fusing palladium alone. In colour and hardness this alloy resembled the former; but it was rather less malleable. Its specific gravity I found to be 15·141.

Silver,

3. "Palladium alloyed with an equal weight of silver, gave a button of the same colour as the preceding alloys. This was harder than silver, but not so hard as wrought iron; and its polished surface was somewhat like platina, but whiter. Its specific gravity was 11·290.

Copper,

4. "The alloy of equal parts of palladium and copper was a little more yellow than any of the preceding alloys, and broke more easily. It was harder than wrought iron; and, by the file, assumed rather a leaden colour. Specific gravity 10·392.

Lead,

5. "Lead increases the fusibility of palladium. An alloy of these metals, but in unknown proportions, was of a grey colour, and its fracture was fine-grained. It was superior to all the former in hardness, but was extremely brittle. I found its specific gravity to be 12·000.

Tin,

6. "Equal parts of palladium and tin gave a greyish button, inferior in hardness to wrought iron, and extremely brittle. Its fracture was compact and fine-grained. Specific gravity 8·175.

Bismuth,

7. "With an equal weight of bismuth, palladium gave a button still more brittle, and nearly as hard as steel. Its colour was grey; but when reduced to powder it was much darker. Its specific gravity I found to be 12·587.

Iron.

8. "Iron, when alloyed with palladium, tends much to diminish its specific gravity, and renders it brittle.

Arsenic increases the fusibility of palladium, and renders it extremely brittle *."

SECT. VI.

OF RHODIUM.

THIS metal has been discovered in crude platina by Dr Wollaston, still more recently than the last. The knowledge of it has enabled him to account for the anomalous appearances which perplexed his experiments on palladium.

Preparation.

I. It may be procured from crude platina by the following method of Wollaston:

The platina was freed from mercury by exposure to a red heat, and from gold and other impurities by digestion in a small quantity of dilute nitro-muriatic acid. It was then treated with dilute nitro-muriatic acid in a moderate sand heat, till the acid was saturated, and the whole was dissolved, except a shining black powder, from which the solution was separated. A solution of sal ammoniac in hot water was poured into this solution, in order to separate the platinum; the greatest part

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* See Chenevix's *Enquiries concerning the Nature of a Metallic Substance called Palladium*, *Phil. Trans.* 1803; and Wollaston's *Paper on a New Metal found in Crude Platina*, *Ibid.* 1804.; and *on the Discovery of Palladium*, *Ibid.* 1805. From these all the facts contained in this Section have been extracted,

of which was precipitated in the form of a yellow powder. Into the solution thus freed from its platinum, a piece of clear zinc was immersed, and allowed to remain till it ceased to produce any farther effect. By the zinc a black powder was thrown down, which was washed and treated with very dilute nitric acid in a gentle heat, in order to dissolve some copper and lead with which it was contaminated. It was then washed and digested in dilute nitro-muriatic acid till the greater part was dissolved. To this solution some common salt was added. The whole was then gently evaporated to dryness, and the residuum washed repeatedly with small quantities of alcohol till it came off nearly colourless. By this means two metallic oxides are washed off in combination with common salt, namely, the oxides of platinum and palladium. There remained behind a deep red-coloured substance, consisting of the oxide of rhodium united to common salt. By solution in water and gradual evaporation, it forms rhomboidal crystals of a deep red colour, whose acute angles are about 75°. When these crystals are dissolved in water, and a plate of zinc immersed in the solution, a black powder precipitates; which being strongly heated with borax becomes white, and assumes a metallic lustre. In this state it is rhodium. From Wollaston's analysis it follows, that crude platina contains about one part in 250 of rhodium.

Properties.

1. Rhodium thus obtained is of a white colour. Its specific gravity seems to exceed 11 somewhat. No degree of heat hitherto applied is capable of fusing it. We do not know, therefore, whether it be malleable; but as it forms malleable alloys with the other metals,

it is probable that it would not be destitute of malleability if it could be fused into a button.

Oxides.

II. This metal does not seem to be oxidized by exposure to air, even though assisted by heat; neither is it much acted upon by acids: but when the red salt, consisting of the oxide of rhodium and common salt, is dissolved in water, potash throws down the metal in the state of a yellow-coloured oxide.

Neither sal ammoniac nor prussiate of potash occasion any precipitate when dropt into this solution. This readily distinguishes rhodium from platinum and palladium.

The solution of this oxide of rhodium in muriatic acid, upon being evaporated, did not crystallize: the residuum was soluble in alcohol, and of a rose colour. Sal ammoniac, nitre, or common salt, caused no precipitation from the muriatic solution, but formed triple salts, which were not soluble in alcohol.

The solution in nitric acid also did not crystallize. A drop of this solution, being placed upon pure silver, occasioned no stain. On the surface of mercury a metallic film was precipitated, but did not appear to amalgamate. The metal was also precipitated by copper and other metals, as might be presumed from the usual order of their affinities for acids.

III. Rhodium unites readily with sulphur, and, like palladium, is rendered fusible by it; so also is it with arsenic. The arsenic or sulphur may be expelled by means of heat; but the metallic button obtained does not become malleable.

Alloys.

IV. The following are the result of the experiments made by Dr Wollaston to alloy rhodium with other metals.

1. " It unites readily with all metals that have been tried, excepting mercury; and with gold or silver it forms very malleable alloys, that are not oxidated by a high degree of heat, but become incrusted with a black oxide when very slowly cooled.

" When four parts of gold are united with one of rhodium, although the alloy may assume a rounded form under the blow-pipe, yet it seems to be more in the state of an amalgam than in complete fusion.

" When six parts of gold are alloyed with one of rhodium, the compound may be perfectly fused, but requires far more heat than fine gold. There is no circumstance in which rhodium differs more from platina than in the colour of this alloy, which might be taken for fine gold by any one who is not very much accustomed to discriminate the different qualities of gold. On the contrary, the colour of an alloy containing the same proportion of platina, differs but little from that of platina. This was originally observed by Dr Lewis. 'The colour was still so dull and pale, that the compound (5 to 1) could scarcely be judged by the eye to contain any gold*.'

" I find that palladium resembles platina, in this property of destroying the colour of a large quantity of gold. When one part of palladium is united to six of gold, the alloy is nearly white.

" When I endeavoured to dissolve an alloy of silver or of gold with rhodium, the rhodium remained untouched by either nitric or nitro-muriatic acids; and when rhodium had been fused with arsenic or with

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[*] Lewis's *Phil. Com.* p. 526.

sulphur, or when merely heated by itself, it was reduced to the same state of insolubility. But when one part of rhodium had been fused with three parts of bismuth, of copper, or of lead, each of these alloys could be dissolved completely in a mixture of two parts, by measure, of muriatic acid with one of nitric. With the two former metals, the proportion of the acids to each other seemed not to be of so much consequence as with lead; but the lead appeared on another account preferable, as it was most easily separated when reduced to an insoluble muriate by evaporation. The muriate of rhodium had then the same colour and properties as when formed from the yellow oxide precipitated from the original salt*."

SECT. VII.

OF IRIDIUM.

History.

This metal was discovered by Mr Smithson Tennant in 1803; but before he communicated the result of his experiments, a dissertation was published on it by Descotils in the *Annales de Chimie*, who had made the same discovery; and the subject was afterwards prosecuted more in detail by Vauquelin and Fourcroy.

When crude platina is dissolved in nitro-muriatic

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* See Dr Wollaston's paper above quoted, from which all the facts contained in this Section have been extracted.

acid, especially if the acid be dilute, and only a moderate heat applied, there remains behind a quantity of black shining powder in small scales, which preceding chemists had mistaken for black lead. Mr Tennant examined these scales, found their specific gravity to be 10·7, and that they consisted of two unknown metals united together. The first of these metals he called *iridium*, from the variety of colours which its solutions exhibit; to the second he gave the name of *osmium*, from the peculiar smell by which its oxides are distinguished.

Dr Wollaston discovered, that in crude platina there exists another substance very similar to the grains of platina in appearance, but differing altogether in its properties. It consists of flat white grains, often distinctly foliated. They are not soluble in any acid, and their specific gravity is no less than 19·25, which is higher than that of any other mineral; the grains of platina by the trials of this accurate chemist not exceeding 17·5. These metallic grains are separated when the platina is dissolved in nitro-muriatic acid. Dr Wollaston has ascertained them to be a compound of iridium and osmium. They are therefore of the same nature with the black powder examined by Mr Tennant.

Preparation.

To separate the two metals from each other, the black powder is to be heated to redness in a silver crucible with its own weight of potash, and kept in that state for some time. The potash is then to be dissolved off by water. A solution is obtained of deep orange colour. The portion of powder that remains undissolved is to be digested in muriatic acid. The acid becomes first blue, then olive green, and lastly deep red. The residual powder which has resisted the action of these agents, is to be treated alternately with potash and muriatic acid, till the whole of it is dissolved. By this process two solutions are obtained: first, the alkaline solution of a deep orange colour, which consists chiefly of the potash united to the oxide of osmium; second, the acid solution of a deep red, which consists chiefly of the muriatic acid united to the oxide of *iridium*.

I. By evaporating this last solution to dryness, dissolving the residuum in water, and evaporating again, octahedral crystals are obtained, consisting of muriatic acid united to oxide of iridium. These crystals being dissolved in water, give a deep red solution, from which the iridium may be precipitated in the state of a black powder by putting into the liquid a plate of zinc or iron, or indeed any metal, except gold and platinum. When heat is applied to this powder it becomes white, and assumes the metallic lustre. In this state it is pure iridium. The metal may be obtained also by exposing the octahedral crystals to a strong heat.

Properties.

It has the appearance of platinum, and seems to resist the action of heat at least as strongly as that metal: for neither the French chemists nor Mr Tennant were able to fuse it. Vauquelin considers it as brittle, and as even occasioning the brittleness of platinum; but as it has not been obtained in a metallic button, and as it forms malleable alloys with all metals tried, that property does not seem to be sufficiently decided.

It resists the action of all acids, even the nitro-muriatic almost completely; much more than three hundred parts being necessary of that acid to dissolve one of iridium *.

Oxides.

II. The affinity between iridium and oxygen seems to be very weak; but like all other metals it unites with that principle. The phenomena of its solution in muriatic acid, indicate that it is capable of uniting with at least two doses of oxygen, and of forming two oxides. The first solution is a deep blue. In that state it seems to be united to a minimum of oxygen; by diluting the solution with water it becomes green. By digesting the blue solution in an open vessel, or by adding nitric acid, it becomes dark red. In this state the metal appears to be united to a maximum of oxygen.

Most of the metals destroy the colour of these solutions by depriving the iridium of its oxygen, and throwing it down in the metallic state. The infusion of galls and the prussiate of potash likewise destroy the colour, but occasion no precipitate. The alkalies precipitate the oxide of iridium, but retain a portion of it in solution.

III. The simple combustibles seem to have little action on iridium. Mr Tennant did not succeed in his attempts to unite it with sulphur.

IV. The following are the results of Mr Tennant's experiments to alloy iridium with the metals:

Alloys.

"It does not combine with arsenic. Lead easily unites with it: but is separated by cupellation, leaving the iridium upon the cupel as a coarse black powder. Copper forms with it a very malleable alloy, which,

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* Fourcroy and Vauquelin, *Ann. de Chim.* l. 24.

after cupellation with the addition of lead, left a small proportion of the iridium, but much less than in the former case. Silver may be united with it, and the compound remains perfectly malleable. The iridium was not separated from it by cupellation, but occasioned on the surface a dark and tarnished hue. It appeared not to be perfectly combined with the silver, but merely diffused through the substance of it in the state of a fine powder. Gold alloyed with iridium is not freed from it by cupellation, nor by quartation with silver. The compound was malleable, and did not differ much in colour from pure gold; though the proportion of alloy was very considerable. If the gold or silver is dissolved, the iridium is left in the form of a black powder *."

SECT. VIII.

OF OSMIUM.

Discovery.

FOR the discovery of this very singular metallic substance, we are indebted to Mr Tennant; Fourcroy and Vauquelin, indeed, observed some of its most re-

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* The whole of the properties of iridium described in this Section have been taken from Mr Tennant's paper on *Two Metals found in the Powder remaining after the Solution of Platina*, *Phil. Trans.* 1804. Descotils did not succeed in obtaining it in a separate state; but he showed

markable properties, but they confounded it with iridium.

Osmium is separated from iridium by the process described in the last Section, and obtained in the alkaline solution, to which it communicates a yellow colour. When the alkaline solution is first formed, a pungent and peculiar smell is perceived, which Fourcroy and Vauquelin compare to that of oxymuriatic acid. As this smell constitutes one of the most remarkable properties of the metallic oxide, Mr Tennant was induced by it to call the metal *osmium*.

How obtained.

I. To obtain the oxide in a separate state, we have only to mix sulphuric acid with the alkaline solution, and distil with a moderate heat. A colourless liquid comes over, consisting of the oxide dissolved in water. This liquid has a sweetish taste and a strong smell. It does not give a red colour to vegetable blues.

The oxide of osmium may be obtained also in a more concentrated state by distilling the black powder from crude platina with nitre. With a degree of heat under redness, there sublimes into the neck of the retort a fluid apparently oily, but which on cooling concretes into a solid semi-transparent mass, soluble in water; and the solution exhibits the same properties as that obtained by the preceding process.

When mercury is shaken in either of these solutions,

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that the red colour which the precipitates of platinum sometimes assume, is owing to the presence of iridium. See his paper, *Ann. de Chim.* xlviii. 153. Fourcroy and Vauquelin confounded together the properties of osmium and iridium, ascribing both to one metal; to which they have given the name of *ptene*. See *Ann. de Chim.* xlix. 177. and l. 5.

they lose their peculiar smell; and the osmium, reduced to the metallic state, forms an amalgam with the mercury. By distilling the mercury from this amalgam, the osmium remains in a state of purity.

Properties.

It has a dark grey or blue colour, and the metallic lustre. When heated in the open air, it evaporates with the usual smell; but in close vessels, when the oxidizement is prevented, it does not appear in the least volatile.

When subjected to a strong white heat in a charcoal crucible, it did not melt nor undergo any apparent alteration.

It is not acted upon by any acid, not even the nitro-muriatic, after exposure to heat; but when heated with potash it combines with that alkali, and forms with it an orange yellow solution.

Oxides.

II. The facility with which osmium is oxidized when heated in the open air, or when fused with potash, though it resists the action of acids, forms one of the singular characters of this metal. In these respects osmium differs from all other metallic bodies.

The great volatility of this oxide, its peculiar smell, its solubility in water, its sweet taste, and the yellow colour which it assumes with potash, are not less anomalous.

Its solution stains the skin of a dark colour, which cannot be effaced. The infusion of galls immediately produces a purple colour, becoming soon after of a deep vivid blue. By this means a mixture of iridium and osmium may be easily detected. The solution of iridium is not apparently altered by being mixed with the oxide of osmium; but on adding an infusion of galls, the red colour of the first is instantly taken away, and soon after the purple and blue colour of the latter appears.

When alcohol or ether is mixed with the solution of oxide of osmium in water, the colour becomes dark, the oxide is reduced, and the osmium precipitates in black films.

This oxide appears to part with its oxygen to all the metals excepting gold and platinum. Silver being kept in a solution of it for some time, acquires a black colour; but does not entirely deprive it of smell. Copper, tin, zinc, and phosphorus, quickly produce a black or grey powder, and deprive the solution of all smell, and of the power of turning galls of a blue colour. This black powder, which consists of the osmium in a metallic state and the oxide of the metal employed to precipitate it, may be dissolved in nitro-muriatic acid, and then becomes blue with infusion of galls.

III. The action of the simple combustibles on osmium has not been tried.

Alloys.

IV. Neither do we know much of its combination with metals. It amalgamates with mercury. Heated with copper and with gold in a charcoal crucible, it melted with each of these metals, forming alloys which were quite malleable. These compounds were easily dissolved in nitro-muriatic acid, and, by distillation, afforded the oxide of osmium with the usual properties *.

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* All the facts in this Section were ascertained by Mr Tennant. It was impossible to use the experiments of the French chemists, because they have confounded iridium and osmium.

SECT. IX.

OF COPPER.

I. 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.

1. 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.

2. Its hardness is 7·5. Its specific gravity varies according to its state. Lewis found the specific gravity of the finest copper he could procure 8·830 [*]. Mr Hatchett found the finest granulated Swedish copper

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[*] Neuman's *Chemistry*, p. 61. Fahrenheit had found it 8·834. *Phil. Trans*. 1724. vol. xxxiii. p. 114.

8·895 *. It is probable that the specimens which have been found of inferior gravity were not quite pure †. Cronstadt states the specific gravity of Japan copper at 9·000.

3. Its malleability is great: 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 0·078 inch in diameter is capable of supporting 302·26 lbs. avoirdupois without breaking ‡.

4. When heated to the temperature of 27° Wedgewood, or, according to the calculation of Mortimer §, to 1450° Fahrenheit, it melts; and if the heat be increased, it evaporates in visible fumes. While in fusion it appears on the surface of a bluish green, nearly like that of melted gold ||. 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.

II. 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 sur-

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* On the *Alloys of Gold*, p. 50. It would have been heavier had it been hammered or rolled. Bergman states the specific gravity of Swedish copper at 9·3243. *Opusc.* ii. 263.

† The following are the results of Mr Hatchett's trials:

Finest granulated Swedish copper,	8·895
Do. Swedish dollar do. - -	8·799
Do. sheet British do. - - -	8·785
Fine granulated British do. -	8·607

‡ Sickengen, *Ann. de Chim.* xxv. 9.

§ *Phil. Trans.* xliv. 672.

|| Dr Lewis, Neuman's *Chemistry*, p. 61.

face of the metal becomes oxidized. 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.

Oxides.

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 oxidizement 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 on 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 in cold water. The scales fall down to the bottom of the water. When copper is kept heated below redness, its surface gradually assumes beautifully variegated shades of orange, yellow, and blue. Thin plates of it are used in this state to ornament children's toys.

In a violent heat, or when copper is exposed to a stream of oxygen and hydrogen gas, the metal takes fire and burns with great brilliancy, emitting a lively green light of such intensity that the eye can scarcely bear the glare. The product is an oxide of copper.

There are two oxides of copper at present known; and it does not appear that the metal is capable of being exhibited in combination with more than two doses of oxygen. The *protoxide* is found native of a red colour, but when formed artificially it is a fine *orange;* but the *peroxide* is *black*, though in combination it assumes various shades of blue, green, and brown.

Protoxide.

1. The protoxide of copper was first observed 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 potash is dropt into this solution, the oxide of copper is precipitated orange. But the easiest process is to dissolve any quantity of copper in muriatic acid by means of heat. The green liquid thus obtained is to be put into a phial, together with some pieces of rolled copper, and the whole is to be corked up closely. The green colour gradually disappears; the liquid becomes dark brown and opaque; and a number of dirty white crystals, like grains of sand, are gradually deposited. When this liquid, or the crystals, are thrown into a solution of potash, the orange coloured oxide precipitates in abundance.

This oxide is composed of 88·5 parts of copper and 11·5 oxygen*. It attracts oxygen with such avidity, that it can scarcely be dried without becoming bluish-green, at least on the surface; but when once dry, it retains its colour pretty well.

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

Peroxide.

2. The peroxide of copper is easily procured pure from the scales which are formed upon the surface of red hot copper. These scales have a violet red colour, owing to the presence of a little metallic copper upon their under surface; but when kept for some time red hot in an open vessel, they become black, and are then pure peroxide of copper. The same oxide may be obtained by dissolving copper in sulphuric or nitric acid, precipitating by means of potash, and then heating the precipitate sufficiently to drive off any water which it may retain.

The peroxide of copper is composed of 80 parts of copper and 20 of oxygen †. When mixed with somewhat less than its own weight of copper in powder, and heated to redness, the whole is converted into protoxide.

The oxides of copper are 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.

Union with combustibles.

III. Copper has never been combined artificially with hydrogen or carbon; but it combines readily with sulphur and phosphorus, and forms with them compounds called *sulphuret* and *phosphuret of copper*.

Sulphuret.

1. 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 Proust, of 78 parts of

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

copper and 22 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, Dieman, 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.

Supersulphuret.

2. Mr Proust has shown that the sulphuret of copper is capable of combining with an additional dose of

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* *Ann. de Chim.* xxxviii. 172.

† *Jour. de Min.* No. i. 85.

sulphur, and of forming a new compound, which may be called *supersulphuret of copper*. It is brittle, has a yellow colour, and a metallic lustre, and is found native abundantly, being well known to mineralogists by the name of *copper pyrites* [*].

Phosphuret.

3. Mr Pelletier formed *phosphuret of copper* by melting together 16 parts of copper, 16 parts of phosphoric 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 [||].

Sage has shown that this compound does not easily part with the whole of its phosphorus, though frequently melted, but retains about a twelfth. In this state it may be considered as a sub-phosphuret. It is more fusible than copper, and has the hardness, the grain,

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[*] *Jour. de Phys.* liii. 95.

[†] *Ann. de Chim.* i. 74.

[‡] *Ann. de Chim.* xiii. 3.

[§] Sage, *Jour. de Phys.* xxxviii. 468.

[||] Fourcroy, vi. 252.

and the colour of steel, and admits of an equally fine polish *.

IV. Copper does not unite to azote. Muriatic acid, when assisted by heat, converts it into an oxide, with which it enters into combination.

Alloys with

V. Copper is capable of combining with most of the metals; and some of its alloys are of very great utility.

Gold.

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. Indeed a little copper heightens the colour of gold without diminishing its ductility. This alloy is more fusible than gold, and is therefore used as a solder for that precious metal †. Copper increases likewise the hardness of gold. According to Muschenbroeck, the hardness of this alloy is a maximum when it is composed of seven parts of gold and one of copper †. Gold alloyed with $\frac{1}{12}$th of pure copper by Mr Hatchett, was perfectly ductile, and of a fine yellow colour, inclining to red. Its specific gravity was 17·157. This was below the mean. Hence the metals had suffered an expansion. Their bulk before union was 2732, after union 2798. So that 916$\frac{2}{3}$ of gold and 83$\frac{1}{3}$ of copper when united, instead of occupying the space of 1000, as would happen were there no expansion, become 1024 ‡.

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* Nicholson's *Jour*. ix. 268.

† Wasserberg, i. 112.

‡ Hatchet on the *Alloys of Gold*, p. 66. The gold was already alloyed with 1-96th of copper; the expansion, had the gold been pure,

Gold coin.

Gold coin, sterling or standard gold, consists of pure gold alloyed with $\frac{1}{12}$th of some other metal. The metal used is always either copper or silver, or a mixture of both, as is most common in British coin. Now it appears that when gold is made standard by a mixture of equal weights of silver and copper, that the expansion is greater than when the copper alone is used, though the specific gravity of gold alloyed with silver differs but little from the mean. The specific gravity of gold alloyed with $\frac{1}{24}$th of silver and $\frac{1}{24}$th of copper was 17·344. The bulk of the metals before combination was 2700; after it 2767*. We learn from the experi-

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would have been greater. For the specific gravity of an alloy of 12 gold and one copper, (supposing the specific gravity of gold 19·3, of copper 8·9), should be by calculation 17·58. Its real specific gravity is only 17·157.

[*] The first guineas coined were made standard by silver, afterwards copper was added to make up for the deficiency of the alloy; and as the proportion of the silver and copper varies, the specific gravity of our gold coin is various also.

The specific gravity of gold made standard by silver is . . . . . 17·927
copper . . . . . 17·157
silver and copper 17·344

The following trials made by Mr Hatchett, will show the specific gravity of our coins in different reigns.

Reign.		*Date.*	*Specific gravity.*
CHARLES II.	a five-guinea piece - -	1681	17·825.
JAMES II.	a two-guinea piece - -	1687	17·634.
WILLIAM III.	a five-guinea piece - -	1701	17·710.
GEORGE I.	a quarter-guinea - -	1718	16·894.
GEORGE II.	a guinea - - -	1735	17·637.
————	a two-guinea piece - -	1740	17·848.
GEORGE III.	one guinea - - -	1761	17·737.
————	one guinea - - -	1766	17·655.
————	one guinea - - -	1774	17·726.

ments of Mr Hatchett that our standard gold suffers less from friction than pure gold, or gold made standard by any other metal besides silver and copper; and that the stamp is not so liable to be obliterated as in pure gold. It therefore answers better for coin. A pound of standard gold is coined into $44\frac{1}{2}$ guineas.

Platinum.

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. The platinum dilutes the colour of the copper very much, and even destroys it, unless it be used sparingly. For the experiments made upon it we are indebted to Dr Lewis *. Strauss has lately proposed a method of coating copper vessels with platinum instead of tin; it consists in rubbing an amalgam of platinum over the copper, and then exposing it to the proper heat †.

Reign.		*Date.*	*Specific gravity.*
George III.	one guinea - - -	1775	17·698.
————	one guinea - - -	1776	17·486.
————	one guinea - - -	1777	17·750.
————	one guinea - - -	1782	17·202.
————	one guinea - - -	1786	17·465.
————	one guinea - - -	1788	17·418.
————	five guineas - - -	1793	17·712.
————	ten half-guineas - -	1801	17·750.
————	15 seven-shilling pieces ‖ -	1802	17·793.

‖ Supposing guineas, half-guineas, and seven shilling pieces, to be made from the same metal, there is reason to expect (in a given comparative sum of each) an increase of specific gravity in the smaller coins, as a natural consequence of rolling, punching, annealing, blanching, milling, and stamping; the effects of which must become more evident in proportion to the number of the small pieces required to form a given sum of the larger coins.

The average specific gravity of our gold coin, at the present time, may probably be estimated at 17·724.

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* *Philosoph. Commerce*, p. 529.

† Nicholson's *Jour.* ix. 303.

3. Silver is easily alloyed with copper by fusion. The compound is harder and more sonorous than silver, and retains its white colour even when the proportion of copper exceeds one-half. The hardness is a maximum when the copper amounts to one-fifth of the silver. The standard or sterling silver of Britain, of which coin is made, is a compound of $12\frac{1}{3}$ silver and one copper. Its specific gravity after simple fusion is 10·200 *. By calculation it should be 10·351. Hence it follows that the alloy expands, as is the case with gold when united to copper. The specific gravity of Paris standard silver, composed of 137 parts silver and seven copper, according to Brisson, is 10·1752; but by hammering, it becomes as high as 10·3765. The French silver coin, at least during the old government, was not nearly so fine, being composed of 261 parts of silver and 27 of copper, or one part of copper alloyed with $9\frac{2}{3}$ of silver. Its specific gravity, according to Brisson, was 10·0476; but after being coined, it became as high as 10·4077. The Austrian silver coin, according to Wasserberg, contains $\frac{13}{288}$ of copper †. The silver coin of the an-

Silver coin.

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* Cavallo's *Nat. Phil.* ii. 76. Dr Shaw makes it 10·535 after hammering, as it appears from his table. Shaw's *Boyle*, ii. 345.

† Wasserberg, i. 155. The following table exhibits the composition of different European coins, according to my experiments.

	Alloy per cent.	*Weight of Silver, that of the Copper being* 1.
British	7·5	12·5
Dutch	8	11·5
French	9	10·1
Austrian	9·5	9·5
Sardinian	9·5	9·5
Spanish	10·5	8·5
	15·5	5·5

cients was nearly pure, and appears not to have been mixed with alloy. This seems to be the case also with coins of the East Indies; at least a rupee which I analysed contained only $\frac{1}{32}$ part of copper; a proportion so small that it can scarcely be supposed to have been added on purpose. A pound of standard silver is coined into 62 shillings.

4. Mercury acts but feebly upon copper, and does not dissolve it while cold; but if a small stream of melted copper be cautiously poured into mercury heated nearly to the boiling point, the two metals combine and form a soft white amalgam *. Boyle pointed out the following method, which succeeds very well: triturate together two parts of mercury, $2\frac{1}{2}$ parts of verdigris, and one part of common salt, with some acetous acid, and keep them for some time over a moderate fire, stirring them constantly, and supplying acid as it evaporates; then wash the amalgam and pour it into a mould; it is at first nearly fluid, but in a few hours it crystallizes and becomes quite solid †. This amalgam may be formed also by keeping plates of copper in a solution of mer-

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	Alloy per cent.	*Weight of Silver, that of the Copper being* 1.
Portuguese - - - -	11 - - - - - - - -	8
Danish - - - - -	12 - - - - - - - -	7·3
Swiss - - - - -	21 - - - - - - - -	3·8
Russian - - - -	24 - - - - - - - -	3·6
Hamburgh - - -	50 - - - - - - - -	1

The first column of this Table gives the supposed proportion of alloy in 100 parts of the respective coin; the second gives the weight of silver contained in each coin, on the supposition that the weight of the copper with which the silver is alloyed is always 1. Nicholson's *Jour.* xiv. 409.

* Lewis, *Neuman's Chem.* p. 65.

† Shaw's *Boyle*, i. 343.

cury in nitric acid. The plate is soon impregnated with mercury. The amalgam of copper is of a 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.

5. All that is known respecting the combination of copper with palladium, rhodium, iridium, and osmium, has been mentioned in the preceding Sections.

SECT. X.

OF IRON.

History.

I. 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

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[*] Deut. iv. 20.

[†] Ibid. viii. 9.

[‡] Numb. xxxv. 16.

[§] Levit. i. 17.

[||] Deut. xviii. 5.

[¶] Ibid. xxvii. 5.

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 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.

1. 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.

2. Its hardness is 9. Its specific gravity varies from 7·6 to 7·8 †.

3. 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 for a very short time.

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* Hesiod, as quoted by Pliny, lib. vii. c. 57.

† Kirwan's *Min.* ii. 155. Dr Shaw states the specific gravity of iron at 7·645. Shaw's *Boyle*, ii. 345. Erisson at 7·788. Mr Hatchett found a specimen 7·700. On the *Alloys of Gold*, p. 66. Swedenburgh states it at 7·817. According to Muschenbroeck, hammered iron softened by heat i of the specific gravity 7·600; the same hammered hot, becomes 7·7633; and the same hammered cold, becomes 7·875. *Wasserberg*, i. 168.

4. 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, 0·078 of an inch in diameter, is capable of supporting 549·25 lbs. avoirdupois without breaking *.

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

Combination with oxygen.

II. 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.

1. 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†.

Combustible.

2. 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. It is capable also 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.

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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.

† Lavoisier and Meusnier, *Mem. Par.* 1781, p. 269.

The number of oxides which iron is capable of forming has not yet been ascertained in a satisfactory manner. Proust has proved that there are *two* very well characterised; the *first* having usually a black colour, the *second*, considered at present as the peroxide, having a red colour. Thenard has endeavoured to prove that there are three oxides of iron, which he distinguishes by the epithets *white*, *green*, and *red*[*]. But the difference between his first and second oxides, as far as he has pointed it out, is not sufficient to characterise each as containing a peculiar quantity of oxygen. Accordingly, his opinion has been called in question by Mr Darso, who has endeavoured to prove, that the *green* colour of Thenard's second oxide is owing to the presence of hydrogen, while he insinuates that the supposed *white* oxide always retains a portion of acid, and owes its colour to that acid[†]. Though Mr Darso's experiments are not sufficiently decisive to establish his own opinion, they serve to shake our confidence in the conclusions of Thenard, which cannot be admitted till they be supported by more exact experiments than those which he has adduced.

Black oxide.

3. The *black* oxide of iron 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

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[*] *Ann. de Chim.* lvi. 59.

[†] Nicholson's *Jour.* xvii. 268.

[‡] The best process is that of De Roover. He exposes a paste formed of iron filings and water to the open air in a stoneware vessel; the paste becomes hot, and the water disappears. It is then moistened again, and

making steam pass through a red hot iron tube. The iron is changed into a brilliant black brittle substance, which when pounded assumes the appearance of 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, and blackish, but retain the metallic lustre. They were examined by Lavoisier, 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 potash into the solution. A green powder falls to the bottom, which assumes the appearance of martial ethiops when dried quickly in close vessels. This 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 native in that state.

Peroxide.

4. The peroxide or *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

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the process repeated till the whole is oxidized. The mass is then pounded, and the powder is heated in an iron vessel till it is perfectly dry, stirring it constantly. See *Ann. de Chim.* xliv. 329.

* *Mem. Par.* 1781, p. 269. The iron is converted into a substance not unlike specular iron ore.

† *Ann. de Chim.* i. 19.

‡ *Ibid.* i. 19. and xxiii. 87.

§ Bergman, iii. 102.

saffron of Mars. Common rust of iron is merely this 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, by which the oxide is precipitated. This oxide is also found native in great abundance. Proust proved it to be composed of 48 parts of oxygen and 52 of iron*. Consequently the black oxide, when converted into red oxide, absorbs 0·40 of oxygen; or, which is the same thing, the red oxide is composed of 66·5 parts of black oxide and 33·5 parts of oxygen. One hundred parts of iron, when converted into a black oxide, absorb 37 parts of oxygen, and the oxide weighs 137; when converted into peroxide, it absorbs 55 additional parts of oxygen, and the oxide weighs 192.

The peroxide cannot be completely 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†.

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* *Ann. de Chim.* xxiii. 87.

† Mr Chenevix, in his excellent paper on the *arseniates of copper*, has given it as his opinion, that iron is susceptible of four different degrees of oxidizement. The first oxide, according to him, is of a *white* colour, the second is *green*, the third *black*, and the fourth *red*. His opinion is chiefly founded upon the different colours which minerals containing iron are observed to possess; namely, *white* (or colourless), *green*, *black*, *red*, *brown*, and *blue*. But it is more likely that these different colours are the results of the various combinations into which the two oxides of iron enter. Difference of colour is a very uncertain mark of difference in the proportion of oxygen combined with a metal. The black oxide of iron dissolves in acids without effervescence, and therefore without any sensible change in the proportion of its oxygen; yet with potash it

The peroxide of iron is not magnetic. It is converted into black oxide by sulphureted 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.

Protoxide.

5. Among the ores of iron there occurs an oxide which is by no means uncommon, and which appears to contain only *half* the oxygen of the black oxide. It has the metallic lustre, the colour of iron, but darker, and is brittle and magnetic. I have attempted in vain to form it artificially from iron, always obtaining the common black oxide above described. This native oxide I consider as the real protoxide of iron. Thenard's *white* oxide is, I presume, the black oxide disguised by the presence of foreign matter. If that philosopher succeeds in establishing the existence of his *green* oxide, the reality of which is still doubtful, we shall be acquainted with four oxides of iron; namely, the protoxide, the black oxide, the green oxide, and the red oxide.

Tempering of steel.

Cutting instruments of steel, after being finished, are hardened by heating them to a cherry red, and then plunging them into a cold liquid. After this hardening, it is absolutely necessary to soften them a little, or

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gives uniformly a greenish-coloured precipitate, which becomes deeper and deeper coloured when exposed to the light; and no difference is observable when the experiments are performed *in vacuo*, or in a close vessel under water. The same oxide yields with phosphoric acid a white precipitate, which becomes blue when dried in the open air; and with prussic acid, a white precipitate, which retains its colour as long as the contact of air is withheld.

to *temper* them as it is called, in order to obtain a fine and durable edge. This is done by heating them till some particular colour appear on their surface. The usual way is to keep them in oil, heated to a particular temperature, till the requisite colours appear. Now these colours follow one another in regular succession according to the temperature. Between 430° and 450°, the instrument assumes a very pale yellowish tinge; at 460°, the colour is a straw yellow, and the instrument has the usual temper of pen-knives, razors, and other fine edge tools. The colour gradually deepens as the temperature rises higher, and at 500° becomes a bright brownish metallic yellow. As the heat increases, the surface is successively yellow, brown, red, and purple, to 580°, when it becomes of a uniform deep blue, like that of watch-springs*. The blue gradually weakens to a water colour, which is the last shade distinguishable before the instrument becomes red hot†. These different shades of colour are supposed to be owing to the combination of the metal with oxygen, and to indicate a succession of oxides; but the hypothesis is unsupported by proof, and is unnecessary, because the colours might be equally well explained by supposing the coat of oxide gradually to increase in thickness. The fact that the colours appear while the iron is under the surface of oil, a liquid which readily decomposes the oxides of iron, is scarcely consistent with the supposition that the colours are owing to oxidizement.

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* See the curious experiments of Mr Stoddart, as related by Mr Nicholson. *Nicholson's Quarto Jour.* iv. 129.

† Lewis, *Neuman's Chem.* p. 79.

III. Iron is capable of combining with all the simple combustible bodies.

Union with combustibles.

1. Hydrogen, indeed, has never been united to 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 carbon, phosphorus, and sulphur, iron forms compounds known by the name of *carburet*, *phosphuret*, and *sulphuret* of iron.

Carburet.

2. 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, is soft, 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 produces no effect upon it, and occasions but little change in its bulk. It is used, in consequence, in making the crucibles called *black lead*. It was long supposed to be incombustible. But Mr Quist published a set of experiments in the Swedish Transactions for 1754, from which it appeared, that when plumbago was exposed to a strong heat in a scorifying dish, under a muffle, it yielded *sulphureous flowers*, and was all wasted away except from $\frac{1}{5}$th to $\frac{1}{10}$th; which

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* The chief mines are at Keswick in Cumberland, and in Airshire.

residuum, according to him, was a mixture of iron and tin[*]. Dr Lewis repeated the experiment. The black lead gradually wasted away on the surface precisely like charcoal, and left behind it $\frac{1}{14}$th part of a dark brown matter, chiefly attracted by the magnet. This result led Dr Lewis to compare plumbago and charcoal with each other, and to consider them as analogous substances[†]. The experiments of Dr Lewis were carried much farther by Scheele, who published a dissertation on it in 1779. He found that none of the acids tried had any effect upon it; that it reduced litharge, and other metallic oxides, precisely as charcoal; that it detonated with nitre, emitted abundance of carbonic acid; and that 10 parts of nitre were necessary to consume it completely, and in that case it left only a little oxide of iron[‡]. The experiments of Scheele were confirmed and elucidated by those of Pelletier, and of Vandermonde, Monge and Berthollet, who exposed it in glass jars filled with oxygen gas to the action of a powerful burning-glass. Nine-tenths of it were consumed and converted into carbonic acid; the remainder was iron. Hence they concluded that plumbago is a compound of

90 carbon
10 iron

100

It is probable that the portion of iron contained in plumbago is considerably less than this. In a recent

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[*] Mr Quist, in fact, used molybdena instead of plumbago in his experiments; hence the anomalous result which he obtained.

[†] *Phil. Commerce*, p. 326.

[‡] Scheele's *Opusc.* ii. 20.

experiment made by Messrs Allen and Pepys, 100 parts of plumbago, burnt in oxygen gas, left only five parts of oxide of iron *.

Plumbago is formed artificially in a variety of processes, especially in iron works.

Phosphuret.

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

History of its discovery.

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

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* On *the quantity of Carbon in Carbonic Acid*, Phil. Trans. 1807.

† Pelletier, *Ann. de Chim.* i. 105.

‡ Id. *Ibid.* xiii. 113.

§ *Opusc.* iii. 109.

|| *Schriften der Berliner Gesellsch. Naturf. Freunde*, 1780, ii. 334. and iii. 380.

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 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 phosphorus 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 phosphu-

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* This process in chemistry is called *reduction*.

† Crell's *Annals*, 1784. i. 390.

‡ Ibid. 195.

§ Crell, i. 112, Eng. Trans.

ret of iron; the phosphoric acid being deprived of its oxygen during the *reduction* *.

Sulphuret.

4. 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 oxidized. 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, and burns without the presence of air, just as copper filings and sulphur, though not with such brilliancy †. But the combustion, as I have observed, is remarkably brilliant, and even accompanied by an explosion, if a considerable mixture of iron filings and sulphur be melted together in a covered crucible. It continues much longer than that of copper and sulphur.

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

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* Rinman has shown that the brittleness and bad qualities of cold short iron may be removed by heating it strongly with limestone, and with this the experiments of Levavasseur correspond. See *Ann. de Chim.* xlii. 331.

† *Jour. de Min.* N. ii, 91.

Book I. Division I.

by him as affording an explanation of the origin of volcanoes *.

From the experiments of Proust it appears that 100 parts of iron unite by fusion to 60 of sulphur. Hence the sulphuret of iron is composed of

62·5 iron
37·5 sulphur
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100·0 †.

Mr Hatchett has lately discovered that this sulphuret exists native in considerable quantities, and that it had been long known to mineralogists under the name of *magnetic pyrites*. Its colour is that of bronze. It has a metallic lustre ; but its powder is blackish grey. Its specific gravity is 4·518. It strikes fire with steel, and easily melts when heated. He found it composed of 63 iron and 37 sulphur, which agrees almost exactly with the analysis of Proust. He has made it probable that the iron is not altogether in the metallic state, but contains about $\frac{1}{13}$ part of its weight of oxygen ‡.

This sulphuret dissolves readily in sulphuric and muriatic acids, emitting abundance of sulphureted hydrogen. When heated with nitric acid, a considerable portion of the sulphur is separated §.

Supersulphuret.

5. Iron is capable of combining with an additional dose of sulphur, and of forming a new compound,

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

† *Jour. de Phys.* liii. 89.

‡ Hatchett's *Analysis of Magnetical Pyrites*, *Phil. Trans.* 1804.

§ Hatchett, *Ibid.*

which may be called *supersulphuret of iron*. This compound is found native in great abundance, and has been long known by the name of *pyrites*. This substance is of a yellow colour, and has the metallic lustre. It is brittle, and sufficiently hard to strike fire with steel. Its specific gravity is about 4·5. It usually crystalizes in cubes. When heated it is decomposed. In the open air the sulphur takes fire: in close vessels filled with charcoal, part of the sulphur is volatilized; and a black substance remains, retaining the original form of the mineral, but falling to powder on the slightest touch. Mr Proust has demonstrated that this black substance is common sulphuret of iron. Pyrites, according to him, when thus treated, gives out 0·20 parts of sulphur, and 0·80 parts of sulphuret remain behind [*]. Hence pyrites is composed of

80	sulphuret of iron
20	sulphur
100	

But this method is not susceptible of great accuracy. Mr Hatchett has lately subjected various specimens of pyrites to analysis with that precision for which he is distinguished. The following Table exhibits a view of the results which he obtained [†]:

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[*] *Jour. de Phys.* liii. 89.

[†] Hatchett, *Phil. Trans.* 1804.

	Pyrites	Specific gravity.	Constituents.		
			Iron.	Sulphur.	Total.
1st	In dodecahedrons	4·830	47·85	52·15	100
2d	Striated cubes		47·50	52·50	100
3d	Smooth cubes	4·831	47·30	52·70	100
4th	Radiated	4·698	46·40	53·60	100
5th	Smaller do.	4·775	45·66	54·34	100

From this table we learn, that the regularly crystallized pyrites contains least sulphur, and the striated most; but the greatest difference is only 2·19 *per cent.*

Common sulphuret of iron is not only attracted by the magnet, but may be itself converted into a magnet by the usual methods; but pyrites is not in the least obedient to the magnet, neither is it susceptible of the magnetic virtues *.

Magnets, compounds of iron

It has been long known that pure iron is not susceptible of retaining the properties of a magnet; but steel, when once magnetized, continues permanently magnetic. Now steel, as we shall see immediately, is a combination of iron and carbon. When the proportion of carbon united to iron is increased to a certain proportion, as in plumbago, the iron loses the property of being acted on by the magnet. The addition of a certain portion of sulphur likewise renders iron susceptible of becoming a permanent magnet. The sulphur may

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* Hatchett, *Phil. Trans.* 1804.

amount to 46 *per cent.* without destroying this property; but when it is increased to 52 *per cent.* the magnetism vanishes completely. Iron may be made permanently magnetic also when united to phosphorus; but whether the magnetism disappears when the proportion of phosphorus is increased, has not been ascertained.

And a certain proportion of a simple combustible.

Thus it appears that pure iron is not susceptible of permanent magnetism. United to a portion of carbon, it forms a compound more or less brittle, soluble in muriatic acid, and susceptible of magnetic impregnation. Saturated with carbon, it becomes brittle, insoluble in muriatic acid, and destitute of magnetic properties.

Iron, united to a portion of sulphur, forms a brittle compound, soluble in muriatic acid, and susceptible of magnetic impregnation. Saturated with sulphur, the compound becomes brittle, insoluble in muriatic acid, and destitute of magnetic properties.

Iron, united to phosphorus, is brittle, and susceptible of magnetic impregnation in a great degree, and in all probability, by saturation, would lose its magnetic properties altogether.

For these facts, which are of the utmost importance, we are indebted to Mr Hatchett, who was led to the discovery of them by his experiments on magnetic pyrites. " Speaking generally of the carburets, sulphurets, and phosphurets of iron, I have no doubt," says this sagacious philosopher, " but that, by accurate experiments, we shall find that a certain proportion of the ingredients of each constitutes a maximum in the magnetical power of these three bodies. When this maximum has been ascertained, it would be proper to compare the relative magnetical power of steel (which hitherto has alone been employed to form artificial magnets) with that of sulphuret and phosphuret of iron; each being first examined in the form of a single mass or bar of equal weight, and afterwards in the state of compound magnets, formed like the large horse-shoe magnets, by the separate arrangement of an equal number of bars of the same substance in a box of brass.

"The effects of the above compound magnets should then be tried against others, composed of bars of the three different substances, various in number, and in the mode of arrangement; and lastly, it would be interesting to make a series of experiments on chemical compounds, formed by uniting different proportions of carbon, sulphur, and phosphorus, with one and the same mass of iron. These quadruple compounds, which, according to the modern chemical nomenclature, may be called carburo-sulphuro phosphurets, or phosphuro-sulphuro carburets, &c. of iron, are as yet unknown as to their chemical properties, and may also, by the investigation of their magnetical properties, afford some curious results. At any rate, an unexplored field of extensive research appears to be opened, which possibly may furnish important additions to the history of magnetism; a branch of science which of late years has been but little augmented, and which, amidst the present rapid progress of human knowledge, remains immersed in considerable obscurity."

Varieties of iron.

6. 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*.

1. 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 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.

Varieties.

The cast iron thus obtained is distinguished by manufacturers into different kinds, from its colour and other qualities. The three following are the most remarkable of these varieties:

1*st*, *White* cast iron, which is extremely hard and brittle, and appears to be composed of a congeries of small crystals. It can neither be filed, bored, nor bent, and is very apt to break when suddenly heated or cooled.

2*d*, *Grey or mottled* cast iron, so called from the inequality of its colour. Its texture is granulated. It is much softer, and less brittle, than the last variety, and may be cut, bored, and turned on the lath. Artillery is made of it.

3*d*, *Black* cast iron, is the most unequal in its texture, the most fusible, and least cohesive of the three *

Properties.

Cast iron melts when heated to about 130° Wedgewood. Its specific gravity varies from 7·2 to 7·6. It contracts considerably when it comes into fusion. It is converted into soft, or malleable iron, by a process which is considered as a *refinement* of it; and hence the furnace in which the operation is performed is called a *finery*.

How converted into malleable iron.

This was usually done in this country by keeping the iron melted for a considerable time in a bed of charcoal and ashes, and the scoriæ of iron, and then forging it repeatedly till it became compact and malleable. The process varies considerably in different countries, according to the nature of the fuel, and of the ore from which the iron was obtained; and the quality of the iron obtained is equally various. Mr Cort, about 16 years ago, proposed a new method, which succeeded in converting every kind of cast iron into malleable iron of the best quality. The cast iron is melted in a reverberatory furnace 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 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

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* Black's *Lectures*, ii. 495.

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.

2. Malleable 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.

3. 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.

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 with flint, and retains the magnetic virtue for any length of time. It loses this hardness by being ignited and

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[*] Beddoes. *Phil. Trans* 1791.

[†] This process is called *cementation*.

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, varying from 7·78 to 7·84.

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

Nature of these varieties

7. 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 contributed much 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 cast iron, he obtained, at an average, 42 ounce measures of hydrogen gas; from 100 parts of steel he obtaied 48 ounce measures; and from 100 parts of

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

† Pliny, lib. xxxiv. 14.

‡ *Opusc.* iii. 1.

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, penetration, and accurate judgment, would alone have secured their ap-

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* Scheele had previously observed, that plumbago is obtained when some kinds of iron are dissolved in sulphuric acid. See his *Dissertation on Plumbago*.

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

plause; 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.

Explained.

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.

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

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

That steel is composed of iron combined with car-

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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 á mesure que ces proportions varient, les produits varient aussi. Un trente-deuxieme de charbon suffit pour rendre le

bon, has been still farther confirmed by Morveau, who formed steel by combining together directly iron and diamond. At the suggestion of Clouet, he enclosed 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 57,800, and the steel obtained 56,384; so that 2,313 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 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 left undissolved by the acid.

Cast iron is iron combined with a still greater proportion of carbon than is necessary for forming steel.

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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 a ramollir au feu." *Jour. de Min.* An. vii. 3.

* *Ann. de Chim.* xxxi. 328.

† Nicholson's *Journal*, iv. 103.

The quantity has not yet been ascertained with precision: Mr Clouet makes it amount to $\frac{1}{8}$th 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 §.

Manufacture of

8. 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.

Soft iron.

The conversion of cast iron into wrought iron is effected by burning away 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 $\frac{1}{4}$th 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 common method of refining cast iron is nothing else than this process of Clouet, as has been pointed out by Dr Black. A considerable quantity of the iron, (about $\frac{1}{3}$d) is scorified or converted into black oxide of iron, known when melted by the name of *finery cinder* ‡.

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§ A substance which shall be described in the next Book.

* A detailed account of the process 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.* n. vii. p. 8.

‡ The French name for this is *laitier*.

This being mixed with the melted iron, and the heat increased, the oxide acts upon the carbon, and both mutually decompose each other. The nicety of the operation depends on knowing how far to carry the calcination of the iron, that there may be just sufficient to consume the whole of the carbon. Much more, however, is actually formed in the large manufactories.

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*.

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 is supposed to combine with the oxygen which cast iron contains, and to fly 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

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* A detailed account of this process, as performed in different iron works, may be seen in the *Jour. de Min.* No. iv. p. 3.

carefully closed up with clay. These troughs are put into a furnace, and kept sufficiently hot till the bars of iron are convered 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 repeatedly in a furnace, and then drawn out into bars, it is called *German* or *shear steel* †. Steel of cementation has a fine grain, is equal, 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, surgeon's 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,

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

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

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*. The carbon, according to Clouet, is obtained by the decomposition of the carbonic acid, which exists abundantly in the chalk; one part of the iron combining with the oxygen of this acid, while the other part combines with the carbon †. But the subsequent experiments of Mr Mushet have rendered it very probable that this theory is erroneous, and that the steel obtained by Clouet was owing to some other unobserved circumstance: for when he repeated it with all possible precision, he obtained only iron which had been melted, and thereby altered in its texture and appearance, but not converted into steel ‡. From the experiments of Clouet, it does not appear that the presence 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.

9. From the preceding detail, it is obvious that iron and carbon are capable of combining together in a variety of different proportions. When the carbon ex-

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* *Jour. de Min.* An. vii. 3.

† Guyton and Darcet, *Ibid.* An. vi. 703

‡ *Phil. Mag.* xii. 27.

Book I. Division I.

ceeds, the compound is carburet of iron or plumbago. When the iron exceeds, the compound is steel or cast iron in various states, according to the proportion. All these compounds may be considered as *subcarburets of iron.* The most complete detail of experiments on these various compounds which have appeared in this country are those of Mr Mushet, published in the Philosophical Magazine. This ingenious practical chemist has observed, that the hardness of iron increases with the proportion of charcoal with which it combines, till the carbon amounts to about $\frac{1}{60}$ of the whole mass. The hardness is then a maximum; the metal acquires the colour of silver, loses its granulated appearance, and assumes a crystallized form. If more carbon be added to the compound, the hardness diminishes in proportion to its quantity [*].

The following TABLE, by the same ingenious chemist, exhibits the proportion of charcoal which disappeared during the conversion of iron to the different varieties of subcarburet known in commerce [†].

Subcarburets of iron.

$\frac{1}{120}$	Soft cast steel
$\frac{1}{100}$	Common cast steel
$\frac{1}{90}$	The same, but harder
$\frac{1}{50}$	The same, too hard for drawing
$\frac{1}{25}$	White cast iron
$\frac{1}{20}$	Mottled cast iron
$\frac{1}{15}$	Black cast iron.

IV. Iron does not combine with azote. Muriatic

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[*] *Phil. Mag.* xiii. 138.

[†] *Ibid.* xiii. p. 142.

acid gas oxidizes it, and combines with the oxide, unless the gas be freed from water.

Alloys with Gold.

V. Iron combines with most metals.

1. Iron unites very readily with gold by fusion in all its states of soft iron, cast iron, and steel. The alloy was examined by Mr Hatchett, who found it remarkably ductile when composed of 11 gold and one iron. It was easily rolled into plates, cut into blocks, and stamped into coin, without its being necessary to anneal it. The colour was a pale yellowish grey approaching to a dull white; its specific gravity was 16·885. The bulk of the metals before fusion was 2799; after their union the bulk was 2843. Hence they suffer an expansion, as had been previously noticed by Gellert. Suppose the bulk before union to have been 1000, after union it becomes 1015·7 *. This alloy is harder than gold. Dr Lewis even says that it is fit for making edge-tools; but in that case the proportion of iron was doubtless increased. When the iron is three or four times the quantity of gold, the alloy, according to Dr Lewis, has the colour of silver †: according to Wallerius it still continues magnetic ‡. Gold answers well as a solder for iron.

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 crude platina, and likewise steel and crude platina. The alloy was excessively hard, very tough, and possessed some ductility when the iron was about ¾ths of

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* Hatchett on the *Alloys of Gold*, p. 37.

† *Phil. Com.* p. 85.

‡ *Wasserberg*, i. 115.

the alloy. The specific gravity greatly exceeded the mean; the platina having destroyed the property which cast iron has of expanding when it becomes solid. This alloy, after being kept ten years, was very little tarnished. At a red heat it was brittle, and appeared, when broken, to be composed of black grains, without any metallic lustre [*].

Silver,

3. The alloy of silver and iron has not been examined by modern chemists. According to Wallerius, the metals unite readily by fusion, and when the quantity of each is equal, the alloy has the colour of silver, but it is harder; it is very ductile, and is attracted by the magnet [†]. Morveau [‡] has shown, that when this alloy is kept in fusion, the metals separate from each other according to their specific gravity, forming two buttons, exceedingly distinct. Neither of these, however, is in a state of purity. The silver retains a little iron, which makes it obedient to the magnet. Coulomb has shown, that the proportion of iron which remained in the silver amounts to $\frac{1}{320}$th part. The iron, on the other hand, retains about $\frac{1}{80}$ of its weight of silver; which gives it an excessive hardness and compactness of structure, of which pure iron is destitute [||].

Mercury,

4. Iron is not acted on by mercury: accordingly this last metal is usually kept in vessels of iron. Mr Arthur Aiken, however, has lately shown that these two metals may be combined together. To form an amalgam of iron, he triturates together iron filings, and the amalgam of the metal called *zinc*, and adds to the mix-

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[*] *Phil. Com.* p. 534, and 551.

[†] *Wasserberg*, i. 156.

[‡] *Jour. de Phys.* 1788.

[||] *Ann. de Chim.* xliii. 47.

ture a solution of iron in muriatic acid. By kneading this mixture, and heating it, the iron and mercury which combine together gradually assume the metallic lustre [*].

Copper.

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. Thenard has ascertained, that it is attracted by the magnet, even when the iron constitutes only $\frac{1}{10}$th of the alloy [†]. Mr Levavasseur has published some observations, which render it probable that the variety of iron called *hot short* iron, because it is brittle when red hot, sometimes owes its peculiarities to the presence of copper. This variety possesses a greater degree of tenacity than common iron, and therefore answers better for some purposes. It may be hammered when white hot. As soon as it cools, so far as to assume a brown colour, the forging must be stopt till it becomes of an obscure cherry red, and then it may be continued till the iron is quite cold [‡].

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[*] *Phil. Mag.* xiii. 416.

[†] *Ann. de Chim.* l. 131.

[‡] *Ibid.* xlii. 183.

SECT. XI.

OF NICKEL.

History. 1. THERE is found in different parts of Germany a heavy mineral of a reddish brown colour, not unlike copper. When exposed to the air, it gradually 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 miners gave it the came of *Kupfer-nickel*, 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 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 ob-

Chap. IV.

tain *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 shown 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.

Nickel is rather a scarce mineral, and it occurs always in combination with several other metals, from which it is exceedingly difficult to separate it. These metals disguise its properties, and account in some measure for the hesitation with which it was admitted as a peculiar metal. Since the great improvements that have been introduced into the art of analysing minerals, chemists of eminence have bestowed much pains upon this metal, and a variety of processes have been published for procuring it in a state of purity. For the brittle metal that is sold under the name of nickel contains abundance of iron and arsenic, and some cobalt, copper, and bismuth. The first set of experiments, after those of Bergman, made expressly to purify nickel,

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* Bergman, ii. 231.

are those of the School of Mines of Paris, of which Fourcroy has published an abstract *. Their method was tedious and incomplete. Since the publication of these experiments, no less than six other processes have been proposed by chemists, all of them ingenious, and attended each with peculiar advantages and inconveniences †.

Properties.

I. Nickel, when as pure as possible, 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 $8\frac{1}{2}$, so that it is rather softer than iron. Its specific gravity, according to Richter, after being melted, is 8·279; but when hammered, it becomes 8·666 §.

It is malleable both cold and hot; and may without difficulty be hammered out into plates not exceeding the hundredth part of an inch in thickness ||.

It is attracted by the magnet at least 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 ¶.

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* *Discours Preliminaire*, p. 117.

† Mr Philips published a process in *Phil. Mag.* xvi. 312; Proust another in *Jour. de Phys.* lvii. 169; Thenard another, in *Ann. de Chim.* l. 117; Bucholz another, in Gehlen's *Jour.* ii. 282, and iii. 201; Richter a fifth, *Ibid.* iii. 244; and Proust a sixth, *Ann. de Chim.* lx. 275. These processes will come under our consideration in a subsequent part of this Work. It is to Richter that we are indebted for the most precise account of the properties of the metal.

‡ Fourcroy, *Discours Preliminaire*, p. 117.

§ Gehlen's *Jour.* iii. 252.

|| Richter, *Ibid.*

¶ Bergman, Klaproth, Fourcroy, Richter, &c.—Mr Chenevix had announced a method of procuring nickel which was not magnetic; but

It requires for fusion a temperature at least equal to 160° Wedgewood *. It has not hitherto been crystallized.

It is not altered by exposure to the air, nor by keeping it under water †.

Oxides.

II. Nickel, when moderatly heated, is soon tarnished; and if in powder, it is even converted into an oxide; but a strong heat reduces it again to the metallic state. For the oxides of nickel, like those of gold, are decomposed by heat ‡. We are at present acquainted with two oxides of Nickel; the colour of the protoxide is *greenish*, that of the peroxide black.

Protoxide.

1. The protoxide is easily procured by means of nitric acid. In that acid it dissolves with effervescence, and forms a fine grass coloured solution. Carbonate of potash throws it down of an apple green colour, and pure potash of a deeper green. When dried and exposed to a faint red heat, its colour darkens to olive green, or even to blackish grey §. In this state it may be considered as the protoxide of nickel nearly pure. By this treatment 100 parts of nickel are converted into 128 of oxide ||, of nearly

78 nickel
22 oxygen

100

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he afterwards ascertained, that it owed this peculiarity to the presence of arsenic.

[*] Bergman, ii. 269. According to Richter, its melting point is as high as that of manganese.

[†] Richter, *Ibid.*

[‡] Ibid. p. 254.

[§] Olive green was the colour in my trials. Richter obtained it greyish black.

[||] Richter, *Ibid.* p. 258.

According to the experiments of Proust, the proportion of oxygen which it contains is not quite so much. He obtained from 100 parts of nickel 125 or 126 of protoxide, indicating a compound of 80 nickel and 20 oxygen *.

This oxide is tasteless, soluble in the acids, and forms with them a grass green solution. It is soluble also in ammonia, and the solution, according to Richter, is pale blue.

Peroxide.

2. The peroxide of nickel was first examined by Thenard. It may be formed by causing a current of oxymuriatic acid to pass through water holding protoxide of nickel suspended in it; a portion is dissolved, and the rest acquires a black colour. This oxide is soluble in ammonia as well as the last; but the solution is accompanied with effervescence, owing to the decomposition of a part of the ammonia by the combination of its hydrogen with part of the oxygen of the oxide. A similar effervescence accompanies its solution in acids, occasioned by the separation of a portion of its oxygen in the state of gas. This oxide is soluble likewise in ammonia †. The proportion of its oxygen has not been ascertained.

Union with combustibles.

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

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.

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* *Ann. de Chim.* lx. 272.

† Thenard, *Ann. de Chim.* l. 125.

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.

IV. Nickel is not acted upon by azote, nor does it combine with muriatic acid.

Alloys with

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

Gold,

Mr Hatchett melted a mixture of 11 gold and one nickel, and obtained an alloy of the colour of fine brass. It was brittle, and broke with a coarse-grained earthy fracture. The specific gravity of the gold was 19·172; of the nickel 7·8; that of the alloy 17·068. The bulk of the metals before fusion was 2792, after fusion 2812; Hence they suffered an expansion. Had their bulk before fusion been 1000, after fusion it would have become 1007. When the proportion of nickel is diminished, and copper substituted for it, the brittleness of the alloy gradually diminishes, and its colour approaches to that of gold. The expansion, as was to be expected, increases with the proportion of copper introduced†.

Other metals.

With copper this metal is said to form a white, hard, brittle alloy, easily oxidized when exposed to the air: with iron it combines very readily, and forms an alloy whose properties have not been sufficiently examined:

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

† Hatchett on the *Alloys of Gold*, p. 21.

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 *.

But as all these trials were made with impure nickel, little dependance can be placed upon their precision.

SECT. XII.

OF NICCOLANUM.

THOUGH this metal, announced some years ago by Richter, has not hitherto been examined nor recognized by other chemists; and though Richter does not appear quite satisfied with respect to its peculiar nature; yet as the properties which he pointed out seem to be peculiar, and as it may throw light on the composition of the ores of nickel hitherto but imperfectly analysed; it ought not to be omitted in this place. Richter gave it the name of *niccolanum,* because it always accompanies nickel in the ores of that metal †.

He had been occupied for a considerable time in purifying nickel, and had collected about half a pound of the oxide of that metal, from which he expected at least a quarter of a pound of metallic nickel. But upon ex-

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* Cronstedt.

† See Gehlen's *Jour.* iv. 392.

posing it to a sufficiently strong heat, not more than one ounce of nickel could be obtained: the rest was converted to a kind of scoria. This matter was reduced to powder, mixed with charcoal, and exposed for 18 hours to the strongest heat of a porcelain furnace. By this means, under a blackish brown scoria, there was found a metallic button which weighed 2¾ ounces. It was to this metallic button thus obtained that Richter gave the name of *niccolanum*.

Properties.

1. Its colour is steel grey with a shade of red. It exhibits a coarse granular structure when broken. It is slightly malleable when cold, but not when red hot. It is attracted by the magnet, but not so powerfully as nickel, though (according to Ritter †) more powerfully than cobalt. Its specific gravity after fusion is 8·55; when hammered 8·60.

2. It dissolves in nitric acid more readily than nickel. The solution has a blackish green colour; and, when concentrated, gelatinizes. When the acid is driven off, a blackish powder remains, which is the peroxide of niccolanum.

3. This oxide is insoluble in nitric acid, unless some sugar or alcohol be added to the mixture. It dissolves in muriatic acid, while oxymuriatic acid exhales. The solution is dark green; when evaporated to dryness, it assumes a red colour, but becomes again green as it attracts moisture from the atmosphere.

4. The sulphate of niccolanum exhibits the same phenomena.

5. Carbonate of potash throws down niccolanum

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* Gehlen's *Jour.* v. 394.

from its solutions of a pale blue colour; pure potash, of a dark greenish blue. Ammonia renders the solution of niccolanum red, but occasions no precipitate.

6. There are two oxides of niccolanum; the first is greenish blue, the second black. Neither of them is reducible *per se*. The last does not combine with acids [*].

SECT. XIII.

OF TIN.

I. TIN was known to the ancients in the most remote ages. The Phœnicians 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.

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

2. Its hardness is 6 [§]. Its specific gravity is 7·291; after hammering, 7·299 [¶].

3. It is very malleable: tin leaf, or *tinfoil* as it is

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[*] Gehlen's *Jour.* iv. 392.

[†] Pliny, lib. iv. cap. 34. and lib. xxxiv. cap. 47.

[‡] Numbers xxxi. 22.

[§] Kirwan's *Miner.* ii. 194.

[¶] Brisson.

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 $\frac{1}{12.0}$ 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.

Chap. IV.

4. When heated to the temperature of 442° † it melts; 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 ‡.

Oxides.

II. When exposed to the air it very soon loses its 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 §.

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 yellow. 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 three different proportions of oxygen, and of forming three oxides; the two last of which are,

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* Muschenbroeck.

† Crichton, *Phil. Mag.* xv. 147.

‡ Pajot, *Jour. de Phys.* xxxviii. 52.

§ Bouillon La Grange, *Ann. de Chim.* xxxv. 208.

usually distinguished, on account of their colour, by the names of the *yellow* and the *white oxide* ||; though the first when pure has a grey colour, and a good deal of the metallic lustre.

Grey oxide.

1. The grey oxide is formed when tin is exposed to a moderate heat for some time; but in that case it is never pure. It may, however, he obtained in a state of purity by the following method: Dissolve tin in muriatic acid, either by means of heat, or by adding a little nitric acid occasionally. When the solution is completed, add to it an excess of potash; a white powder falls, but is partly taken up again. But the remainder, on standing, assumes a dark grey colour, and even a metallic lustre; this remainder is pure grey oxide of tin *. It is tasteless, readily soluble in acids, and gradually in potash; and when united to other bodies, it absorbs oxygen with great avidity. According to the analysis of Proust, 100 parts of tin, when reduced to the state of grey oxide, combine with 25 of oxygen. Hence it is composed of

80 tin
20 oxygen

100

Peroxide.

2. The peroxide may be obtained by heating tin in concentrated 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

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|| Ibid. xxviii. 213.

* See Proust, *Ibid.* and Berthollet, junior, *Statique Chimique*, ii. 457.

tin. This oxide is not altered by exposure to the air. It dissolves very readily in potash, and likewise in muriatic acid.

Protoxide.

3. The existence of the third oxide, which is in fact a protoxide of tin, has been lately ascertained by Proust, though he has not succeeded in obtaining it in a separate state, nor in ascertaining the proportion of oxygen which it contains. The salt composed of muriatic acid, and the grey oxide of tin previously reduced to a dry mass, was fused in a retort and mixed with sulphur. The oxide of tin was divided into two parts. One portion sublimed in combination with the muriatic acid, in the state of peroxide of tin, another portion combined with sulphur, and formed the compound called *aurum musivum* or *mosaic gold*. Pelletier had demonstrated that the tin in this compound is in the state of an oxide. It is obvious from the experiment of Proust, that it contains less oxygen than the grey oxide, as it must have resigned a portion of the oxygen which it originally contained, in order to convert the portion of tin which sublimed into peroxide. This conclusion Mr Proust confirmed by several additional experiments *. But nothing farther is at present known respecting the properties of this protoxide of tin.

Union with combustibles.

III. Tin combines with sulphur and phosphorus; but it has never been united to carbon nor hydrogen.

Sulphuret.

1. 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, hea-

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* Nicholson's *Jour.* xiv. 39.

vier 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 100 parts of tin and 20 of sulphur; According to Pelletier, of 85 parts of tin and 15 of sulphur [*]. Proust's analysis coincides with that of Bergman [†].

Sulphureted oxide.

2. 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 oxide of tin, formerly called *aurum musivum*, *musicum*, or *mosaicum*, and now *sulphureted oxide of tin*. It consists of beautiful gold coloured flakes, exceedingly light, which adhere to the skin. 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 [‡]. Its nature has been still farther investigated by Proust, who has shown that the oxide in combining with the sulphur loses a portion of its oxygen, and is converted into protoxide. According to him it contains a smaller proportion of sulphur than was assigned by Pelletier. Neither nitric nor muriatic acids act upon it, but if nitromuriatic acid be boiled upon it, the mosaic gold is slowly converted into sulphate of tin, consisting of sulphuric acid combined with the peroxide. It explodes violently when heated with twice its weight of nitre.

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[*] *Ann. de Chim.* xiii. 287.

[†] Nicholson's *Jour.* xiv. 45.

[‡] See his Memoir, *Ann. de Chim.* xiii. 280.

It dissolves in liquid potash when assisted by heat. The solution is greenish. It appears from the experiments of Proust, that during this solution water is decomposed, the oxygen of which converts the tin to a peroxide, while its hydrogen combining with the sulphur forms sulphureted hydrogen, which unites with the peroxide *.

Phosphuret.

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

IV. Tin does not combine with azote nor muriatic acid; though the last substance converts it into an oxide.

Alloys with

V. Tin is capable of combining with most of the me-

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* See Proust, Nicholson's *Jour.* xiv. 42.

† *Ann. de Chim.* xiii. 116.

tals, and some of its alloys are much employed. The greater number of them are brittle. The older metallurgists considered it as a property of tin to render other metals brittle. Hence they called it *diabolus metallorum* [*].

Gold.

1. It unites readily with gold by fusion, and was supposed by the older chemists to have the property of communicating brittleness to the alloy in how small a portion soever it was united to the precious metal; but later and more precise experiments have shown that this opinion was ill founded. The mistake was first removed by Mr Alchorne, in a set of experiments on this alloy published in the Philosophical Transactions for 1784; and these have been amply confirmed by the subsequent trials of Mr Hatchett. An alloy of 11 gold and one tin has a very pale whitish colour; brittle when thick; but when cast thin, it bends easily, but breaks when passed between rollers. The fracture is fine grained, and has an earthy appearance. The specific gravity of this alloy was 17·307. The bulk of the two metals before fusion being reckoned 1000, after fusion, it was reduced to 981; so that the metals contract very considerably by uniting together [†]. When gold was made standard by equal parts of tin and copper, an alloy was obtained of a pale yellow colour, and brittle; but when the tin amounted only to $\frac{1}{60}$ of the whole, the alloy was perfectly ductile [‡]. Indeed, from the experiments of Mr Alchorne, we learn, that when gold is alloyed with no more than $\frac{1}{37}$th of tin, it retains its duc-

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[*] See Etmuller's *Chemistry*, p. 332.

[†] Hatchett on the *Alloys of Gold*, p. 32.

[‡] Hatchett, *Ibid.*

tility sufficiently to be rolled and stamped in the usual way. But Mr Tillet showed, as was indeed to have been expected, that when heated to redness, it falls to pieces, owing to the fusion of the tin. Both of these facts have been confirmed by the late experiments of Mr Bingley. He found that an alloy of gold with $\frac{1}{60}$th of tin, when annealed in a red heat, just visible by daylight, which is equal to 5° of Wedgewood, was quite ductile, and capable of being worked into any form; but when heated to a cherry red, or to 10° Wedgewood, blisters began to appear on the surface of the bar; its edges curled up; and at last it lost its continuity, and fell into a dark-coloured mass, with little of the metallic lustre*.

Platinum,

2. From the experiments of Dr Lewis we learn, that tin and platinum readily melt, and form an alloy which is brittle and dark coloured when the proportions of the two metals are equal, and continues so till the platinum amounts only to $\frac{1}{9}$th of the alloy; after this the ductility and white colour increase as the proportion of platinum diminishes. When this alloy is kept, its surface gradually tarnishes and becomes yellow, but not so readily if it has been polished †.

Silver,

3. The alloy of silver and tin is very brittle and hard. It was examined by Kraft and Muschenbroeck. According to them, one part of tin and four of silver form a compound as hard as bronze. The addition of more tin softens the alloy. It has a granular appearance, and is easily oxidized. According to Gellert,

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[*] Hatchett *on the Alloys of Gold*, p. 32.

[†] *Philosoph. Commerce*, p. 510.

these metals contract in uniting [*]. Mr Hatchett found that silver made standard by tin was brittle, and did not ring well [†].

Mercury,

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.

This alloy is used in *silvering* the backs of looking glasses. A sheet of tinfoil is spread upon a table, and mercury rubbed upon it with a hare's foot, till the two metals incorporate; then a plate of glass is slid over it, and kept down with weights. The excess of mercury is driven off, and in a short time the tinfoil adheres to the glass and converts it into a mirror [‡].

Copper.

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

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[*] *Metallurgic Chem.* p. 140.

[†] On the *Alloys of Gold*, p. 33.

[‡] See Watson's *Chem. Essays*, p. 240. Dr Watson has rendered it probable that the art of forming mirrors by coating glass with a plate of metal, was known at least as early as the first century.

density increases with the tin; and that the specific gravity, when the alloy contains 100 parts of copper and 16 of 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 0·79*. 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.

Gun metal.

Bronze and the metal of cannons are composed of from 8 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†.

The term *brass* is often applied to this alloy, though, in a strict sense, it means a compound of copper and zinc. Brass guns are made in no other part of Britain except Woolwich. The proportion of tin varies from 8 to 12 to the 100 of copper; the purest cop-

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

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

per requiring the most, and the coarsest the least. This alloy is more sonorous than iron; hence brass guns give a much louder report than those made of cast iron *.

Bell metal.

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 oxidized, and thrown upon the surface. According to Swedenburg, the English bell metal is usually made from the scoriæ of the brass gun foundery, melted over again †. The proportion of tin in bell metal varies. Less tin is used for church bells than clock bells; and in small bells, as those of watches, a little zinc is added to the alloy ‡. According to Gerbert, the *conch* of the East Indians is composed of tin and copper, in the same proportions as in bell metal §.

Mirror metal.

The alloy used for the mirrors of telescopes was employed by the ancients for the composition of their mirrors. It consists of about two parts of copper, united to one part of tin. Mr Mudge ascertained that the best proportions were 32 copper to 14·5 of tin; a specimen of an ancient mirror analysed by Klaproth was composed of

62 copper
32 tin
8 lead

100

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* See Watson's *Chem. Essays*, iv. 127.

† *Wasserberg*, i. 262.

‡ Watson's *Essays*, iv. 132.

§ *Wasserberg*, i. 261.

But the lead he considers as accidental[*]. This alloy is very hard, of the colour of steel, and admits of a fine polish. But besides this, there are many other compounds often used for the same purpose[†].

Tinned copper.

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.

Iron.

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 experi-

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[*] *Phil. Mag.* xvii. 294.

[†] See *Wasserberg*, i. 262, and Watson's *Chem. Essays*, iv. 139.

ments 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 *.

Tinplate. 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. It is usual to add about $\frac{1}{10}$th of copper to the tin, to prevent it from forming too thick a coat upon the iron †.

SECT. XIV.

OF LEAD.

I. 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. 1. Lead is of a bluish white colour; and when newly melted is very bright, but it soon becomes tarnished by

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* Bergman, iii. 471.

† See Watson's *Chem. Essays*, iv. 191.

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.

2. Its hardness is $5\frac{1}{2}$; its specific gravity is 11·3523 *. Its specific gravity is not increased by hammering; so far from it, that Muschenbroeck found lead when drawn out into a wire, or long hammered, actually diminished in its specific gravity. A specimen at first of the specific gravity 11·479, being drawn out into a fine wire, was of the specific gravity 11·317; and on being hammered, it became 11·2187: yet its tenacity was nearly tripled †.

3. 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 $\frac{1}{12\cdot8}$ inch diameter is capable of supporting only 18·4 pounds without breaking.

4. From the late experiments of Mr Crichton of Glasgow we learn, that lead melts when heated to the temperature 612° ‡. When a very strong heat is applied the metal boils and evaporates. 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 §.

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* Brisson. Fahrenheit found it 11·3500, Phil. Trans. 1724. Vol. xxxiii. p. 114. I found a specimen of milled lead 11·407 at the temperature of 64°.

† *Wasserberg*, i. 441.

‡ *Phil. Mag.* xvi. 49.

§ *Jour. de Phys.* xxxviii. 53.

Oxides.

II. 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 oxid: but this conversion is exceedingly slow; the external crust of oxide, which forms first, preserving 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.

It is believed at present, that lead is capable of uniting with at least four doses of oxygen, and of forming four different oxides.

Yellow oxide.

1. The yellow oxide of lead, which has been longest known, and most carefully examined, may be obtained by dissolving lead in a sufficient quantity of nitric acid, so as to form a colourless solution, and then supersaturating it with carbonate of potash. A white powder falls, which when dried, and heated nearly to redness, assumes a yellow colour. It is pure *yellow oxide of lead.* This oxide is tasteless, insoluble in water, but soluble in potash and in acids. It readily melts when heated, and forms a yellow, semi-transparent, brittle, hard glass. In violent heats a portion of it is dissipated. When kept heated in the open air, its surface becomes brick red. According to Proust, it is composed of 91 lead and nine

oxygen *. My analysis gave 89·7 lead, 10·3 oxygen †. If we consider the mean of these two results as nearest the truth, we shall have yellow oxide of lead composed of about

90·5	lead
9·5	oxygen
100·0	

Or 100 parts of lead, when converted into yellow oxide, unite with 10·6 of oxygen.

But Bucholz, who has repeated the analysis with much care, and upon a much greater quantity of lead than I employed, obtained for the result yellow oxide, composed of 100 lead and 8 oxygen ‡.

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 succeeds it; and by continuing the heat, the whole of the lead may soon be converted into this substance. If these pellicles be heated and agitated for a short time in an open vessel, they assume the form of a greenish yellow powder. Mr Proust has shown that this powder is a mixture of yellow oxide and a portion of lead in the metallic state. It owes its green colour to the blue and yellow powders which are mixed in it. If we continue to expose this powder to heat for some time longer in an open vessel, it absords more oxygen, assumes a yellow colour, and is then known in commerce by the name of *massicot*. The reason of this change is obvi-

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* *Jour. de Phys.* lvi. 206.

† Nicholson's *Jour.* viii. 283.

‡ Gehlen's *Jour.* v. 259.

Book I. Division I.

ous: The metallic portion of the powder gradually absorbs oxygen, and the whole of course is converted into yellow oxide.

White 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 powder used formerly to be considered as a peculiar oxide of lead; but it is now known that it is a compound of the yellow oxide and carbonic acid.

Protoxide.

2. Yellow oxide of lead was formerly considered by chemists as lead combined with a minimum of oxygen; but Mr Proust has pointed out the following method of procuring an oxide containing a still smaller proportion of oxygen: Dissolve lead in nitric acid, and boil the crystals which that solution yields along with pieces of metallic lead. The consequence is the formation of scaly crystals of a yellow colour, brilliant, and very soluble in water. These crystals, according to Proust, are composed of the protoxide of lead combined with nitric acid.

Upon repeating Proust's experiment, and decomposing the yellow salt by means of potash, and examining the oxide, it presented the same properties nearly as the yellow; and when combined with nitric acid, yielded almost the same quantity of salt as the yellow. The utmost difference was such only as to indicate Proust's protoxide to be composed of

91·5 lead
8·5 oxygen

100·0

A difference so small that I was disposed to consider it as an error in the experiment, and to ascribe the difference between Proust's yellow salt and common nitrate of lead to an alteration in the proportion of acid. But upon reconsidering the subject, the phenomena scarcely appear compatible with that supposition. At any rate, my experiments are insufficient to demonstrate the identity of the two oxides. We must therefore at present, I think, consider Proust's oxide as distinct, and as containing a very little less oxygen than the yellow. It is therefore a *protoxide of lead.*

Red oxide.

3. If massicot, ground to a fine powder, be 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 *tritoxide* or *red oxide of lead.*

Red lead is a tasteless powder, of an intense red colour, often inclining to orange, and very heavy; its specific gravity, according to Muschenbroeck, being 8·940. It loses no sensible weight in a heat of 400°; but when heated to redness, it gives out oxygen gas, and gradually runs into a dark brown glass of considerable hardness. By this treatment it loses from four to seven parts in the hundred of its weight, and a part of the lead is reduced to the metallic state. Red lead does not appear to combine with acids. Many acids indeed act upon it, but they reduce it in the first place to the

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* See an account of the method of manufacturing *red lead* in Watson's *Chemical Essays*, iii. 338.

state of yellow oxide. From my trials, this oxide is composed of

88 lead
12 oxygen

100

Hence 100 parts of lead in becoming red lead combine with 13·6 of oxygen.

Peroxide.

4. If nitric acid, of the specific gravity 1·260, be poured upon the red-coloured 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 *peroxide* or *brown oxide of lead*, first discovered by Scheele. The best method of preparing it is the following, which was pointed out by Proust, and afterwards still farther improved by Vauquelin: Put a quantity of red oxide of lead into a vessel partly filled with water, and make oxymuriatic acid gas pass into it. The oxide becomes deeper and deeper coloured, and is at last dissolved. Pour potash 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 a tasteless powder of a flea-brown colour, and very fine and light. It is not acted on by sulphuric or nitric acids. To muriatic acid it gives out oxygen, and converts it into oxymuriatic acid. When heated it gives out 9 *per cent.* of oxygen, and is converted into yellow oxide. Proust's analysis makes

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

† Fourcroy, iv. 91.

it a compound of 79 lead and 21 oxygen; mine, of 81·6 lead and 18·4 oxygen. The mean of both gives us this oxide composed of about

80 lead
20 oxygen

100

Hence 100 parts of lead in becoming brown oxide absorb 25 parts of oxygen.

Cupellation.

5. All the oxides of lead are very easily converted into glass; and in that state they oxidize and combine with almost all the other metals except gold, platinum, silver, and the metals recently discovered in crude platina. 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 for some time in that state in a flat cup, called a *cupel*, made of burnt bones, and the ashes of wood. 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*.

Refining lead.

6. Lead when first extracted from its ore always contains a certain portion of silver, variable, according to the ore, from a few grains to 20 ounces or more in the fodder. When the silver contained in lead is sufficient to repay the expence, it is usual to separate it; and the process is known by the name of *refining* the lead. The lead is placed gradually upon a very large flat dish called a *test*, made by beating a mixture of burnt bones and fern ashes into an iron hoop, and scooping out the

surface to a certain depth. Being acted upon by the flame of the furnace, it gradually assumes a kind of a vitriform state, and is blown off the test, or sinks into it, while the silver remains unaltered. The lead by this process is converted into the substance called

Litharge.

litharge. As it is thrown off in a melted state, the litharge at first coheres in masses, but it gradually falls down by exposure to the air, and then consists of fine scales, partly red and partly of a golden yellow. It consists of yellow oxide of lead combined with a certain portion of carbonic acid *.

Union with combustibles.

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

Phosphuret.

1. 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 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 †.

Sulphuret.

2. 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

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* Some improvements in the method of separating silver from lead by cupellation may be seen in a dissertation by Duhamel, published in the 3d Vol. of the *Memoirs de l' Institute*, p. 406. They had been previously practised in this country.

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

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. The specific gravity varies somewhat, but is not much below 7.

Lead appears capable of uniting with two different proportions of sulphur. With the minimum it forms *sulphuret* of lead, which is the common galena of mineralogists. It is composed of about 86 lead and 14 sulphur; or 100 parts of lead in the sulphuret are combined with about 16 of sulphur.

Supersulphuret.

Besides this common sulphuret of lead there occurs another occasionally, lighter in colour, and more brilliant, which burns in the flame of a candle, or when put upon burning coals, emiting a blue flame. It contains at least 25 *per cent*. or $\frac{1}{4}$th of its weight of sulphur. It is therefore a *super-sulphuret* of lead. This variety has not hitherto been noticed by mineralogists, neither has it been made artificially by chemists.

IV. Lead does not combine with azotic gas. Muriatic acid gradually corrodes it, and converts it into a white coloured oxide.

V. Lead is capable of combining with most of the metals.

Alloys with Gold,

1. When 11 parts of gold are melted with one of lead, an alloy is formed, which has externally the colour of gold, but is rather more pale. It is exceedingly brittle, breaking like glass, and exhibiting a fine-grained fracture, of a pale brown colour, without any metallic lustre, and having the appearance of porcelain. The brittleness continues even when the proportion of lead is so far diminished that it amounts only to $\frac{1}{1920}$th

Book I.
Division I.

of the alloy. Even the fumes of lead are sufficient to destroy the ductility of gold. The specific gravity of the alloy of 11 gold and one lead is 18·080, which is somewhat less than the mean; so that the metals undergo an expansion. This expansion increases as the lead diminishes (the gold remaining the same, and the deficiency being supplied by copper), and becomes a maximum when the lead amounts only to $\frac{1}{960}$th of the alloy. The following Table exhibits a view of this remarkable expansion:

Metals.	Grains.	Specific gravity of alloy.	Bulk before union.	Do. after.	Expansion.
Gold Lead	442 38	18·080	1000	1005	5
Gold Lead Copper	442 19 19	17·765	1000	1006	6
Gold Copper Lead	442 30 8	17·312	1000	1022	22
Gold Copper Lead	442 34 4	17·032	1000	1035	35
Gold Copper Lead	442 37·5 0·5	16·627	1000	1057	57
Gold Copper Lead	442 37·75 0·25	17·039	1000	1031	31*

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* See Hatchett on the *Alloys of Gold*, p. 29 and 67.

Platinum,

2. Dr Lewis fused crude platina and lead together in various proportions; a violent heat was necessary to enable the lead to take up the platinum. Hence a portion of the lead was dissipated. The alloys had a fibrous or leafy texture, and soon acquired a purple colour when exposed to the air. When equal parts of the metals were used, the alloy was very hard and brittle; and these qualities diminished with the proportion of platinum. When the alloys were melted again, a portion of the platinum subsided*. 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†.

Silver,

3. Melted lead dissolves a great portion of silver at a slightly red heat. The alloy is very brittle‡; its colour approaches to that of lead; and, according to Kraft, its specific gravity is greater than the mean density of the two metals united. The tenacity of silver, according to the experiments of Muschenbroeck, is diminished by the addition of lead. This alloy is easily decomposed, and the lead separated by cupellation.

Mercury,

4. Mercury amalgamates readily with lead in any proportion, either by triturating 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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* *Philos. Commerce*, p. 512.

† Ibid. p. 561.

‡ Lewis, *Neuman's Chem.* p. 57.

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

Copper,

5. Copper does not unite with melted lead till the fire is raised so high as to make the lead boil and smoke, and of a bright red heat. When pieces of copper are thrown in at that temperature, they soon disappear. The alloy thus formed is of a grey colour, brittle when cold, and of a granular texture [†]. According to Kraft, it is rarer than the mean [‡]. The union between the two metals is very slight. When the alloy is exposed to a heat sufficient only to melt the lead, almost the whole of the lead runs off, and leaves the copper nearly pure [§]. The little lead that remains may be scorified by exposing the copper to a red heat. If the lead that runs off carries with it any copper, on melting it the copper swims on the surface, and may be easily skimmed off [‖]. This alloy is said to be employed sometimes for the purpose of making printers types for very large characters [¶].

Iron,

6. The older chemists affirm, that iron is not taken up by melted lead at any temperature whatever, but that it constantly swims upon the surface. Muschenbroeck, however, succeeded in uniting by fusion 400 parts of iron with 134 parts of lead, and formed a hard alloy, whose tenacity was not one-half of that of pure

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[*] Dijon Academicians.

[†] Lewis, Ibid.

[‡] *Wasserberg*. i. 263.

[§] Lewis, Neuman's *Chemistry*, p. 57. This curious mode of separation is called in Chemistry *eliquation*.

[‖] Lewis, Ibid.

[¶] Fourcroy, vi. 266. It has been lately ascertained by Mr Hatchett, that copper cannot be used to alloy gold unless it be free from lead. The smallest portion of this metal, though too minute to affect the copper itself, produces a sensible change on the ductility of gold.

iron. The specific gravity of an alloy of ten iron and one lead, according to him, is 4·250[*]. The experiments of Guyton Morveau have proved, that when the two metals are melted together, two distinct alloys are formed. At the bottom is found a button of lead containing a little iron; above is the iron combined with a small portion of lead[†].

Tin.

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 three parts of tin and one of lead. The presence of the tin seems to prevent in a great measure the noxious qualities of the lead from becoming sensible when food is dressed in vessels of this mixture.

This mixture is often employed to tin copper vessels, and the noxious nature of lead having raised a suspicion, that such vessels when employed to dress acid food, might prove injurious to the health, Mr Proust was employed by the Spanish government to examine the subject. The result of his experiments was, that vinegar and lemon juice, when boiled long in such vessels, dissolve a small portion of tin, but no lead, the presence of the former metal uniformly preventing the latter from being acted on. The vessels of course are innocent[‡]. The specific gravity of this alloy increases with the lead, as might be expected. Hence the proportion of the two metals in such alloys may be estimated nearly from the specific gravity, as will appear from the

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[*] *Wasserberg*. i. 212.

[†] *Ann. de Chim.* lvii. 47.

[‡] *Ann. de Chim.* lvii. 73.

following Table, drawn up by Dr Watson from his own experiments *.

Tin.	Lead.	Sp. Grav.
0	100	11·270
100	0	7·170
32	1	7·321
16	1	7·438
8	1	7·560
5	1	7·645
3	1	7·940
2	1	8·160
1	1	8·817

Pewter.

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.

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* *Chemical Essays*, iv. 165.

† There are three kinds of *pewter* in common use; namely, *plate*, *trifle*, and *ley*. The plate pewter is used for plates and dishes; the trifle chiefly for pints and quarts; and the ley metal for wine measures, &c. Their relative specific gravities are as follows: Plate, 7·248; trifle, 7·359; ley, 7·963. The best pewter it said to consist of 100 tin and 17 antimony. See Watson's *Chemical Essays*, iv. 167.

SECT. XV.

OF ZINC.

History.

I. The ancients were acquainted with a mineral to which they gave the name of *Cadmia*, 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 contained 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 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 the

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

† 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 de 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 cum non distillat ab ipso, sed evaporat in ignem, et sic

Book I.
Division I.

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[‡]. At present there are three works in this country in which zinc is extracted from its ore; two in the neighbourhood of Bristol, and one at Swan-

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relinquitur cinis inutilis, et hic lapis notus est apud alchymicos, 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 manifeste 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 race sua."

[*] 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.

sey. The ore (sulphuret of zinc) is roasted and reduced to powder, mixed with charcoal, and exposed to a strong heat in large closed clay pots. The zinc is reduced, and gradually drops down through an iron tube issuing from the bottom of the pot, and falls into a vessel of water. The zinc is afterwards melted and cast into ingots. A considerable quantity of zinc is yearly exported from Britain, chiefly to the north of Europe[*].

Properties.

1. 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.

2. Its hardness is $6\frac{1}{2}$. When rubbed upon the fingers it tinges them of a black colour. The specific gravity of melted zinc varies from 6·861 to 7·1[†]; the lightest being esteemed the purest. When hammered it becomes as high as 7·1908[‡].

3. 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

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[*] See an account of the manufacture of this metal in Watson's *Chem. Essays*, iv. 1.

[†] Brisson and Dr Lewis. A specimen of Goslar zinc was found by Dr Watson of the specific gravity 6·953; Bristol zinc 7·028. *Chemical Essays*, iv. 41. A specimen of zinc tried by Mr Hatchett was 7·065. On the *Alloys of Gold*, p. 67.

[‡] Brisson.

elastic, but cannot be folded without breaking. This property of zinc was first ascertained by Mr Sage [*]. When heated somewhat above 212°, it becomes very malleable. It may be beat at pleasure without breaking, and hammered out into thin plates. When carefully annealed, it may (it is said) be passed through rollers. It may be very readily turned on the lath. When heated to about 400°, it becomes so brittle that it may be reduced to powder in a mortar.

4. It possesses a certain degree of ductility, and may with care be drawn out into wire [†]. Its tenacity from the experiments of Muschenbroeck, is such, that a wire whose diameter is equal to $\frac{1}{10}$th of an inch, is capable of supporting a weight of about 26 lbs [‡].

5. When heated to the temperature of about 680° [§], 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 [‖].

Combination with oxygen.

II. 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 ra-

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

[†] Black's *Lectures*, ii. 583.

[‡] He found a rod of an inch diameter to support 2600 lbs. Now if the cohesion increase as the square of the diameter, the strength of a wire of 1-10th inch, will not differ much from that assigned in the text.

[§] Black's *Lectures*, ii. 583.

[‖] Mongez.

pidly; and if the steam of water is made to pass over zinc at a very high temperature, it is decomposed with great rapidity *.

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 oxidized. 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 a strong red heat in an open vessel, it takes fire, and burns with a 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 †.

Two different oxides of zinc are at present known.

Peroxide.

1. The peroxide, or white oxide of zinc, is the oxide usually formed in the different processes to which the metal is subjected. We are indebted to Mr Proust for an exact analysis of this oxide and its combinations. It 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 pre-

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* Lavoisier, *Mem. Par.* 1781, p. 274.

† Εριον τολυπαι αφομοιουνται, V. 85. p. 352.

‡ *Ann. de Chim.* xxxv. 51.

cipitating it by potash. This oxide has been proposed as a paint; but its colour must be perfectly white. When pure it is light, and has a considerable resemblance to chalk. It is tasteless and insoluble in water, and not liable to be changed by exposure to the atmosphere.

Protoxide.

2. The protoxide, or zinc combined with a minimum of oxygen, is obtained by exposing the peroxide to a strong heat in an earthen ware retort or covered crucible. From the experiments of Desormes and Clement, it appears, that by this process the zinc loses a portion of its oxygen, and assumes a yellow colour. According to the analysis of these chemists, the protoxide of zinc is composed of 88 parts zinc and 12 parts of oxygen[*].

3. The reduction of the oxides of zinc is an operation of difficulty, in consequence of the strong affinity which exists between zinc and oxygen, and the consequent tendency of the zinc after reduction to unite with oxygen. It must be mixed with charcoal, and exposed to a strong heat in vessels which screen it from the contact of the external air.

Union with simple combustibles.

III. Most of the simple combustibles combine with zinc.

Hydrogen.

1. 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 carries along with it a little zinc in solution; but it deposites it again upon the sides of the glass jars, and on the surface of the water over which it stands.

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[*] *Ann. de Chim.* xxxix. 32.

The gas thus mpregnated was recommended by Mr Watt as likely to be serviceable in cases of diseased lungs.

2. Hydrogen gas procured from zinc by means of diluted sulphuric acid, when burnt, produced a certain portion of carbonic acid. Hence it was inferred that it contained originally some carbureted hydrogen [*]. As the zinc dissolves, a black powder makes its appearance in the solution. This black powder the French chemists affirm to be plumbago, and to its presence they ascribe the cause of the formation of carbureted hydrogen; but this opinion has not been verified by accurate experiments, and is indeed unlikely to be true [†].

Phosphuret.

3. Zinc may be combined with phosphorus, by dropping 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 splendour, 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 [‡].

4. Phosphorus combines also with the oxide of zinc; a compound which Margraf had obtained during his experiments on phosphorus. When 12 parts of oxide

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[*] See the experiments of Fourcroy, Vauquelin and Seguin, *Ann. de Chim.* viii. 230.

[†] 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. On separating this black powder and drying it, I found that it assumed an olive-green colour. It proved in all my trials to be a mixture of copper and lead.

[‡] *Ann. de Chim.* xiii. 129.

Phosphureted 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 phosphureted oxide of zinc. When heated by the blowpipe, the phosphorus burns, and leaves behind a glass, transparent while in fusion, but opaque after cooling [*].

Phosphureted 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 phosphureted oxide of zinc; 4. Needleform crystals, of a metallic brilliancy, and a bluish colour. These also Pelletier considers as phosphureted oxide of zinc [†].

Sulphuret.

5. Sulphur cannot be artificially combined with zinc; but when melted with the oxide of zinc, a combination is formed, as was first discovered by Dehne in 1781 [‡]. The experiment was afterwards repeated by Morveau [§]. A similar compound is formed when sulphureted hydrogen, in combination with an alkali, is dropt into a solution of zinc. It is at first white, but becomes darker on drying. It was considered by chemists as sulphur united to the oxide of zinc; but experiment does not confirm the opinion. The zinc seems to be in the metallic state.

One of the most common ores of zinc is a foliated mineral, usually of a brown colour, called *blende*;

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[*] Pelletier, *Ibid.* 128.

[†] *Ann. de Chim.* xiii. 125.

[‡] *Chem. Jour.* p. 46. and Crell's *Annals*, 1786, i. 7.

[§] *Mem. de l' Acad. de Dijon*, 1783.

tasteless, insoluble in water, and of a specific gravity about 4. Bergman showed that this ore consisted chiefly of zinc and sulphur. Chemists were disposed to consider it as a sulphureted oxide of zinc, in consequence chiefly of the experiments of Morveau, above referred to; but the analyses of Bergman were inconsistent with this notion. Proust gave it as his opinion, that blende is essentially a compound of zinc in the metallic state with sulphur *. Upon examining several specimens of blende, I found the phenomena and the proportion of the constituents to agree exactly with this opinion, and cannot therefore hesitate to embrace it.

IV. Zinc does not combine with azote. Muriatic acid readily converts it into an oxide.

Alloys with

V. Zinc combines with almost all the metals, and some of its alloys are of great importance.

Gold.

1. It may be united to gold in any proportion by fusion. The alloy is the whiter and the more brittle the 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 Hellot † as very proper for the specula of telescopes. Mr Hatchett united 11 parts of gold and one of zinc. The alloy was of a pale greenish yellow like brass, and very brittle. Its specific gravity was 16·937. The bulk of the metals before union was 1000; after it, 997 nearly. Hence the union is accompanied with a small degree of contraction. The brittleness continued though the zinc was reduced to $\frac{1}{60}$th of the alloy, $\frac{4}{60}$ths of copper being

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* *Jour. de Phys.* lvi. 79.

† *Mem. Acad. Par.* 1735.

added to reduce the gold to the standard value. Even the fumes of zinc near melted gold, are sufficient to render the precious metal brittle [*]. Hellot affirms, that when one part of gold is alloyed with seven of zinc, if the zinc be elevated in the state of flowers, the whole of the gold rises along with it.

Platinum,

2. Dr Lewis found that platinum unites with the fumes of zinc reduced from its ore, and acquires about $\frac{1}{3}$d of additional weight. The two metals very readily melt, even when the zinc does not exceed $\frac{1}{4}$th of the platinum. The alloy is very brittle, of a bluish white colour, and much harder than zinc. One-twentieth of platinum destroys the malleability of zinc, and one-fourth of zinc renders platinum brittle [†].

Silver,

3. Silver unites to zinc with facility, and produces a brittle alloy of a bluish white colour, and a granular texture. Its specific gravity, according to Gellert, is greater than the mean. When an alloy of 11 zinc and one silver is sublimed in open vessels, the whole of the silver arises along with the flowers of zinc [‡].

Mercury,

4. The amalgam of zinc was examined by Malouin. According to him, it is formed most readily by pouring mercury upon zinc, heated so as to char paper, but not to burn it. Its consistence varies with the proportion of zinc. Eight parts zinc, and one mercury, form a white very brittle compound. One zinc and $2\frac{1}{2}$ mercury form an alloy, which, when melted and cooled slowly, crystallizes. This amalgam is used to promote the excitement of electric machines [§].

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[*] Hatchett on the *Alloys of Gold*, p. 17.

[†] *Phil. Commerce*, p. 520.

[‡] *Wasserberg*, i. 160.

[§] It was first recommended for that purpose by Dr Higgins. See *Phil. Trans.* 1778, p. 861.

Copper.

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 mixing granulated copper, a native oxide of zinc called *calamine*, and a proper proportion of charcoal in powder. The heat is kept up for five or six hours, and then raised sufficiently high to melt the compound. It is afterwards poured into a mould of granite edged round with iron, and cast into plates. This compound is usually known in this country by the name of *brass*. The metals are capable of uniting in various proportions, and according to them, the colour and other qualities of the brass vary also. According to Dr Lewis, who made a large set of experiments on the subject, a very small portion of zinc dilutes the colour of copper, and renders it pale; when the copper has imbibed one-twelfth of its weight the colour inclines to yellow. The yellowness increases with the zinc, till the weight of that metal in the alloy equals the copper. Beyond this point, if the zinc be increased, the alloy becomes paler and paler, and at last white *. The proportion of zinc imbibed by the copper varies in different manufactories according to the process, and the purposes to which the brass is to be applied. In some of the British manufactories the brass made contains $\frac{1}{3}$d of its weight of zinc. In Germany and Sweden, at least if the statements of Swedenburg be accurate, the proportion of zinc varies from $\frac{1}{5}$th to $\frac{1}{4}$th of the copper †. Brass is much more fusible than copper; it is malleable while cold, unless the portion of zinc be excessive; but when heated it becomes brittle. It is

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* *Neuman's Chem.* p. 65.

† *Wasserberg*, i. 267.

ductile, may be drawn out into fine wire, and is much tougher than copper, according to the experiments of Muschenbroeck. According to Gellert, its specific gravity is greater than the mean. It varies considerably according to the proportion of zinc. Dr Watson found a specimen of plate brass from Bristol 8·441 [*]: while Brisson makes common cast brass only 7·824. Brass may be readily turned upon the lath, and indeed works more kindly than any other metal.

When zinc in the metallic state is melted with copper or brass, the alloy is known by the names of *pinchbeck*, *prince's metal*, *Prince Rupert's metal*, &c. The proportion of zinc is equally variable in this alloy as in brass; sometimes amounting nearly to one half of the whole, and at other times much less. The colour of pinchbeck approaches more nearly to that of gold, but it is brittle, or at least much less malleable than brass. 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 [‡].

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[*] *Chem. Essays*, iv. 58.

[†] *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.

Iron,

6. It is difficult to combine zinc with iron, because the heat necessary to melt the latter metal dissipates the former. The alloy, according to Lewis, when formed, is hard, somewhat malleable, and of a white colour approaching to that of silver*. Malouin has shown that zinc may be used instead of tin to cover iron plates; a proof that there is an affinity between the two metals†.

Tin,

6. Tin and zinc may be easily combined by fusion. The alloy is much harder than zinc, much stronger than tin, and still ductile. This alloy, it is said, is often the principal ingredient in the compound called *pewter*.

Lead,

8. The alloy of lead and zinc has been examined by Wallerius, Gellert, Muschenbroek, 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 approach-

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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*.

[*] *Neuman's Chem.* p. 69.

[†] *Mem. Par.* 1742.

ed to one of zinc and 16 of lead, when the alloy differed from the last metal only in being somewhat harder *.

ickel.

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

Such are the properties of the malleable metals, the most numerous and by far the most important of the four classes into which we have divided them. Eight of them have been discovered by modern chemists; namely, platinum, palladium, rhodium, iridium, osmium, nickel, niccolanum, and zinc. The remaining seven were known to the ancients. To these last the names of the planets were formerly assigned, and each was denoted by a particular mark which represented both the planet and the metal.

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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

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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.

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.

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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 μολιβδον, 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 molities; 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.* Hasniæ, 1668, 4to. p. 29.

Their supposed origin.

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 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.

Origin according to Beckmann.

Brofessor 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 Στιλϐῶν, one needs only look at the abbrevi-

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

ations 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 ᴗ, and added under it the next letter τ. If those to whom this deduction appears improbable will only take the trouble 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."

CLASS II.

BRITTLE AND EASILY FUSED METALS.

THE metals belonging to this class are only four in number; namely, bismuth, antimony, tellurium, arsenic. Their brittleness renders them of much inferior importance, as metals, to those belonging to the first class. But the low temperature at which they melt (between 800° and 476°), makes it easy to cast them into moulds, and even to alloy them with the more fusible of the ductile metals. The activity of the preparations of antimony, and the poisonous nature of arsenic, have given these metals importance in a medical point of view. None of the metals belonging to this class seem to have been known to the ancients in the metallic state.

SECT. XVI.

OF BISMUTH.

History.

I. THE ores of this metal are very few in number, and occur chiefly in Germany. This, in some measure, accounts for the ignorance of the Greeks and Arabians, neither of whom appear to have been acquainted with bismuth. The German miners, however, seem to have distinguished it at a pretty early period, and to have given it the name of *bismuth*; for Agricola, in his treatise intitled *Bermannus*, written at least as early as 1529, describes it under that name as well known in Germany, and considers it as a peculiar metal. The miners gave it also the name of *tectum argenti*; and appear to have considered it as silver beginning to form, and not yet completed*. Mr Pott collected in his dissertation on bismuth every thing respecting it contained in the writings of the alchymists. Becher seems to have been the first chemist who pointed out some of its most remarkable properties. Pott's dissertation, published in 1739, contained an account of its habitudes with different chemical substances. Several additional facts were given by Neuman in his chemistry, by Hellot, and Dufay; but Geoffroy, junior, was the first who

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* Konig's *Regnum Minerale*, p. 80. Even so late as the end of the 17th century it was considered as a species of lead. There are three kinds of lead, says Etmuller; namely, common lead, tin, and bismuth. Bismuth approaches nearest to silver. Etmuller's *Chemistry*, p. 321.

undertook a complete series of experiments on it. The first part of his labours was published in the Memoirs of the French Academy for 1753; but his death prevented the completion of his plan. Chemists for some time were disposed to consider bismuth as an alloy, but this opinion was gradually laid aside.

Properties.

1. Bismuth is of a 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*.

2. Its hardness is 7. Its specific gravity is 9·822†.

3. 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, from the trials of Muschenbroeck, appears to be such, that a rod $\frac{1}{10}$th inch in diameter is capable of sustaining a weight of nearly 29lbs.

4. When heated to the temperature of 476° ‡, 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.

II. When exposed to the air, it soon loses its lustre,

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* *Jour. de Min.* An. v. p. 582.

† Brisson and Hatchett.

‡ Irvine, Nicholson's *Jour.* ix. 46.

but scarcely undergoes any other change. It is not altered when kept under water.

Combination with oxygen.

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 oxidized. When these pellicles are kept hot and agitated in an open vessel, they are soon converted into a brownish or yellowish powder.

When bismuth is raised to a strong red heat, it takes fire and burns with a faint blue flame, and emits a yellow smoke, as was first observed by Geoffroy. When this is collected, it is a yellow powder, not volatile, which has been called *yellow oxide of bismuth.*

Peroxide.

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.* This powder is used as a paint, under the name of *pearl* or *flake white.* Bucholz has demonstrated that this powder is a compound of oxide of bismuth and nitric acid. From his experiments, compared with those of Klaproth[*], we learn that the yellow oxide of bismuth is composed of 100 bismuth and 12 oxygen, or *per cent.* of about

89·3	bismuth
10·7	oxygen
100·0	

This is the only oxide of bismuth at present known with precision. It is tasteless and insoluble in water. In the fire it is fixed, but melts readily into a brown

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[*] Klaproth's *Beitrage*, ii. 294. Bucholz's *Beitrage*, iii. 3.

glass. In this respect it resembles the oxides of lead. 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.

Phosphuret.

III. Bismuth has not been combined with carbon nor hydrogen. Neither does it seem capable of combining in any notable proportion 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 which did not apparently differ from bismuth, but which, when exposed to the blowpipe, 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.

2. Sulphur combines readily with bismuth by fusion. The sulphuret of bismuth is of a bluish grey colour, It crystallizes in beautiful tetrahedral needles, which cross each other. It is very brittle and fusible, and bears a strong resemblance to sulphuret of antimony, but is rather brighter coloured. One hundred parts of bismuth, according to Wenzel's experiments, unite by fusion to 17·5 of sulphur. Hence the sulphuret of bismuth is composed of about

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[*] *Ann. de Chim.* xiii. 30.

85 bismuth
15 sulphur

100 *

V. Bismuth combines readily with most metallic bodies, and forms compounds, few of which have been applied to any useful purposes.

Alloys with gold.

1. Gold combines very readily with bismuth by fusion. An alloy composed of 11 gold and one bismuth was found by Hatchett to have a greenish yellow colour, like bad brass. It was very brittle, and had a fine grained earthy fracture. Its specific gravity was 18·038. The bulk of the metals before fusion was 1000, after it only 988. They had suffered, therefore, a considerable contraction. The properties of the alloy continued nearly the same when the bismuth amounted to $\frac{1}{60}$th of the compound; the requisite quantity of copper to reduce the gold to standard being added. When the bismuth was diminished beyond this proportion, the colour of the alloy became nearly that of gold; but its brittleness continued even when the bismuth did not exceed $\frac{1}{1920}$th of the mass. As the proportion of bismuth diminished, and that of the copper increased (the gold being always standard), the contraction disappeared, and an expansion took place, which was soon much greater than when copper alone was used to alloy the gold. This curious progression will appear evident from the following Table †.

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* Verwandtschaft, p. 280.

† The specific gravity of the gold was 19·172 (it was 23 carats 8½ grains fine), of the bismuth 9·822, of the copper 8·895.

Chap. IV.

Metals.	Grains.	Specific gravity of alloy.	Bulk before fusion.	Do. after.	Change of bulk.
Gold Bismuth	442 38	18·038	1000	988	—12
Gold Copper Bismuth	442 30 8	17·302	1000	1018	+18
Gold Copper Bismuth	442 34 4	16·846	1000	1044	+44
Gold Copper Bismuth	442 37·5 0·5	16·780	1000	1047	+47
Gold Copper Bismuth	442 37·75 0·25	17·095	1000	1027	+27

So great is the tendency of bismuth to give brittleness to gold, that the precious metal is deprived of its ductility, merely by keeping it, while in fusion, near bismuth raised to the same temperature *.

Platinum.

2. Bismuth and platinum readily melt and combine when exposed rapidly to a strong heat. Dr Lewis fused the metals in various proportions, from one of bismuth to 24 with one of platinum. The alloys were all as brittle, and nearly as soft as bismuth; and when broken, the fracture had a foliated appearance. When this alloy is exposed to the air, it assumes a purple, vio-

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* See Hatchett on the *Alloys of Gold*, p. 26.

let or blue colour. The bismuth can scarcely be separated by heat *.

Silver,

3. Bismuth combines readily with silver by fusion. The alloy is brittle; its colour is nearly that of bismuth; its texture lamellar; and its specific gravity greater than the mean. According to Muschenbroeck, the specific gravity of an alloy of equal parts bismuth and silver is 10·7097 †.

Mercury,

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 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 curious fact was first described by Beccher, who affirmed that a mixture of three parts mercury, one lead, and one bismuth, form a perfectly fluid amalgam. This triple compound may be filtered through shamois 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 sphericle, 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. This amalgam is used hot for silvering glass balls.

Copper,

5. Copper forms with bismuth a brittle alloy of a

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* *Philosoph. Commerce*, p. 509 and 573.

† Wasserberg, i. 160.

pale red colour, and a specific gravity exactly the mean of that of the two metals alloyed [*].

Iron.

6. Bismuth combines but imperfectly with iron [†]. The alloy is brittle, and attracted by the magnet even when the bismuth amounts to ¾ths of the whole [‡]. The specific gravity of this alloy is less than the mean [§].

Tin.

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° [‖].

Lead.

8. The alloy of lead and bismuth is of a dark grey 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. When eight parts of bismuth, five of lead, and three of tin, are melted together, a white coloured alloy is obtained, which melts at the temperature of 212°, and therefore remains melted under boiling water.

Nickel.

10. The alloy of bismuth and nickel is brittle, and formed of thin plates [‡‡].

11. Bismuth does not combine with zinc.

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[*] Gellert.
[†] Muschenbroeck.
[‡] Henkel.
[§] Gellert.
[‖] Dr Lewis, *Neuman's Chem.* p. 111.
[¶] Wallerius.
[**] Baumé.
[††] Gellert.
[‡‡] Cronstedt.

SECT. XVII.

OF ANTIMONY.

History.

I. 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 eighth century. This mineral is composed of the metal now called *antimony* and sulphur; but it was 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

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

[†] Kirwan's *Miner.* ii. 110.

[‡] Pliny, ibid.

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

[§] Mr Roux, indeed, who at the request of Count Caylus analysed an 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.

from 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 fifteenth 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 1788, 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, Thenard, and Proust, are the modern chemists who have thrown the greatest light upon its properties †.

Properties.

1. 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,

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* *Analysis Antimonii Physico-chim. Rationalis.*

† The word *alcohol*, which is still employed in chemistry, was, if we believe Homerus 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, *Othia*, *alkofol*, *alkosol*, *aries*, *saturnus philosophorum*, *magnesia saturni*, *filius* and *nothus saturni*.

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.

2. Its hardness is $6\frac{1}{2}$. Its specific gravity is, according to Brisson, 6·702; according to Bergman, 6·86. Hatchett found it 6·712 †.

3. It is very brittle, and may be easily reduced in a mortar to a fine powder. Its tenacity, from the experiments of Muschenbroeck, appears to be such, that a rod of $\frac{1}{10}$th inch diameter is capable of supporting about 10 pounds weight.

4. When heated to 810° 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.

Oxides.

II. 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 colour-

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

† On the *Alloys of Gold*, p. 68.

‡ Mortimer.

§ Lavoisier and Meusnier, *Mem. Par.* 1781, p. 274.

ed 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 coloured oxide.

According to Thenard [*], who published an excellent dissertation on antimony some time ago, this metal is capable of combining with no less than six different doses of oxygen, and of forming six oxides, which may be exhibited in a separate state. But his method of obtaining most of these bodies, namely, by the application of heat, does not seem capable of leading to any very precise result; while at the same time several of his oxides differ from each other only by one or two hundredth parts of oxygen; a degree of precision much greater than chemists are able at present to attain. Proust has lately examined this important question, and has found antimony capable of forming only two oxides, agreeing in this respect with most of the other metals.

Protoxide.

1. The protoxide of antimony may be obtained by the following process. Dissolve antimony in muriatic acid, and dilute the solution with water: a white precipitate appears, composed of the protoxide of antimony combined with a little muriatic acid [†]. Wash this precipitate with water, and boil it for some time in a solution of *carbonate of potash*. Then wash it well, and dry it on a filter [‡].

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

[†] The white powder thus obtained was formerly called *powder of* Algaroth, from Victor Algarothi, a physician in Verona, who first procured it in that manner from muriate of antimony.

[‡] Proust *Jour. de Phys.* lv. 328.

The protoxide thus procured is of a dirty white colour, without any lustre. When raised to a moderate red heat it melts, and may be kept for a long time in fusion in a retort. When allowed to cool, its surface becomes covered with small opaque crystals lying close together, and of a yellowish white colour. It is indeed extremely fusible, and always becomes opaque on cooling. A part of it is volatilized with a moderate heat, provided air be present. It is composed of

81·5 antimony
18·5 oxygen

100·0

This oxide may be kept melted in contact with antimony any length of time without alteration *.

Peroxide.

2. The peroxide of antimony may be obtained by exposing the metal in the open air to a violent heat: it takes fire, and a white oxide is sublimed, formerly called *argentine flowers of antimony*. It is obtained also by causing nitric acid to act upon antimony, and by throwing the metal into red hot nitre. After the combustion there remains in the crucible a white mass, consisting of the oxide of antimony combined with the potash 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 peroxide of antimony.

This oxide is of a white colour; it is insoluble in water, and not nearly so soluble in acids as the protoxide. Neither is it so fusible as that oxide, requiring

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* Proust *Jour. de Phys.* lv. 328.

a pretty violent heat; but it is volatilized at a lower temperature, forming white prismatic crystals of a silvery lustre. It is composed of 77 antimony
23 oxygen

100

When melted with a fourth part of antimony, the whole is converted into protoxide[*].

Union with combustibles.

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

Sulphuret.

1. 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, according to Bergman, of 74 parts of antimony and 26 of sulphur[†]. With this estimate the late experiments of Proust coincide almost exactly. According to that very accurate chemist, sulphuret of antimony is composed of

75 antimony
25 sulphur

100[‡]

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[*] Proust, *Jour. de Phys.* lv. 328.

[†] Berg. iii. 167.

[‡] *Jour. de Phys.* lv. 325.

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* *.

Glass of antimony.

2. The protoxide of antimony has the property of dissolving different proportions of sulphuret when in a state of fusion. The resulting compound is a semitransparent substance of a brownish red colour, differing considerably in its appearance according to the proportion of its ingredients. When it is composed of about eight parts of oxide and one part of sulphuret, it has a red colour, and is semitransparent. It is then called *glass of antimony*. When it contains eight parts oxide and two sulphuret, it is opaque, and of a red colour inclining to yellow. This is the *crocus metallorum* of apothecaries. Eight parts of oxide and four of sulphuret form an opaque mass of a dark red colour. This is the *liver of antimony* of apothecaries †.

When sulphur is heated with either of the oxides, it reduces them to the metallic state, if sufficient in quantity; if too small for that, it deoxidizes a portion, combines with it, and the sulphuret formed unites with the remaining oxide, always converted to a protoxide. Hence the reason that these different compounds may

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[*] 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 removed by oxidizing 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, sumit. *Homeri Poppii Basilica Antimonii*, c. 1.

[†] Proust, *Jour. de Phys.* lv. 334.

be formed by a great variety of processes. The glass of antimony 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 protoxide. 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 formed *. 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 oxidized sulphuret is fused; for these crucibles contain a very great proportion of siliceous earth.

The peroxide of antimony is incapable of dissolving any sulphuret. Of course it does not form a glass.

Phosphuret.

3. 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 a number of small cubic facettes are observable. 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 phos-

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* Bergman, iii. 166.

† *Ann. de Chim.* xxxiv. 139.

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

phoric glass, or by dropping phosphorus into melted antimony *.

IV. Antimony does not combine with azote, nor with muriatic acid.

Alloys with

V. Antimony combines readily with most of the metals; but the greater number of its alloys have not been applied to any use.

Gold,

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 antimony and then purifying it †.

Gold made standard by antimony, in Mr Hatchett's experiments, was of a dull pale colour, not unlike tutenague. It was exceedingly brittle, and in the fracture was of an ash colour, with a fine close grain, not unlike that of porcelain. Its specific gravity was 16·929. The bulk of the two metals before fusion being 1000, after fusion it was 987. Hence they suffer a considerable contraction. A very small proportion of antimony destroys the ductility of gold; the alloy was perfectly brittle when the antimony did not exceed $\frac{1}{1920}$th part of the mass. Even the fumes of antimony, in the neighbourhood of melted gold, are sufficient to destroy its ductility ‡.

Platinum.

2. Platinum easily combines with antimony. The alloy of equal parts is brittle, and of a much duller

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* 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.

‡ Hatchett *on the Alloys of Gold*, p. 13.

colour than antimony. The antimony cannot afterwards be completely separated by heat. When the antimony exceeds, the platinum is apt to subside in slow cooling [*].

Silver.

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.

Mercury.

4. Pott first observed, that antimony, reduced from its sulphuret by means of iron and chalk, unites readily with mercury by trituration. Antimony may be easily amalgamated by pouring it while in fusion into mercury almost boiling hot [‡]. When three parts of mercury are mixed in this manner with one part of melted antimony, a soft amalgam is obtained, which very soon decomposes of itself [§]. Gellert also succeeded in forming this amalgam [||].

Copper.

5. Copper combines readily with antimony by fusion. The alloy is brittle 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.

Iron.

6. Iron combines with antimony by fusion, and forms a brittle hard white coloured 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 most other

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[*] Lewis, *Phil. Com.* p. 521.

[†] *Metallurgic Chemistry*, p. 136.

[‡] Lewis, *Neuman's Chem.* p. 131.

[§] Wallerius.

[||] *Metall. Chem.* p. 141.

[¶] Gellert, p. 136.

metals[*]. 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*.

Tin, 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[‡]. Pewter often consists chiefly of this alloy.

Thenard has pointed out a remarkable property in this alloy. If its solution in muriatic acid be deluted with water the whole of the two metals is precipitated[§].

Lead, 8. When equal quantities of lead and antimony are 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[**].

Zinc, 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 interdiate[††].

Bismuth, 10. Antimony forms a brittle alloy with bismuth;

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[*] Gellert, p. 136.

[†] Ibid.

[‡] Fourcroy, vi. 25.

[§] *Ann. de Chim.* lv. 276.

[‖] Gmelin, *Ann. de Chim.* viii. 319.

[¶] Muschenbroeck.

[**] Gellert, p. 136.

[††] Ibid.

to manganese it unites but imperfectly [*]: the compounds which it forms with nickel and cobalt have not been examined.

SECT. XVIII.

OF TELLURIUM.

History.

I. 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*, 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

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[*] Gmelin, *Ann. de Chim.* xix. 367.

[†] Born, ii. 468.

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.

Properties.

1. Its colour is bluish white, intermediate between that of zinc and lead; its texture is laminated like antimony, and its brilliancy is considerable.

2. Its hardness has not been ascertained. Its specific gravity, according to Klaproth, is 6·115 ‡.

3. It is very brittle, and may be easily reduced to powder.

4. 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 mercury and arsenic, the most volatile of all the metals. When cooled slowly, it crystallizes.

Oxides.

II. 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, ac-

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* Crell's *Annals*, 1798, i. 91.

† Ibid. 1799, i. 275. and 36[illegible].

‡ Muller found it 6·343; but probably his specimen was not pure.

cording to Klaproth, has a smell not unlike that of radishes §.

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 potash 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.

III. Tellurium may be combined with sulphur by fusion. This sulphuret has a leaden grey colour, and a radiated rexture: 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.

SECT. XIX.

OF ARSENIC.

History.

I. THE word *arsenic* (αρσενικον) occurs first in the works of Dioscorides, and of some other authors who wrote

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§ Gmelin could not perceive this smell.

Book I, Division I.

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 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.

Properties.

1. 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.

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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.*

[||] *Opusc,* ii, 272.

[¶] Scheele, i. 129.

2. Its hardness scarcely exceeds 5. Its specific gravity is 8·31 *.

3. 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.

4. 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 356° †. When sublimed slowly, it crystallizes in tetrahedrons, which Hauy has demonstrated to be the form of its integrant particles.

Oxides.

II. 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.

Arsenic is capable of combining with two doses of oxygen, and of forming two compounds, which might be termed the *protoxide* and *peroxide* of arsenic, were it not that they possess several of the properties of acids.

Protoxide.

1. 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 a pale blue flame. Arsenic indeed is one of the most combustible of the metals. The substance which sublimes was formerly called *arsenic* or *white arsenic*, and is still 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.

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[*] Bergman, ii. 279. According to Brandt, 8·308.

[†] Bergman, ii. 279.

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 alliaceous 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. It is soluble also in between 70 and 80 times its weight of alcohol, and in oils. This oxide sublimes when heated to 383° : 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. From the experiments of Proust, it appears that it is composed of

75·2	arsenic
24·8	oxygen
100·0 [‡]	

When the white oxide of arsenic is mixed with black flux, and slowly heated to redness in a matrass or retort, the arsenic is reduced into the metallic state, and slowly sublimes. By this means the metal may be procured

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[*] Bergman, ii. 291.

[†] Ibid. ii. 286.

[‡] *Jour. de Phys.*

in a state of purity. This method of reducing arsenic was first pointed out by Brandt, to whom we are indebted for most of the properties of the white oxide above described.

Peroxide or arsenic acid.

2. 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*. The process prescribed by Scheele, is to dissolve three parts of white oxide of arsenic in seven parts of muriatic acid, to add five parts of nitric acid, to put the mixture into a retort, and distil to dryness. The dry mass is to be merely brought to a red heat, and then cooled again. It is solid arsenic acid. Mr Bucholz has lately shown, that the whole quantity of muriatic acid prescribed by Scheele is not necessary. The formula which he considers as the best is the following: Mix together in a crucible 2 parts of muriatic acid of the specific gravity 1·200, 8 parts of white oxide of arsenic, and 24 parts of nitric acid, of the specific gravity 1·25. Evaporate to dryness, and expose the dry mass to a slight red heat*.

The acid thus prepared has no very strong taste when dry; but when dissolved in water, it acquires an excessively sour taste, and remains liquid even when evaporated to the consistence of a jelly. It is as noxious as the white oxide of arsenic. From the experiments of Proust, it follows, that it is composed of 65·4 parts of arsenic, and 34·6 parts of oxygen: and with these proportions the determination of Bucholz very nearly corresponds. But Thenard makes the oxygen to amount to 36 parts in the hundred of oxide†.

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* Van Mon's *Journal de Chimie*, iv. 16.

† *Ann. de Chim.* l. 123.

[illegible]

III. Arsenic combines readily with all the simple combustibles, except carbon, with which it has not hitherto been united by chemists.

Union with combustibles.

Arsenical hydrogen gas.

1. That hydrogen gas has the property of dissolving arsenic, and retaining it in the gaseous form, was discovered by Scheele during his experiments on arsenic acid[*]. It was afterwards noticed by Proust, during his experiments on tin. Trommsdorf has lately examined it in detail, and published an account of its properties[†].

The easiest method of procuring it, according to the last mentioned chemist, is to mix together four parts of granulated zinc and one part of arsenic, and to treat them with sulphuric acid diluted with twice its weight of water. Hydrogen gas is disengaged in abundance, which, coming in a nascent state in contact with the arsenic, dissolves it, and forms the gas wanted. Stromeyer, who examined this gas more recently, recommends an alloy composed of 15 parts of tin and one of arsenic. When this alloy is digested in muriatic acid, the hydrogen evolved carries off the whole of the arsenic, and leaves the tin pure[‡].

Arsenical hydrogen gas, thus formed, is colourless, has a nauseous smell, is not sensibly absorbed by water; extinguishes flame, and destroys animal life. Its specific gravity (barometer about 30 inches) is 0·5293, that of air being one: hence 100 cubic inches of it weigh 16·4 grains.

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[*] Scheele's *Opusc.* i. 182. French translation.

Nicholson's *Jour.* vi. 200.

[‡] Ibid. xix. 381.

It burns with a blue flame; and if the neck of the vessel containing it be narrow, the arsenic is deposited. When two parts of this gas, mixed with three of oxygen, are brought in contact with a lighted taper, an explosion takes place, and water and white oxide of arsenic are formed. Equal parts of these gases do not explode so loudly, but give a more vivid flame. Two parts of this gas and one of oxygen leave a small residue. According to Stromeyer it requires for combustion 0·72 parts of its bulk of oxygen gas.

Arsenical hydrogen gas is not altered by common air, azotic gas, nor hydrogen. Nitrous gas occasions a diminution of about two *per cent*. Sulphureted hydrogen gas occasions no change in it; but if oxymuriatic acid be added to the mixture of these two gases, the bulk diminishes, and yellow-coloured flakes are deposited. Hence these two gases furnish us with a delicate test for detecting the presence of arsenical hydrogen.

Concentrated nitric acid, when suddenly mixed with this gas, causes an evolution of red fumes, and an explosion accompanied with flame. When the acid is diluted, it oxidizes and removes the arsenic, leaving the hydrogen pure. Trommsdorf, to whom we are indebted for all these facts, did not succeed in analysing this gas, though it appears from his experiments, that it is a compound of arsenic and hydrogen [*]. Stromeyer informs us that he succeeded in analysing it by means of nitric acid, and that he found it composed of 106 parts arsenic and 2·19 hydrogen [†]. Proportions which do

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[*] See Nicholson's *Journal*, vi. 200.

[†] Ibid. xix. 383.

not well accord with the specific gravity of the gas, as stated by Trommsdorf.

Sulphurets.

2. Sulphur combines readily with arsenic. If we put a mixture of these two bodies into a covered crucible and melt them, a red vitreous mass is obtained, which is obviously a sulphuret of arsenic. It may be formed also by heating together the white oxide of arsenic, or arsenic acid and sulphur; but in that case a portion of the sulphur absorbs the oxygen from the arsenic, and makes its escape in the form of sulphurous acid gas*. This sulphuret of arsenic is found native in different parts of Europe. It is usually called *realgar*. It has a scarlet colour, and is often crystallised in transparent prisms. Its specific gravity is 3·225†. It is tasteless, and not nearly so hurtful as the oxides of arsenic, though Macquer affirms that it is poisonous‡. It is sometimes used as a paint. According to the experiments of Westrumb, this sulphuret is composed of 80 parts of arsenic and 20 of sulphur§. According to Thenard, it consists of 60 parts of arsenic and 30 of sulphur||.

1. Realgar.

2. Orpiment.

3. If the white oxide of arsenic be dissolved in muriatic acid, and a solution of sulphureted hydrogen in water be poured into the liquid, a fine yellow-coloured powder falls to the bottom. This powder is usually called *orpiment*. It may be formed by subliming arsenic and sulphur by a heat not sufficient to melt them. This substance is found native. It is composed of thin

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[*] Proust, *Jour. de Phys.* liii. 94.

[†] Bergman, ii. 298.

[‡] Hoffman informs us, that he gave two scruples of it to a dog without any bad effects whatever. *Observ. Physico-Chemico-Select.* p. 236.

[§] Crell's *Annals*, 1785, i. 299.

[||] *Ann. de Chim.* lix. 290.

plates, which have a considerable degree of flexibility. Its specific gravity is 5·315. It has been supposed by some chemists, that orpiment differs from realgar merely in containing a smaller proportion of sulphur; by others, that the arsenic exists in it in the state of an oxide; by others, that it contains sulphureted hydrogen. But Mr Proust has ascertained, that when heated sufficiently it melts without emitting any gas, and on cooling assumes the appearance of realgar [*]. Hence he concludes, that like realgar it is merely a sulphuret of arsenic. This opinion has been confirmed by the experiments of Thenard, who found orpiment a compound of three parts of sulphur and four of arsenic [†].

Phosphuret.

4. Arsenic combines readily with phosphorus. The 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 [‡].

IV. Arsenic does not combine with azotic gas nor muriatic acid; neither is it readily oxidized by the action of that acid.

Alloys with

V. Arsenic unites with most metals, and in general renders them more brittle and more fusible.

Gold,

1. There appears to be a strong affinity beeween gold and arsenic; but in consequence of the great volatility of the latter metal, it is difficult to unite them by fusion.

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[*] *Jour. de Phys.* liii. 94.

[†] *Ann. de Chim.* lxix. 290.

[‡] Pelletier, *Ann. de Chim.* xiii. 139.

Bergman succeeded in making gold take up $\frac{1}{60}$th of its weight of arsenic [*]. Mr Hatchett added 453 grains of arsenic to 5307 grains of melted gold, and, stirring the whole rapidly with an iron rod, poured the mixture into an iron mould. Only six grains of the arsenic was retained; so that the alloy contained only $\frac{1}{885}$th of arsenic. It had the colour of fine gold; and though brittle, yet it bent in some measure before it broke. When once united to gold, arsenic is not easily expelled by heat. Mr Hatchett discovered that gold readily imbibes, and combines with, arsenic, when heated to redness. A plate of gold was exposed red hot to the fumes of arsenic by suspending it near the top of a dome, made by luting one crucible inverted over another. In the lower crucible some arsenic was put, and the whole exposed to a common fire for about 15 minutes. The arsenic had acted on the gold, and combined with its surface. The alloy being very fusible had dropt off as it formed, leaving the gold thinner, but quite smooth. The alloy of gold and arsenic formed a button in the undermost crucible. This button had a grey colour, and was extremely brittle [†].

Platinum,

2. The alloy of arsenic and platinum was first examined by Scheffer, and afterwards by Dr Lewis. The addition of white oxide of arsenic causes strongly heated platinum to melt; but the mixture does not flow thin, and cannot be poured out of the crucible. The alloy is brittle and of a grey colour. The arsenic is mostly expelled in a strong heat, leaving the platinum in the state of a spongy mass [‡].

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[*] *Opusc.* ii. 281.

[†] On the *Alloys of Gold*, p. 7.

[‡] *Phil. Com.* p. 515.

Silver,

3. Melted silver takes up $\frac{1}{14}$th of arsenic*. The alloy is brittle, yellow-coloured, and useless.

Mercury,

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 †.

Copper,

5. Copper may be combined with arsenic by fusing them together in a close crucible, while their surface is covered with common salt to prevent the action of the air, which would oxidize 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 ‡.

Iron,

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 §.

Tin,

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 one 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 ||.

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* Bergman, ii. 281.

† Ibid.

‡ *Neuman's Chem.* p. 144.

§ Bergman, ii. 281.

|| Bayen.

Lead,

8. Lead and arsenic may be combined by fusion. The alloy is brittle, dark-coloured, and composed of plates. Lead takes up $\frac{1}{6}$th of its weight of arsenic *.

Nickel,

9. Nickel combines readily with arsenic, and indeed is seldom found without being more or less contaminated by that metal. The compound has a shade of red, considerable hardness, and a specific gravity considerably under the mean. It is not magnetic. Arsenic possesses the curious property of destroying the magnetic virtue of iron, and all other metals susceptible of that virtue.

Zinc,

10. 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.

Antimony.

11. Antimony forms with arsenic an alloy which is very brittle, very hard, and very fusible; and composed, according to Bergman, of seven parts of antimony and one part of arsenic.

Bismuth.

12. Bismuth may be combined with about $\frac{1}{5}$th of its weight of arsenic ‡; but the properties of this alloy have not been examined.

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* Bergman.

† Malouin.

‡ Bergman, ii. 281.

CLASS III.

BRITTLE AND DIFFICULTLY FUSED METALS.

THE metals belonging to this class are six in number. They were all unknown to the ancients, and were not examined till chemical analysis had acquired a considerable degree of perfection. None of them are of much value in the metallic state; their brittleness and difficult fusion rendering it impossible to work them with facility: But some of them are of considerable importance in the state of oxides.

SECT. XX.

OF COBALT.

History. I. 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 celebra-

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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 Beckman'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.

ted Swedish chemist obtained from it a new metal, to which he gave the name of *cobalt*[*]. Lehmann published a very full account of every thing relating to this metal in 1761[†]. 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[||]. In 1802, a new series of trials was published by Thenard, which throw considerable light on its combinations with oxygen[¶]. And in 1806, Mr Proust published a set of experiments upon the same subject[**]. Considerable attention has been lately paid to the purification of this metal; but hitherto no one seems to have been fortunate enough to hit upon a method altogether free from objections[††].

Properties

1. 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.

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[*] *Acta Upsal*, 1733 and 174 .

[†] *Cadmialogia, oder Geschichte des Farben-Kobolds.*

[‡] *Opusc.* ii. 444, 501. and iv 371.

[§] *Ann. de Chim.* xxviii. 101.

[||] Fourcroy, *Discours Preliminaire*, p. 114.

[¶] *Ann. de Chim.* xlii. 210.

[**] Ibid. lx. 260.

[††] See Richter, Gehlen's *Jour.* ii. 53; Bucholz, *Ibid.* iii. 201; Philips, *Phil. Mag.* xvi 312.

[‡‡] *L'Ecole des Mines.*

Book I.
Division I.

2. Its hardness is 6. Its specific gravity, according to Bergman and the School of Mines at Paris, is 7·7. Mr Hatchett found a specimen 7·645[*].

3. It is brittle, and easily reduced to powder; but if we believe Leonhardi, it is somewhat malleable when red hot. Its tenacity is unknown.

4. 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 surface of the metal congeals, it may be obtained crystallized in irregular prisms[†].

5. 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.

Oxides.

II. 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.

When kept red hot in an open vessel, it gradually imbibes oxygen, and is converted into a powder at first blue, 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.

From the experiments of Thenard, it follows that cobalt is capable of combining with three doses of oxygen at least, and of forming three distinct oxides, which may be exhited in a separate state.

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[*] On the *Alloys of Gold*, p. 68.

[†] Fourcroy, v. 137.

Protoxide.

1. The protoxide of cobalt has a blue colour. It may be obtained by dissolving cobalt in nitric acid, and precipitating the cobalt from the solution by means of potash. The precipitate has a blue colour, but when dried in the open air it gradually becomes black. This black powder is to be kept for half an hour in that degree of heat known to manufacturers of iron utensils by the name of *cherry red.* This heat expels the oxygen which it had absorbed in drying, and converts it into a fine blue colour. This oxide dissolves in acids without effervescence. The solution of it in muriatic acid, if concentrated, is green; but if diluted with water, it is red. Its solution in sulphuric and nitric acids is always of a red colour [*]. According to the analysis of Proust, this oxide is composed of 83½ of cobalt, and 16½ of oxygen [†].

Deutoxide.

2. When the protoxide of cobalt, newly precipitated from acids by potash, is exposed to the air, it gradually combines with an additional dose of oxygen, as Thenard ascertained by experiment, and assumes an olive green colour; and by cautiously drying it without the aid of heat, it may be obtained in that state. This is the *deutoxide* of cobalt. When this oxide is treated with diluted muriatic acid, a moderate heat developes oxymuriatic acid gas, and a red coloured solution is obtained. Hence we see that the deutoxide of cobalt loses a portion of its oxygen during its solution in muriatic acid [‡].

Peroxide.

3. When the protoxide or deutoxide of cobalt, newly precipitated from an acid, is dried by heating it in the

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[*] *Ann. de Chim.* xlii. 213.

[†] *Ibid.* lx. 267.

[‡] *Ibid.* xlii. 212.

open air, it assumes a flea-brown colour, which gradually deepens till at last it becomes black. This is the peroxide of cobalt. It dissolves with effervescence in muriatic acid, and a great quantity of oxymuriatic acid gas is exhaled. Mr Thenard considers the brown colour which the oxide of cobalt first assumes before it becomes black as a *tritoxide*; but his experiments are not sufficient to decide that point.

According to the experiments of Proust, the peroxide is composed of 80 parts cobalt and 20 parts oxygen [*]. But it is not unlikely, from the method employed by this ingenious chemist, that the proportion of oxygen which he obtained was too small.

With respect to the reddish precipitate which is sometimes obtained by precipitating cobalt from acids, and which has been considered as a peculiar oxide of cobalt, Mr Thenard suspects, that it is a combination of the oxide of cobalt with arsenic acid [†].

Proust however has shown that the blue oxide has the property of combining with water, and forming what he calls a *hydrate* of cobalt, and this hydrate has a *red* colour.

Union with combustibles.

III. 1. Cobalt does not combine with carbon nor hydrogen.

Sulphuret.

2. 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 potash. It has a yellowish white colour, displays the rudiments of crystals, and can scarcely be decomposed by heat.

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[*] *Ann. de Chim.* lx. 267.

[†] *Ann. de Chim.* xlii. 214.

The sulphuret of cobalt, according to Proust, may be formed by heating together the oxide of cobalt and sulphur. It is composed, according to his experiments, of $71\frac{1}{2}$ parts of cobalt, and $28\frac{1}{2}$ of sulphur[*]; but he does not place much confidence in the accuracy of this result.

Phosphuret.

3. 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[†].

IV. Cobalt does not combine with azotic gas nor muriatic acid gas.

Alloys with

V. Cobalt seems capable of combining with most of the metals, but its alloys are very imperfectly known.

Gold,

1. Mr Hatchett melted together 11 parts of gold and one part of cobalt. The alloy was of a dull yellow colour, very brittle, and the fracture exhibited an earthy grain. Its specific gravity was 17·112. The bulk of the metals before fusion being 1000, after fusion, became 1001. Hence they experienced a very small degree of expansion. The brittleness of gold alloyed with cobalt continues when the cobalt does not exceed $\frac{1}{60}$th of the whole; but when it is reduced be-

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Ann. de Chim. lx. 272.

[†] Pelletier, *Ibid.* xiii. 134.

low that proportion, the gold becomes somewhat ductile *.

2. The alloy of cobalt and platinum has not been examined.

3. When two parts of cobalt and one 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.

Iron,

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.

Tin,

7. The alloy of tin and cobalt is of a light violet colour, and formed of small grains.

Lead,

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.

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* Hatchett on the *Alloys of Gold*, p. 19.

† Gellert, p. 137.

‡ Cronstedt.

‖ Gellert, p. 137.

Equal parts of lead and cobalt produced an alloy, in which the metals appeared pretty uniformly distributed, though in some cases the lead predominated. It was brittle, received a better polish than lead, which metal it resembled rather than cobalt; 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 *.

Nickel.

9. Cobalt is often found naturally combined with nickel.

10. It does not seem capable of combining with bismuth nor with zinc by fusion.

SECT. XXI.

OF MANGANESE.

History.

1. THE dark grey or brown mineral called *manganese*, in Latin *magnesia* (according to Boyle from its resem-

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* *Ann. de Chim.* xix. 357.

blance 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 Waiz 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 master piece of analysis, 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

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[*] *Prosperitas Germaniæ.*

[†] Weigleb's *Geschichte*, i. 127.

[‡] *Mem. Stockholm*, 1765, p. 235.

[§] *De Metallis dubiis*, p. 48.

[||] *Opusc.* ii. 201.

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.

Properties.

1. 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.

2. Its hardness is 9, or equal to that of iron. Its specific gravity, according to Bergman, is about 6·850 †.

3. It is very brittle; of course it can neither be hammered nor drawn out into wire. Its tenacity is unknown.

4. It requires, according to Morveau, the temperature of 160° Wedgewood to melt it; it is therefore somewhat less fusible than iron.

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* Bergman, ii. 211.

† *Opusc.* ii. 203.

5. When reduced to powder, it is attracted by the magnet, owing probably to a small portion of iron, from which it can with difficulty be parted.

Oxides.

II. Manganese, when exposed to the air, attracts oxygen with considerable rapidity. It soon loses its lustre, and becomes grey, violet, brown, and at last black. These changes take place still more rapidly if the metal be heated in an open vessel.

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*.

Protoxide.

1. The protoxide or white oxide may be obtained by dissolving the black oxide of manganese in nitric acid by 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 potash; the protoxide 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 *.

Deutoxide.

2. The deutoxide or *red* oxide may be obtained by dissolving the black oxide in sulphuric acid, without the addition of any combustible substance. When black oxide of manganese, 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, consist-

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* *Opusc.* ii. 221.

ing of the sulphate of manganese dissolved in the water. On the addition of an alkali, a red substance 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.

Peroxide.

3. The peroxide or *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 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 nearly to the state of red oxide. If it be exposed to the air, and moistened occasionally, it absorbs a new dose of oxygen; and thus the same process may again be repeated[‡]. 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

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[*] *Opusc.* ii. 215.

[†] Fourcroy, v. 177.

[‡] It may be necessary to mention, that with me this absorption has succeeded but imperfectly, unless when the red or white oxides of manganese have been precipitated from an acid.

gas *. 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.

Union with combustibles.

III. 1. Manganese does not combine with hydrogen. 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.

Sulphuret.

2. Bergman did not succeed in his attempt to combine manganese with sulphur; but he formed a sulphureted 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 sulphureted hydrogen gas when acted on by acids ‡. It cannot be doubted, however, that sulphur is capable of combining with manganese; for Proust has found native sulphuret of manganese in that ore of tellurium which is known by the name of gold ore of Nagyag §.

Phosphuret.

3. 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

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* Owing most likely to the filtration of air through the earthen ware retort, in which the manganese was heated. I have never observed any azotic gas when manganese is heated in an iron bottle.

† Bergman, ii. 216.

‡ Ibid. p. 221.

§ *Jour. de Phys.* lvi. 1.

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 is oxidized *.

IV. Manganese does not combine with either of the simple incombustibles.

Alloys.

V. Manganese combines with many of the metals, and forms with them alloys which have been but very imperfectly examined.

Gold.

1. We are indebted to Mr Hatchett for some curious experiments on the alloy of manganese and gold. Olive oil was repeatedly mixed and burned with black oxide of manganese, after which a piece of gold was imbedded in the oxide, placed in a crucible lined with charcoal, and well luted. The crucible was exposed for three hours to a strong heat. By this means a portion of manganese was reduced and combined with the gold. The alloy was externally of a pale yellowish grey colour, with a considerable lustre, almost equal to that of polished steel. It was very hard, and possessed some ductility. The fracture was coarse, very spongy, and of a reddish grey colour. It was not altered by exposure to the air. From the analysis of Mr Bingley, the alloy was found to vary in the proportion of manganese from $\frac{1}{8}$th to $\frac{1}{9}$th of the whole. It is more difficult of fusion than gold. When kept melted with access of air, the whole manganese is oxidized, and swims on the surface. The manganese may be separated by cupellation with lead †.

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* Pelletier, *Ann. de Chim.* xiii. 137.

† Hatchett on the *Alloys of Gold*, p. 22.

Copper,

Manganese unites 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 *.

Iron,

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 †.

Mercury.

It does not combine with mercury nor with bismuth. Gmelin found that manganese cannot be alloyed with bismuth without great difficulty; and that it unites to antimony very imperfectly ‡. Chemists have not attempted to combine it with platinum, silver, nickel, nor cobalt.

SECT. XXII.

OF CHROMIUM.

History.

I. IN the year 1766, Lehman, in a letter to Buffon, published the first description of a beautiful red mine-

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* Gottingen Comment. 1787, vol. ix. p. 75.

† Bergman, ii. 205

‡ *Ann. de Chim.* xix. 366.

ral 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 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, molybdic 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 *chromium* †. The experiments of Vauquelin have been since repeated and verified by

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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.

Klaproth[*], Gmelin[†], and Moussin Pouschkin[‡]. Richter has lately succeeded in reducing chromium to the metallic state, and in ascertaining some of its most important properties[§].

Properties.

The colour of chromium is white, intermediate between that of tin and steel. Its specific gravity is only 5·90.

It is extremely brittle, assumes a good polish, and, according to the observation of Ritter, is magnetic, but inferior in this respect to iron, nickel, and cobalt[‖]. Acids act upon it with great difficulty. According to Richter, neither nitric nor muriatic acid dissolve it, even at a boiling heat; but nitro-muriatic acid converts it very slowly into muriate of chromium.

It requires a very high temperature to melt it; but the precise degree has not been ascertained. Richter succeeded in melting it in small grains in a porcelain furnace.

Oxides.

II. Chromium is not altered by exposure to the air: but when heated it is gradually converted into an oxide. Whether it is altered by being kept under water has not been ascertained. Chromium 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*.

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[*] 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.

[§] Gehlen's *Jour.* v. 351.

[‖] Ibid. v. 394.

1. The protoxide, or green oxide, may be obtained by exposing chromic acid to heat in close vessels; oxygen gas passes over, and the green oxide remains behind.

2. The deutoxide, or 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*.

3. The peroxide, or 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 chromium and 67 of oxygen.

The remaining properties of chromium have not been examined.

SECT. XXIII.

OF URANIUM.

History.

I. THERE is a mineral found in the George Wagsfort mine at Johnan-Georganstadt, 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 even, and (in the smallest particles)

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* Crell's *Annals*, 1798, ii. 445.

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 distinguished 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 was afterwards examined by Richter, and more lately an elaborate set of experiments has been published on it by Bucholz ||.

How obtained.

To obtain uranium from its ore, the mineral is to be treated with nitric acid, which dissolves the metallic

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* Klaproth, Crell's *Jour.* Engl. 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*.

|| Gehlen's *Jour.* iv. 17.

portion, and leaves the greater part of the foreign bodies. The solution usually contains iron, copper, and lime as well as uranium. By evaporating it to dryness, and exposing the dry mass to a moderately strong heat, the iron is rendered insoluble, while the other ingredients are taken up by distilled water. Ammonia poured into this solution, and digested in it for some time, retains the copper, but throws down the uranium. The precipitate is to be well washed with ammonia till the liquid comes off colourless; it is then to be dissolved in nitric acid, concentrated by evaporation, and set by to crystallize. The green coloured crystals that form are to be picked out, dried on blotting paper, dissolved in water, and the liquid again crystallized. By this means the whole of the lime, should any be present, is gradually left behind, and the crystals consist at last of pure oxide of uranium, united to nitric acid. They are to be exposed to a red heat; a yellow powder remains, which is oxide of uranium. This powder is to be mixed with a small quantity of charcoal powder, and exposed to a violent heat. By this method it is reduced to the metallic state *.

Properties.

1. Hitherto uranium has not been obtained in masses of any considerable size; the heat requisite to melt it being much greater than can be raised in furnaces. It follows, from the trials of Bucholz, that no flux is of any service in facilitating the fusion of this metal; that its refractoriness does not, as Richter suspected, proceed from the presence of iron; that charcoal powder, when

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* See Klaproth's *Beitrage*, ii. 476. Eng. trans. and Bucholz, *Geblen's Jour.* iv. 19.

mixed in a large proportion, obstructs the success; and that we accomplish our purpose best when the oxide is mixed with a portion of charcoal not exceeding $\frac{1}{20}$th of the weight. This mixture is to be inclosed in a charcoal crucible, to exclude the air, and exposed to the strongest heat that can be raised. Klaproth, in a heat of 170° Wedgewood, obtained a porous metallic mass, firmly cohering; and Bucholz procured it nearly in the same state.

2. Its colour, when thus obtained, is iron grey; it has considerable lustre, and is soft enough to yield to the file. Its malleability and ductility are of course unknown. Its specific gravity, in Klaproth's trials, was only 8·100. But Bucholz obtained it as high as 9·000.

Combination with oxygen.

II. From the experiments of Bucholz, we learn that uranium is capable of uniting with various doses of oxygen.

Protoxide.

1. When uranium is heated to redness in an open vessel, it undergoes a species of combustion, glowing like a live coal, and is soon converted into a greyish black powder, which undergoes no farther change, though the heat be continued. This powder is the protoxide of uranium. One hundred parts of the metal, when thus oxidized, increase in weight so as to become 105·17. Hence this oxide is composed of about

95·1 uranium
4·9 oxygen

100·0 [*]

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[*] Bucholz, Ibid. p. 35.

Peroxide.

2. When uranium or its oxide is dissolved in nitric acid, and the solution is treated with an alkali, the metal is precipitated in the state of a peroxide. The same peroxide is procured by precipitating uranium from sulphuric or muriatic acids, and exposing it while moist to the air. The peroxide thus obtained, when well washed and dried, is yellow, tasteless, and insoluble in water. When treated with muriatic acid, it dissolves with effervescence, oxymuriatic acid gas being disengaged. This oxide, according to Bucholz, is composed of from 76 to 80 parts of uranium, united with from 14 to 20 of oxygen. Hence 100 parts of the metal, when peroxidized, increase in weight so as to become between 126 and 131. Experiment has not hitherto ascertained the exact proportion *.

Other oxides.

3. Bucholz is of opinion, that besides these two oxides there are several intermediate degrees of oxidizement of which the metal is susceptible, each of which is characterized by a peculiar shade of colour. When the black oxide is dissolved in sulphuric acid, and thrown down by ammonia, it is at first blackish grey, but soon assumes a violet colour. When the solution of uranium in nitric acid is evaporated to dryness, and exposed to a red heat, a yellowish brown powder remains, inclining to green. All these colours Bucholz considers as indicating so many degrees of oxidizement. The following, according to him, is the suite of colours through which the oxides of uranium pass, every one including a peculiar oxide †.

Protoxide....... Greyish black.

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* Bucholz, Ibid. p. 27.

† Ibid. p. 40.

Second oxide	Dark grey, inclining to violet.
Third oxide	Greenish brown.
Fourth oxide	Greyish green.
Fifth oxide	Orange.
Peroxide	Lemon yellow.

III. No experiments have been made to ascertain the compounds which uranium is capable of forming with any of the simple combustibles, except with sulphur.

Sulphuret.

1. Klaproth mixed the peroxide of uranium with twice its weight of sulphur, and heated it in a retort till most of the sulphur was driven off. The residuum was a blackish brown compact mass. By increasing the heat, the whole of the sulphur was driven off, and the uranium remained in the metallic state in the form of a black heavy coarse powder *. Bucholz's experiments though made in a different way, led nearly to the same result. He boiled a mixture of sulphur and oxide of uranium in an alkaline solution to dryness, heated the residue to redness, and then treated it with distilled water. A blackish brown powder remained behind, and small needles of a red colour appeared in the solution. In one trial, the compound which he obtained gave out some sulphureted hydrogen when dissolved in muriatic acid. This is a proof that it was not a sulphureted oxide, but a sulphuret of uranium †.

IV. Uranium is but imperfectly soluble in muriatic acid. Azote, we may infer from analogy, does not act upon it.

V. Nothing is known respecting the combinations of uranium with the other metals; Bucholz having been

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* *Beitrage*, ii. 213.

† Gehlen's *Jour.* iv. 47.

hitherto prevented from making any experiments on that part of the subject, by the want of a sufficient quantity of uranium.

SECT. XXIV.

OF MOLYBDENUM.

History.

I. The Greek word μολυβδαινα, and its Latin translation *plumbago,* seems 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

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* Scheele, i. 236.

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 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 much new light upon the nature of this metal ¶. We are indebted to Bucholz for the last and not the least elaborate and important set of experiments on this refractory metal and its compounds **.

How procured.

The simplest method of procuring molybdenum in a state of purity, seems to be that put in practice by Hielm. Molybdena is roasted in a moderate red heat slowly and repeatedly, till the whole is reduced to the state of a fine powder, and passes through a sieve. The powder is to be dissolved in ammonia, the solution filtered, and evaporated to dryness. The residuum being moderately heated (adding a little nitric acid) leaves a

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* Bergman's *Sciagraphia*, p. 19. Eng. transl.

† Crell's *Annals*, 1790, i. 39, &c.

‡ *Jour. de Phys.* 1785, Decembre.

§ Crell's *Annals*, 1787, i. 407.

‖ Ibid. 1787, ii. 21. and 124.

¶ *Phil. Trans.* 1795, p. 323.

** Gehlen's *Jour.* iv. 398.

white powder, which is the pure oxide of molybdenum *. By mixing this oxide with some oil or charcoal powder, and exposing it to a violent heat, it is reduced to the metallic state. The method followed by Bucholz was nearly similar. He has shown that heat reduces the oxide to the metallic state without its being necessary to add any charcoal. But no heat which he could raise was high enough to melt this refractory metal into a solid button. The experiments of preceding chemists had been equally unfortunate.

Properties.

I. Hitherto the metal has been obtained only in small grains, or in pieces imperfectly agglutinated, and which break readily when struck. Its colour, from the observations of Bucholz, seems to be silvery white, but it frequently has a shade of yellow. Hielm found its specific gravity only 7·400; but Bucholz, whose specimens had doubtless been exposed to a more violent heat, and were more compact, found it as high as 8·611 †.

Molybdenum is brittle. It is not altered though kept under water. The effect of exposure to the air has not been ascertained in a satisfactory manner.

Oxides.

II. 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*.

From the experiments of Bucholz, compared with the previous observations of Hatchett, we learn that molybdenum is capable of combining with at least four

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* Crell's *Annals*, iii. 338. Eng. trans.

† Gehlen's *Jour*. iv. 618.

different doses of oxygen, and of forming four oxides; namely, 1. the brown; 2. the violet; 3. the blue; and 4. the white, commonly known by the name of molybdic acid.

Protoxide.

1. The *brown* oxide is obtained by exposing molybdenum in powder to a red heat. Nothing is known respecting the proportion of oxygen which it contains. Indeed Bucholz inferred from the colour merely that it is a peculiar oxide, without subjecting it to a particular examination.

Second oxide,

2. By exposing the metal to a longer and rather a more violent heat, it assumes a *violet brown* colour, which Bucholz considers as the second oxide. When the molybdate of ammonia is exposed to a violent heat in a crucible, a *violet brown* mass remains behind, having more or less cohesion according to the temperature, and a considerable degree of metallic lustre. This residue Bucholz considered at first as the metal reduced, but a more complete investigation convinced him that it was a peculiar oxide. Probably it is the same with the second oxide obtained directly by heating the metal.

Blue oxide.

3. The *blue* oxide may be obtained by carrying the heating of the molybdenum a little farther. But Bucholz found this a very tedious and uncertain method. The following process succeeded much better: Mix together one part of molybdenum in powder and two parts of molybdic acid, and triturate them in a porcelain mortar made into a pap with hot water till the mixture becomes blue, then add eight or ten parts of water, and boil the whole for a few minutes. Filter the solution, and evaporate in a temperature not exceeding 120°. The blue oxide remains in the state of a fine powder. If the whole of the mixture of molybdenum and mo-

lybdic acid be not dissolved, the process may be repeated with the residue as often as is necessary. This blue oxide possesses in fact the properties of an acid. It converts vegetable blues to red, is soluble in water, combines with the saline bases, and forms salts. The name of *molybous acid* may be given to it. Molybdenum appears always to be converted into this oxide when left in contact with water and air, or when water mixed with it is slowly evaporated. The blue oxide seems to be composed of about 100 parts metal and 34 oxygen.

Molybdic acid.

4. The white oxide, or molybdic acid, is obtained most easily from native molybdena, by roasting it for some time, and then dissolving the grey residue in ammonia. Nitric acid dropt into the solution precipitates the molybdic acid in a state of purity *. The acid thus obtained is in fine white scales; but when melted and sublimed it becomes yellow. Its properties were first investigated by Scheele. It converts vegetable blues to red; but according to Bucholz, not with so much readiness as the blue oxide, which in his opinion is the more powerful acid of the two. It is composed, according to his experiments, of about $66\frac{2}{3}$ parts metal, and $33\frac{1}{3}$ oxygen, or of 100 metal and 50 oxygen.

Bucholz supposes, that between the blue and the white oxides there is an intermediate oxide, the colour of which is *bluish green*, and which likewise possesses acid properties.

Union with combustibles.

III. 1. Molybdenum combines readily with sulphur; and the compound has exactly the properties of mo-

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* Bucholz, *Geblen's Jour*. iv. 604.

lybdena, 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. From the experiments of Bucholz we learn, that it is composed of about

60	metal
40	sulphur
100 [†].	

2. Molybdenum is also capable of combining with phosphorus [‡].

IV. Muriatic acid has but little effect upon molybdenum; but it dissolves its oxide. The action of azote has not been examined.

Alloys with

V. To the indefatigable industry of Hielm, we are indebted for a set of experiments on the alloys of molybdenum with other metals.

Gold.

1. With gold it melts only imperfectly, and forms a blackish brittle mass, from which a considerable portion of the gold eliquates when it is kept in a strong heat. The alloy is attacked by nitric acid. The gold subsides in the state of a fine powder, and the molybdenum lies over it in the form of white oxide. The proportions tried were

Gold	6,	4,	2.
Molybdenum	2,	2,	2.

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[*] Pelletier, *Jour. de Phys.* 1785.

[†] Gehlen's *Jour.* iv. 603.

[‡] Pelletier, *Ann. de Chim.* xiii. 137.

None of these compounds could be brought into perfect fusion even by the assistance of borax *.

Platinum,

2. Equal parts of platinum and molybdenum melted into a hard irregular brittle mass, of a close texture, a light grey colour, and a metallic lustre. Three parts of molybdenum, and one of platinum, did not melt completely. The same difficulty of fusion was experienced when the proportion of platinum was augmented. The specific gravity of this alloy was found by Hielm to be 20 †.

Silver,

3. Four parts of silver and two of molybdenum were strongly heated in a crucible, but did not yield a button. By continuing the heat a portion of the silver eliquated, still retaining a part of the molybdenum, and becoming bluish when heated. The residuum being melted again in charcoal, became more compact, was brittle, of a grey colour, and a granular texture. When melted by itself silver eliquated. By nitric acid the silver was taken up from this alloy, and the molybdenum converted into white oxide.

Four parts of silver and one of molybdenum gave a malleable compound, but it could not be melted into a round button. It was of a silver colour and granular texture.

One part of silver and two of molybdenum melted into a granular, brittle, greyish lump. When heated on charcoal the molybdenum evaporated, and the silver remained. The molybdenum may be separated from silver by cupellation, especially if the alloy has been previously calcined ‡.

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* Hielm, Crell's *Annals*, iii. 356. Eng. trans.

† Ibid. p. 52. and *Ann. de Chim.* iv. 17.

‡ Crell's *Annals*, iii. 361.

Book I. Division I.

4. Hielm could not succeed in his attempts to unite mercury and molybdenum *.

Copper,

5. Equal parts of molybdenum and copper formed an alloy which yielded to the hammer a little, but at length broke in pieces, exhibiting a granular texture, and a bluish colour mixed with red. It admitted of being filed; and the surface thus exposed was paler than copper, and did not lose its lustre by exposure to the air. Four parts of copper and $1\frac{1}{2}$ molybdenum formed an alloy not very different in its properties; but when the metals were mixed in the proportion of one part copper and two molybdenum, the alloy was brittle, and of a reddish grey colour. Nitric acid dissolved the copper, and left the white oxide of molybdenum †.

Iron,

6. Equal quantities of iron and molybdenum melt readily, and form a brittle alloy, of a bluish grey colour, and considerable hardness. Its fracture was fine, scaly, and granular. Before the blow-pipe it melted with intumescence, but without sparks. One part of iron and two of molybdenum formed a brittle alloy, of a fine grained texture, and light grey colour. It was magnetic, and did not melt before the blow-pipe. Of all the metals, iron seems to unite most readily with molybdenum ‡.

Nickel,

7. Equal quantities of molybdenum and nickel melted into a button, internally of a light grey colour, yielding somewhat to the hammer before it broke, and exhibiting a granular texture. It was not magnetic, and did not melt before the blow-pipe. When the proportion of molybdenum is increased, the fusion of the al-

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* Crell's *Annals*, iii. 358.

† Ibid. p. 366.

‡ Ibid. p. 370.

loy becomes more difficult; in other respects, its properties continue nearly the same *.

Tin.

8. Equal parts of tin and molybdenum melted into a blackish grey, granular, brittle, soft mass. When two parts of tin and one of molybdenum were melted together, the alloy was harder than the preceding, but in other respects agreed with it. Four parts of tin and one of molybdenum formed a still harder alloy, which admitted of being hammered a little, did not crackle like tin when bent, and in its fracture exhibited a greyish colour and granular texture. When strongly heated, the tin did not eliquate till the alloy was pressed with the forceps †.

Lead.

9. Ten parts of lead and one of molybdenum, when melted together, form an alloy which is somewhat malleable, and whiter than pure lead. When kept heated, the lead partly eliquates. When the proportion of molybdenum is increased, the alloy becomes brittle, dark coloured, and more difficult of fusion ‡.

Zinc.

10. The volatility of zinc renders it difficult to alloy that metal with molybdenum. Equal parts of the two metals, strongly heated in a covered crucible, left a black mass almost in a powdery state §.

Bismuth.

11. The combination of bismuth and molybdenum is equally obstructed by the volatility of the former metal. When they are melted together, the bismuth is driven off, and a black brittle mass remains, consisting chiefly of molybdenum. Four parts of bismuth and one of molybdenum, being melted together in a bed of charcoal, gave a black brittle mass, together with a but-

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[*] Crell's *Annals*, iii. 367.

[†] Ibid. p. 373.

[‡] Ibid. p. 388.

[§] Ibid. p. 375.

ton of bismuth, which retained a portion of molybdenum. This button bore a few strokes of the hammer, but at length broke in pieces. Its texture was closer than bismuth, and it was very fusible *.

Antimony, 12. When antimony and molybdenum were melted together, the antimony exhaled, leaving the molybdenum in the state of a black mass. By adding antimony to this mass, and repeating the fusion twice, a portion of the antimony adhered to the molybdenum, and formed an alloy of a yellowish grey colour and brittle †.

Arsenic, 13. When arsenic and molybdenum are melted together, the whole of the arsenic sublimes; but when oxide of arsenic is employed, a combination takes place, from which the arsenic is not easily separable again ‡.

Cobalt, 14. Equal parts of cobalt and molybdenum melted into a button of a grey colour, brittle, and of difficult fusion. Two parts of cobalt and four of molybdenum gave an alloy of a sparkling reddish grey colour, hard, brittle, not attracted by the magnet, internally granular, and of a bluish grey colour §.

Manganese. 15. Equal parts of manganese and molybdenum melted into an irregular button, not fusible before the blow-pipe, and not colouring borax till after it had been roasted ||.

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* Crell's *Annals*, p. 363.

† Ibid. p. 377.

‡ Ibid. p. 368.

§ Ibid. p. 371.

|| Ibid. p. 376.

SECT. XXV.

OF TUNGSTEN.

History.

I. 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 conjectured that the basis of this acid is a metal[†]; and this conjecture was soon after fully confirmed by the experiments of Messrs D'Elhuyar, 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

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[*] Scheele, ii. 81.

[†] Ibid. ii. 91.

[‡] Wolfram had been analysed in 1761 by Lehmann. He imagined it a compound of iron and tin. See his *Probierkunst*, p. 8.

large as a pin-head. The metal thus obtained is called *tungsten*. The manner in which it is 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. The fusion of this metal has been also accomplised by Messrs Allen and Aiken of London. They succeeded by applying a strong heat to the combination of the oxide of tungsten and ammonia [||].

Properties.

1. Tungsten, called by some of the German chemists *scheelium*, is of a greyish-white colour, or rather like that of steel, and has a good deal of brilliancy.

2. 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; according to Allen and Aiken, 17·33 [¶]. It is therefore the heaviest of the metals after gold and platinum.

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[*] *Mem. Thoulouse*, ii. 141. This memoir has been translated into English.

[†] *Jour. de Min.* No. xix. 3.

[‡] *Transl. of the Chem. Nomenclature.*

[§] *Observ. on the Fossils of Cornwall*, p. 77.

[||] Aiken's *Dictionary of Chemistry*, ii. 445.

[¶] Ibid.

2. 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.

3. It is not attracted by the magnet.

Oxides.

II. 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 *blue* and the *yellow*.

Protoxide.

1. The protoxide, or blue oxide, may be obtained by heating the yellow oxide for some hours in a covered crucible.

It is formed when a muriate of tin is poured into a solution of molybdate.

eroxide.

2. The peroxide or yellow oxide, known also by the name of *tungstic acid**, may be obtained by boiling three parts of muriatic acid on one part of wolfram. The acid is to be decanted 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 *yel-*

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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, potash, and the acid employed to decompose the mineral from which it is obtained.

low 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 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.

Union with combustibles.

III. 1. The sulphuret of tungsten is of a bluish black colour, hard, and capable of crystallizing.

2. Phosphorus is capable of combining with tungsten[†]. But none of the properties of the phosphuret have been ascertained.

IV. The simple incombustibles do not seem capable of uniting with tungsten.

Alloys.

V. 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:

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[*] A more economical process for procuring this oxide has been proposed by Bucholz. His formula is as follows: Mix one part of wolfram in fine powder with two parts of *subcarbonate of potash*; keep the mixture melted in a crucible for an hour, stirring it occasionally. Then pour it into an iron cone. Before the mass be quite cold, reduce it to powder, and boil water on it repeatedly till the liquid comes off tasteless. Mix all the watery solutions together, and pour muriatic acid into them as long as any precipitate appears. Wash the precipitate; dissolve it in boiling carbonate of potash, precipitate again by muriatic acid, wash the precipitate, and dry it upon filtering paper. It is pure peroxide of tungsten. See *Jour. de Chim.* iii. 220.

[†] Pelletier, *Ann. de Chim.* xiii. 137.

Chap. IV.

1. With gold it did not melt completely. The button weighed 139 grains. By cupellation with lead the gold was reduced to its original purity. With platinum it refused likewise to melt. The mass obtained weighed 140 grains.

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.

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 *.

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* Chemical analysis of Wolfram, translated by Cullen, p. 59.

Chap. IV.

CLASS IV.

REFRACTORY METALS.

ALL of the metals belonging to the preceding class, if we except cobalt and manganese, are so difficult of fusion, that it has been impossible to procure them in large masses, but merely in the state of agglutinated grains. The remaining metals are still more refractory, so much so indeed, that they are still unknown in the metallic state; their oxides only, and the compounds which they form with other bodies, having been examined. Perhaps titanium may be an exception; but as the reduction of this substance to the metallic state is still somewhat doubtful, it was thought better to arrange it among the refractory metals.

SECT. XXVI.

OF TITANIUM.

History.

I. In the valley of Menachan, in Cornwall, there is found a black sand, bearing a strong resemblance to gunpowder. It was examined in 1781 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 to show 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 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 *mena-*

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* *Jour. de Phys.* xxxix. 72. and 152.

† Beitrage, i. 233.

‡ Ibid. ii. 226.

chine is the same with *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, and by Lampadius, the following properties of titanium have been ascertained.

1. Lampadius is said to have reduced it by exposing the oxide with charcoal to a violent heat. Its colour is that of copper, but deeper. It has considerable lustre. It is brittle, but in thin plates has considerable elasticity. It is highly infusible [‡].

Oxides.

II. When exposed to the air, it tarnishes, and is easily oxidized by heat, assuming a blue colour. It detonates when thrown into red hot nitre [§].

It seems capable of forming three different oxides; namely, the *blue* or *purple*, the *red*, and the *white*.

Protoxide.

1. The protoxide, which is of a blue or purple colour, is formed when titanium is exposed hot to the open air, evidently in consequence of the absorption of oxygen.

Deutoxide.

2. The deutoxide or 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 ur-

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[*] *Jour. de Min.* No. xv. 10.

[†] Crell's *Annals*, 1799, i. 183.

[‡] Nicholson's *Jour.* vi. 62.

[§] Lampadius, ibid.

ged by a very violent fire, some of it is volatilized. When heated sufficiently along with charcoal, it is reduced to the metallic state.

Peroxide.

3. The peroxide or white oxide may be obtained by fusing the red oxide in a crucible with four times its weight of potash, 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.

Union with combustibles.

III. 1. Titanium does not seem to be capable of combining with sulphur *.

Phosphuret.

2. Phosphuret of titanium has been formed by Mr Chenevix by the following process. He put a mixture of charcoal, phosphate 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 blow-pipe †.

loys.

IV. 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.

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* Gregor.

† Nicholson's *Jour.* v. 234.

SECT. XXVII.

OF COLUMBIUM.

History.

I. In the year 1802, while Mr Hatchett was engaged in arranging some minerals in the British Museum, a dark-coloured heavy substance attracted his attention, on account of some resemblance which it bore to *chromate of iron*. The specimen was small. It was described in Sir Hans Sloane's catalogue as " A very heavy black stone with golden streaks;" and it appears that it was sent along with various specimens of iron ores to Sir Hans Sloane by Mr Winthrop of Massachusets. Its colour was a dark brown grey; its longitudinal fracture imperfectly lamellated, and its cross fracture showed a fine grain. Its lustre was glassy, and in some parts slightly metallic. It was moderately hard, but very brittle. By trituration it yielded a powder of a dark chocolate brown, not attracted by the magnet. Its specific gravity, at the temperature of 65°, was 5·918.

By an ingenious analysis of this mineral, Mr Hatchett ascertained that it was composed of one part of oxide of iron, and rather more than three parts of a white coloured substance which possessed the properties of an acid, and exhibited undoubted proofs of being composed of oxygen united to a metallic basis. The properties of this metallic acid will be described hereafter.

Mr Hatchett demonstrated, that it differs from all the metallic acids hitherto examined; of course its metallic basis must be also peculiar, and required a distinct name. Accordingly he gave it the name of *columbium*.

Attempts to reduce it.

Various attempts were made to reduce this acid to the metallic state, but none of them succeeded completely. A portion of it was put into a crucible lined with charcoal, and exposed to a violent heat in a small wind furnace for about an hour and a half. The oxide was found in a pulverulent state, and had assumed a black colour.

Mr Hatchett ascertained, that, like most of the other metals, it is capable of combining with different doses of oxygen, distinguished from each other by their different colours and different actions upon the acids.

Though strongly heated with sulphur, it showed no disposition to combine with the substance, or to form a sulphuret.

Phosphuret.

In order to form a phosphuret some phosphoric acid was poured upon a portion of the white oxide; and being evaporated to dryness, the whole was put into a crucible lined with charcoal. It was then exposed for half an hour to the heat of a forge. The inclosed matter was spongy, and of a dark brown: it in some measure resembled phosphuret of titanium *.

Ekeberg has announced his opinion, that this metal is the same with tungsten, but he has not communicated the experiments upon which this opinion is founded †. The ore of columbium was reported some years ago to have been discovered in Switzerland, but we do not know how far that report was correct.

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* *Phil. Trans.* 1802.

† Gehlen's *Jour.* v. 348.

SECT. XXVIII.

OF CERIUM.

History.

In the year 1750 there was discovered, in the copper mine of Bastnâs at Ridderhytta, in Westmannland in Sweden, a mineral which, from its great weight, was for some time confounded with *tungsten*. This mineral is opaque, of a flesh colour, with various shades of intensity, and very rarely yellow. Its streak is greyish white, and when pounded it becomes reddish grey. It is compact, with a fine splintery fracture, and fragments of no determinate form; moderately hard; its specific gravity, according to Cronstedt, 4·988 [*], according to Klaproth 4·660 [†], according to Messrs Hisinger and Berzelius, from 4·489 to 4·619 [‡]. This mineral was first examined by M. D'Elhuyar: the result of whose analysis was published by Bergman in 1784 [§]. It ascertained that the mineral in question contained no tungsten.

No farther attention was paid to this mineral till Klaproth published an analysis of it in 1804, under the name of *Ochroits* [||], and announced that it contained a *new earth*, to which he gave the name of *ochroita*. He sent a specimen of this new product to Vauquelin, who made a few experiments on it, but hesitated whether to

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[*] Gehlen's *Jour.* ii. 305.

[†] Ibid.

[‡] Ibid. ii. 398.

[§] *Opusc.* vi. 108.

[||] Gehlen's *Jour.* ii. 203.

consider ochroita as an earth or a *metallic oxide*[*]. Meanwhile the mineral had undergone a still more complete examination in Sweden by Hisinger and Berzelius, who gave it the name of *cerit;* detected in it a peculiar substance, which they considered as a metallic oxide, and to which they gave the name of *cerium*, from the planet *Ceres*, lately discovered by Piazzi[†]. But the attempts of these chemists to reduce the supposed oxide to the metallic state were unsuccessful. Nor were the subsequent trials of Gahn, to reduce it by violent heat along with charcoal, or to alloy it with other metals, attended with greater success[‡]. Vauquelin has re-examined it lately; but his attempts have been only partially successful[§]. They demonstrate, however, that the substance in question is a metal; though from its refractory nature, and its volatility, only minute globules of it were obtained.

How obtained.

I. To obtain the metal, the combination of oxide of cerium with tartaric acid was mixed with some lamp-black and oil, and exposed to the violent heat of a forge in a crucible lined with charcoal, and inclosed in another filled with sand. Only a small metallic button was obtained, not exceeding the 50th part of the oxide of cerium exposed to heat. It was white, brittle, dissolved with great difficulty in nitro-muriatic acid, and proved a mixture of iron and cerium. Another attempt to obtain the metal by heating its tartrate in a porcelain retort was not more successful. Most

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[*] *Ann. de Chim.* l. 140.

[†] Gehlen's *Jour.* ii. 297.

[‡] Ibid. iii. 217.

[§] *Ann. de Chim.* liv. 28.

of it was dissipated, small globules only remaining, which proved as before a mixture of cerium and iron[*].

How procured.

I. To procure oxide of cerium in a state of purity, the Swedish chemists employed the following method: The mineral was reduced to a fine powder, and digested in nitric acid till every thing soluble was taken up. The solution being decanted off is evaporated to dryness, and the residue dissolved in water. Into this solution ammonia is poured, till every thing precipitable by means of it is thrown down. This precipitate being well washed is redissolved in nitric acid; the acid is neutralized; and then *tartrate of potash*[†] is added to the solution. The precipitate which is separated being heated to redness, and well washed with vinegar, and dried, is pure oxide of cerium[‡].

1. When first procured it has a white colour, but when heated to redness it becomes reddish brown.

Reduction.

2. When made into a paste with oil, and heated in a charcoal crucible, it loses weight. When urged by a strong fire on charcoal, it does not melt, but continues in powder. It exhibited, however, brilliant particles, and dissolved in muriatic acid, disengaging at first sulphureted hydrogen, and afterwards pure hydrogen gas[§].

Oxides.

3. According to the Swedish chemists, it is susceptible of various degrees of oxidizement. This they conclude from the various colours which it assumes in different circumstances; namely, white, yellow, red, and dark brown. That it contains oxygen they have rendered manifest: by digesting muriatic acid upon it, a

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[*] *Ann. de Chim.* liv. 59.

[†] A salt to be described hereafter.

[‡] Gehlen's *Jour.* ii. 401.

[§] Hisinger and Berzelius, Ibid.

portion is driven off in the state of oxymuriatic acid gas. Vauquelin considers it as capable of two states of oxidizement; the protoxide of a white colour, and the peroxide reddish brown *.

4. The oxide of cerium does not melt by itself; but when treated with borax before the blow-pipe, it melts readily, and swells. The globule heated by the outermost flame assumes the colour of blood, which, by cooling, passes into yellowish green, and at length becomes colourless, and perfectly transparent. Melted by the blue flame, these changes do not take place; the globule at once assuming the state of colourless glass †. These phenomena serve to distinguish it from every other metallic substance.

Action of combustibles.

II. Few experiments have been made on the combinations of cerium with the simple combustibles.

1. When a stick of phosphorus was put into a solution of cerium in muriatic acid, and kept for some days on a stove, the bottom and sides of the vessel were covered with a white precipitate, and the phosphorus was covered with a hard brown crust, which was tenacious, and shone in the dark. When heated it took fire, and left a small quantity of oxide of cerium. But this experiment did not succeed when repeated ‡.

2. Hydro-sulphuret of ammonia throws down cerium

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* *Ann. de Chim.* liv. 46.

† Hisinger and Berzelius, ibid. The phenomena described by Klaproth are different. According to him, borax does not dissolve the oxide. but acquires from it a brown yellow colour. Vauquelin says merely, that it tinges borax yellow, and that the globule becomes opaque when saturated with the oxide.

‡ Hisinger and Berzelius, ibid.

at first of a brown colour, but it becomes deep green as we continue to add the reagent. The precipitate when dried becomes bright green. When heated it burns, and leaves the yellow oxide of cerium; but the colour of the precipitate varies according to the state of the cerium held in solution *.

III. The attempt made by Gahn to unite cerium with lead did not succeed, and hitherto no other combination of it with metals has been tried, if we except the alloy of cerium and iron obtained by Vauquelin.

SECT. XXX.

GENERAL REMARKS.

Tantalum.

We have omitted, in the preceding sections, the metallic substance discovered by Ekeberg, and announced by him as a peculiar metal under the name of Tantalum; because this chemist has lately published an acknowledgement that the supposed peculiar oxide was in reality an oxide of tin. As the result of his experiments has not hitherto been published, we do not know the real constituents of the minerals to which he gave the names of *tantalite* and *yttrotantalite*.

The object of the preceding Sections has been to describe the properties of the metals, and to examine the compounds which they form with oxygen, with simple combustibles, and with each other. It will be

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* Hisinger and Berzelius, Ibid. With Vauquelin the result was different. The precipitate which he obtained was white, and contained no sulphureted hydrogen.

attended with considerable advantage to exhibit a synoptical view of the most remarkable of these properties and combinations. This will be the business of the present Section.

Properties of the metals.

I. The principle properties of the metals, as far as they have been ascertained, will be found in the following Table:

Metals.	Colour.	Hardnes	Sp. Gravity.	Melting Point.		Tenacity.
				Fahren.	Wedge.	
Gold	Yellow	6·5	19·361	—	32	150·07
Plat.	White	8	23·000	—	170+	274·31
Silver	White	7	10·510	—	22	187·13
Mer.	White	0	13·568	—39	—	—
Pallad.	White	9+	11·871	—	160+	
Rhod.	White		11·+	—	160+	
Irid.	White			—	160+	
Osm.	Blue			—	160+	
Copper	Red	7·5	8·895	—	27	302·26
Iron	Grey	9	7·8	—	158	549·25
Nickel	White	8·5	8·666	—	160+	
Nicol.	Grey		8·6			
Tin	White	6	7·299	442	—	31·0
Lead	Blue	5·5	11·352	612	—	18·4
Zinc	White	6·5	6·861	680	—	18·2
Bism.	Red white	7	9·822	476	—	20·1
Antim.	Gr. white	6.5	6·712	810	—	7
Tellur.	Bl. white		6·115	612+	—	
Arsen.	Bl. white	5	8·31	400+	—	
Cobalt	Grey	6	7·7	—	130	
Mang.	Grey	9	6·850	—	160	
Chro.	White		5·90	—	170+	
Uran.	Iron-grey		9·000	—	170+	
Molyb.	Y. white		8·611	—	170+	
Tung.	Gr. white	9+	17·6	—	170+	
Titan.	Red.			—	170+	

Oxides.

II. All the metals are capable of combining with oxygen; and this property constitutes one of their most striking characters. This combination takes place in a variety of circumstances.

By the air,

1. Some metals absorb it from the atmosphere, and gradually crumble into a powder when left exposed to the open air. Arsenic, manganese, and iron, are the only metals known at present to possess that property. The effect is not proportional to the affinity of the metals for oxygen, but is owing to the combined action of a variety of agents. The air, water, and carbonic acid, are the most conspicuous of these. Most metals, when they are left exposed to the air, lose their brilliancy, which can only be preserved by frequent cleaning. They are then said to be *tarnished*. This tarnish is supposed at present to be a commencement of oxidizement; and the tenacity of the metal is considered as the reason why it proceeds no farther than the surface. Gold and platinum are not liable to tarnish; neither is mercury in a perceptible degree. Silver tarnishes not from oxidizement, but from the action of sulphur.

By heat,

2. When the metals are heated, their combination with oxygen is much facilitated. This is ascribed at present to the effect of heat in diminishing the cohesion of the metallic particles. If the heat be sufficiently high, it appears that all metals are oxidized more or less. The metals when sufficiently heated take fire, and burn with more or less brilliancy. Arsenic is the most combustible of the metals; then comes zinc. Antimony and bismuth likewise burn at a red heat, but with little brilliancy. Tin has a more brilliant combustion. Iron requires a white heat, but it burns with

Combustion,

Book I. Division I.

great splendour. The combustibility of the remaining metals is much inferior to these. When metals burn, they always combine with a determinate quantity of oxygen. Some metals, as iron and arsenic, are capable, after combustion, of uniting with more oxygen; while others, as zinc, antimony, and bismuth, combine during combustion with a maximum of oxygen.

By decomposing water.

3. Some metals have the property of taking oxygen from water when the action is assisted by heat. Zinc, iron, tin, and antimony, are the only metals hitherto examined which have that property. When they are heated to redness, and steam passed over them, they are oxidized, while hydrogen gas is evolved.

4. Metals vary exceedingly from each other in the proportion of oxygen with which they are capable of combining; but in every particular metal the dose seems determinate. Most metals have likewise a minimum of oxygen with which they unite, and in several there are one or more states of oxidizement equally well determined between the protoxide and peroxide; while in others no such determinate intermediate states can be discovered.

Table of metallic oxides.

The following Table exhibits a view of the number of oxides known to be formed by each metal, of the colour of each when known, and of the proportion of oxygen united to 100 of metal by weight, which constitutes each particular oxide.

Metals.	Oxides	Colour.	Oxyg.
Gold	1	Purple	
	2	Yellow	32
Platin.	1	Green	7·5
	2	Brown	15
Silver	1	—	—
	2	Olive	12·8
Mercury	1	Black	4·16
	2	Yellow	12
	3	Red	17·6
Pallad.	1	Blue	
	2	Yell.?	
Rhod.	P.	Yellow	
Iridium	1	Blue?	
	2	Red?	
Osmium	P.	Transp	
Copper	1	Red	13
	2	Black	25
Iron	1	Grey	18
	2	Black	37
	3	Red	92·3
Nickel	1	Green	28
	2	Black	
Niccola.	1	Blue	
	2	Black	
Tin	1	—	—
	2	Grey	25
	3	White	38·8
Lead	1	—	—
	2	Yellow	8
	3	Red	13·6

Metals.	Oxides.	Colour.	Oxyg.
Zinc	1	Yellow	13·6
	2	White	25·0
Bism.	P.	Yellow	12
Antim.	1	White	22·7
	2	White	30
Tellur.	P.	White	
Arsenic	1	White	33
	2	Acid	53
Cobalt	1	Blue	19·7
	2	Green	
	3	Black	25
Mangan.	1	White	25
	2	Red	35
	3	Black	66·6
Chrom.	1	Green	
	2	Brown	
	3	Red	200
Uran.	1	Black	5·17
	2	Yellow	28·0
Molyb.	1	Brown	
	2	Violet	
	3	Blue	34
	4	White	50
Tungst.	1	Black	15
	2	Yellow	25
Titan.	1	Blue	16
	2	Red	33
	3	White	49
Colum.	P.	White	
Cerium	1	White	

Proportion of oxygen absorbed by metals.

5. From this Table, it appears that the metals, with respect to the quantity of oxygen which they are capable of condensing, observe the following order:

Chromium	200
Iron	92·3
Manganese	66
Arsenic	53
Tin	38·8
Antimony	30
Zinc	25
Copper	25
Lead	25
Tungsten	25
Mercury	17·6
Platinum	15
Silver	12·8
Bismuth	12

Were we to suppose with Berthollet, that the affinity of these bodies for oxygen is proportional to the quantity of that principle which they are capable of condensing, without acquiring acid properties, in that case the preceding Table, omitting chromium, arsenic, and tungsten, would indicate the order of the affinities. But there are many circumstances which militate against this supposition. Probably, indeed, the comparison is not fair, unless the metals compared are oxidized in the same circumstances, and by the same agents. For example, when the seven most combustible metals are exposed to a strong heat, they take fire, and unite with oxygen in the following proportions:

Oxygen absorbed during combustion.

Iron	37
Arsenic	33

Antimony	30
Tin	25 ?
Zinc	25
Bismuth	12
Lead	8

Here the circumstances being the same, it is more probable that the dose bears some relation to the affinity for oxygen. When the same metals are exposed to the action of nitric acid, they combine with different doses of oxygen, but follow notwithstanding nearly the same order, as is obvious from the following Table:

By the action of nitric acid.

Iron	92
Arsenic	53
Antimony	30
Tin	38·8
Zinc	25
Bismuth	12
Lead	8

Properties of oxides.

5. The metallic oxides differ very considerably from each other. The greater number of them are tasteless powders; but some of them are acrid, and others have even the properties of acids. The peroxides of mercury and osmium, and the protoxide of arsenic, are soluble in water. The peroxides of arsenic, chromium, molybdenum, tungsten, and columbium, belong to the class of acids. It was formerly the opinion of chemists, that all metals are susceptible of acidification by combining them with a sufficient quantity of oxygen; but subsequent experience has not confirmed this opinion.

Reduction by heat.

6. When heat is applied to the peroxides, they give out a portion, or the whole, of their oxygen: but in this respect they differ exceedingly from each other. A mo-

derate heat reduces the oxides of gold, platinum, silver, mercury, and nickel, to the metallic state; and the same thing would happen also to the oxide of lead, were it not so susceptible of melting into a glass. The other metals require a violent heat, and are but imperfectly reduced. Were we to arrange them according to the difficulty of separating their oxygen by heat, the metals would assume an order not very different from the following *:

1. Refractory metals
2. Manganese
3. Zinc
4. Iron
5. Tin
6. Uranium
7. Molybdenum
8. Tungsten
9. Cobalt
10. Antimony
11. Arsenic
12. Chromium
13. Bismuth
14. Lead
15. Copper
16. Tellurium
17. Nickel
18. Platinum
19. Palladium
20. Mercury
21. Silver
22. Gold

Union with combustibles.

III. Of the four simple combustibles, there is one, namely *carbon*, which has been hitherto combined only with one of the metals, iron.

1. Hydrogen gas dissolves arsenic, zinc, and iron, and holds them suspended seemingly in the metallic state.

Phosphurets.

2. Phosphorus combines with most of the metals hitherto tried. 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,

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* Vauquelin, Patrin's *Mineralogy*, v. 189.

and zinc. The phosphorus may be expelled by heat The following Table exhibits a view of the proportion of phosphorus united to 100 parts of the metals in the phosphurets hitherto examined.

Silver	25
Copper	25
Iron	25
Tin	25
Nickel	20
Lead	15
Cobalt	7
Gold	4·3
Bismuth	4

Sulphurets.

3. More attention has been paid to the metallic sulphurets, because they occur often native, and have been applied to a variety of useful purposes. Sulphur unites in different proportions with some of the metals. The following table exhibits a view of the colour and specific gravity of the sulphurets, and of the proportion of sulphur combined in each with 100 of the metal, as far as the point has been ascertained.

Sulphurets of	Colour.	Specific gravity.	Sulphur.
Gold Platin.	Unknown		
Silver	Black-grey	7·2	17·[illegible]
Mercury	1. Black 2. Red	10	17·6
Pallad.	White		
Rhod.	White		
Iridium Osmium	Unknown		
Copper	1 Grey 2. Yell.		28·2
Iron	1. Yell. 2. Yell.	4·518 4·83	60 112
Nickel	Yellow		
Tin	Blue		17·6
Lead	Leaden grey	7	16
Zinc			
Bismuth	Leaden grey	6·131	17·5
Antim.	Leaden grey	4·368	33·3
Tellur.	Leaden grey		
Arsenic	1. Red 2. Yell.	3·225 5·315	25 43
Cobalt	Yellow		39·8
Mangan Chrom.	Unknown		
Uran.	Brown		
Molyb.	Leaden grey	4·73	66
Tungst.	Bluish black		
Titan. Colum.	Unknown		
Cerium			

Decomposition of sulphurets.

The metals are capable of taking sulphur from each other when assisted by heat. They all follow, in this respect, a determinate order. Thus iron is capable of depriving lead, antimony, silver, and mercury, of sulphur; but neither lead nor any of the other metals can decompose the sulphuret of iron. The following, according to Bergman, is the order that the metals follow in depriving each other of sulphur; every metal being understood to be capable of decomposing the sulphurets of all the metals that follow it in the column.

1. Iron
2. Copper
3. Tin
4. Lead
5. Silver
6. Bismuth
7. Antimony
8. Mercury
9. Arsenic
10. Molybdenum

Alloys.

IV. 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 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. 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.

Table of the alloys.

Their most interesting qualities, in an economical point of view, are their brittleness or malleability; while the change of bulk which they undergo during their combination is of considerable importance to the chemist. The three following tables exhibit a view of these properties, as far as ascertained in all the metallic alloys. The first comprehends the alloys of the malleable metals with each other; the second, the alloys

Book I.
Division I.

of the brittle metals; and the third, the alloys of the malleable with the brittle metals[*].

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[*] In these tables, the letter M signifies malleable; B, brittle; S, submalleable, used when the alloy is malleable in certain proportions, but brittle in others. O is used when the metals do not unite. The sign + is used when the alloy occupies a greater bulk than the separate metals; the sign —, when the alloy occupies a smaller bulk. The first indicates an expansion, the second a condensation.

I. MALLEABLE METALS.

Zinc													
M	Lead												
M	M+	Tin											
O	O	B	Nickel										
S	B+	M	M	Iron									
S—	B+	B—	B	S	Copper								
					M	Iridium							
					M		Osmium						
								Rhodium					
	B	B+		B	S—				Palladium				
B	B	B	O	B	B			O	B	Mercury			
B—	B—	B—	O	M	M+	M		M	M—	B—	Silver		
B	S—	S—		M—	M—	M			M+	B	M+	Platinum	
B—	B+	S—	M+	M+	M+	M	M	M	M	B	M+	M+	Gold

II. BRITTLE METALS.

Titanium										
	Tungsten									
		Chromium								
			Uranium							
				Molybdenum						
	B			B	Manganese					
				B		Cobalt				
				B		B	Arsenic			
								Tellurium		
		B		B	O		B		Antimony	
		B		S	O	O	B		B	Bismuth

TABLE III.

	Bismuth.	Antimony.	Tellurium.	Arsenic.	Cobalt.	Manganese.	Molybden.	Uranium.	Chromium.	Tungsten.	Titanium.
Gold	B —	B —		B	B—	M	B				
Platin.	B	B		B			B—				
Silver	B —	B —		B	B		B			M	
Merc.	B	B		B	O	O	O				
Pallad.	B —			B							
Rhod.				O							
Osmi.											
Iridium											
Copper	B =	B —		M		M	S			M	
Iron	B +	B +		B	B	S	B			B	S
Nickel	B			B+	B		S				
Tin	M	M ? +		B		B ?				S	
Lead	M—	M —		B	B		S			M	
Zinc	O	B +		B	O	O	O				

Chap. I.

DIVISION II.

OF

UNCONFINABLE BODIES.

THE substances described in the 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 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 them 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. The number of them which are at present known, or supposed to exist, amounts to four; namely, Light, Heat, Electricity, and Magnetism: But the last of these is scarcely at present considered as belonging to chemistry; and the third I pro-

Book I. Division II.

pose to consider in a separate work. I shall therefore confine myself to the first two bodies, which I shall consider in the following Chapters. 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.

CHAP. I.

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.

Nature of light.

Concerning the nature of *this light*, two different theories have been advanced by philosophers. Huygens considered it as a subtle 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 firmest 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 hypotheses, 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 shown, 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 of its particles.

2. From this astonishing velocity we are enabled to form some notion of the size of the particles of light. Mechannical philosophers have demonstrated, that the

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* *Phil. Trans.* xii. 83.

† Ibid. xxxv. 637, and xlv. 1.

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, 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 900 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 chan-

ging 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 would otherwise 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

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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. 72.

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 pen knives, 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 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 uni-

formly 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.

Decomposable into seven 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 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 least refrangible, the violet the most; 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 are exposed. Most of these substances, indeed, lose their 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

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[*] *Phil. Trans.* 1800, p. 255.

[†] Ibid. lxi. 212.

[‡] Ibid. lviii. 337.

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 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

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* Dr Higgins has added considerable improvements to the method of preparing Canton's pyrophorus. He stratifies the oyster shells and sulphur in a crucible without pounding them; and after exposing them to the proper heat, they are put into phials furnished with ground stoppers.

Book I. Division II.

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 basin 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 basin 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 exhibited 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 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 putrefy, become luminous in the dark, and of course give out light. This is the case in particular with the whiting, the herring, and the mackerel. 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 $\frac{1}{2}$ a dram of common salt, or two drams of sulphate 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 is again emitted as soon as

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* *Jour. de Phys.* xx. 270.

† *Phil. Trans.* lix. 446.

‡ Ibid. 1800. p. 161.

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 sulphureted hydrogen gas, fermented liquors, spiritous liquors, acids, alkalies, and water saturated with a variety of salts, as sal-ammoniac, common salt, sulphate 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 the constituent parts which makes its escape when the substance containing it is beginning to be decomposed.

Colour explained.

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.

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* The same experiments succeed with Canton's pyrophorus, as Dr Hulme has shown.

Light produces changes on 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 de-

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* The following very curious observation by Professor Robinson deserves particular attention: " Having occasion, in autumn 1774, to go down and inspect a drain in a coalwork, where an embankment had been made to keep off a lateral run of water, and crawling along, I laid my hand on a very luxuriant plant, having a copious, deep-indented, white foliage, quite unknown to me. I inquired of the colliers what it was? None of them could tell me. It being curious, I made a sod be carried up to the day-light, to learn of the workmen what sort of a plant it was. But nobody had ever seen any like it. A few days after, looking at the sod, as it lay at the mouth of the pit, I observed that the plant had languished and died for want of water, as I imagined. But looking at it more attentively, I observed that a new vegetation was beginning with little sproutings from the same stem, and that this new growth was of a green colour. This instantly brought to my recollection the curious observations of Mr Dufay; and I caused the sod to be set in the ground and carefully watered. I was the more incited to this, because I thought that my fingers had contracted a sensible aromatic smell, by handling the plant at this time. After about a week, this root set out several stems and leaves of common tansy. The workmen now recollected that the sods had been taken from an old cottage garden hard by, where a great deal of tansy was still growing among the grass. I now sent down for more of the same stuff, and several sods were brought up, having the same luxuriant white foliage. This, when bruised between the fingers, gave no aromatic smell whatever. All these plants withered and died down, though carefully watered, and, in each, there sprouted from the same stocks fresh stems, and a copious foliage, and produced, among others, common tansy, fully impregnated with the or-

pend incontestibly upon the agency of light. Another very remarkable instance of the agency of light is the reduction of the metallic oxides. The red oxide of mercury and of lead become much lighter when exposed to the sun; and the white salts of silver, in the same situation, soon become black, and the oxide 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 reduced the oxide of silver sooner than any of the other rays *; and Sennebier 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 ‡.

Contains deoxidizing rays, not colorific.

It was supposed till lately, that those reductions of metallic oxides were produced by the colorific rays of light; but Messrs Wollaston, Ritter, and Bockmann, have lately ascertained, that muriate of silver is black-

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dinary juices of that plant, and of a full green colour. I have repeated the same experiments with great care on lovage (*levisticum vulgare*), mint, and caraways. As these plants throve very well below, in the dark, but with a blanched foliage, which did not spread upwards, but lay flat on the ground; in all of them there was no resemblance of shape to the ordinary foliage of the plant. All of them died down when brought into day-light; and the stocks then produced the proper plants in their usual dress, and having all their distinguishing smells."—Dr Black's *Lectures*, i. 532.

* On *Fire*, p. 78. and 98.

† *Mem. Phisico-chim.* ii. 72.

‡ *Jour. de Phys.* xxix. 81. When muriate of silver is exposed to the solar light, it blackens almost instantaneously. In that case it is not oxygen gas which is emitted, but muriatic acid, as has been observed also by Berthollet. See *Jour. de Phys.* lvi. 80.

ened most rapidly when it is placed beyond the violet ray, and entirely out of the prismatic spectrum. Hence it follows, that the change is produced, not merely by the colorific rays, but by rays which are incapable of rendering objects visible; neither do they produce any sensible heat. We see that they are more refrangible than the colorific rays, as they extend beyond the violet end of the spectrum. From these remarkable experiments it follows, that the solar light is composed of at least two sets of rays; one set which renders bodies visible, and another set which blackens muriate of silver, and reduces metallic oxides. It is by no means unlikely, that all the other chemical changes produced on bodies by solar light, is owing to the second set of rays, which hitherto have obtained no name. As the effect of the different prismatic colours on metallic oxides increases with their refrangibility, and as the effect is greatest at a certain distance beyond the violet ray, we can scarcely hesitate to admit, that the colorific rays have no influence whatever in the phenomena; but that it is owing to the other or *deoxidizing* rays, which of course are mixed with the colorific, and increase in quantity with the refrangibility. We shall find afterwards that solar light, besides these two sets, contains also a third species of ray, different from both in its nature and effects.

16. Such are the properties of light as far as they have been examined. They are sufficient to induce us to believe 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. But it is distinguished from all the substances hitherto described, by possessing three peculiar proper-

Light possesses three peculiar properties.

ties, 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; 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.

17. 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.

18. Light is emitted in every case of *combustion*. Now combustion, as far at least as regards simple combustibles and metals, is 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 combustible or with the oxygen. But this subject will be resumed in the next Chapter, where the nature of combustion will be particularly considered.

3. Heat.

19. 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

Book I. Division II.

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. 9.), bent so in the middle that it could be sunk, and make several turns in the large crucible C, which was filled

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[*] Dr Irvine has shown that this point is rather too low. For mercury, which he found to boil at 572°, does not become the least luminous at that temperature. Irvine's *Essays*, p. 32.

[†] T. Wedgewood, *Phil. Trans.* 1792.

[‡] Id. Ibid.

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.

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 doubted; but to suppose them combined with oxygen is contrary to all experience; for these stones never show 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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* Lamanon, *Jour. de Phys.* 1785.

† *Ann. de Chim.* xvi. 206.

CHAP. II.

OF CALORIC.

Definition.

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 six Sections: The first

Book I. Division II.

will be occupied with the nature of caloric; in the second, I will consider its propagation through bodies; in the third, its distribution; in the fourth, the effects which it produces on bodies; in the fifth, the quantity of it which exists in bodies; and in the sixth, the different sources from which it is obtained.

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 Herschel, has at last nearly put an end to the dispute, by demonstrating, that caloric is not a property, but a peculiar substance; or at least that we have the same reason for considering it to be a substance, as we have for the believing light to be material.

Discovery of rays of caloric.

1. Dr Herschel had been employed in making observations on the sun by means of telescopes. To prevent the inconvenience arising from the heat, he used coloured 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 Herschel 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 Herschel 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.

These important experiments have been lately repeated and fully confirmed by Sir Henry Englefield*, in the presence of some very good judges. The apparatus was very different from that of Dr Herschel, and contrived on purpose to obviate certain objections which had been made to the conclusion drawn by that illustrious philosopher. The bulbs of the thermometers used were mostly blackened. The following TABLE exhibits the result obtained in one of these experiments.

Thermometer in the blue ray rose in	3′ from	55° to	56
green	3	54	58
yellow	3	56	62
full red	2½	56	72
confines of red	2½	58	73½
beyond the visible light	2½	61	79

The thermometer, with its bulb blackened, rose much more when placed in the same circumstances, than the thermometer whose bulb was either naked or whitened with paint. This will be apparent from the following TABLE:

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* *Journal of the Royal Institution*, i. 202.

		Time.	From	To
Red ray	Black therm.	3′	58°	61°
	White therm.		55	58
Dark	Black therm.	3	59	64
	White therm.		58	58½
Confines of red	Black therm.	3	59	71
	White therm.		57½	60½

Both Dr Herschel and Sir Henry Englefield take notice of a faint blush of red, of a semioval form, visible when the rays beyond the red end of the spectrum were collected by a lense.

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 Herschel 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 Dr Hooke[*], and afterwards 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 shows 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

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[*] Birche's *History of the Royal Society*, iv. 137.

[†] *On Fire*, p. 70. Eng. Edit.

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. Thus it appears that solar light is composed of three sets of rays, the colorific, the calorific, and the deoxidizing.

Refracted.

2. The rays of caloric are refracted by transparent bodies just as the rays of light. We see, too, that, like the 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 different 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 Herschel 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 fires, 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 Herschel; but it had been demonstrated long ago by Scheele, who had even before 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,

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* A similar set of experiments had been made by Mr King as early as 1785: See his *Morsels of Criticism*, vol. 1st.

Book I.
Division II.

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 to 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 3·50. 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. All the phenomena concur to show that the rays of caloric move with a very considerable velocity; though the rate has not been ascertained in a satisfactory manner. The experiments of Mr Leslie would lead us to conclude that they move with the same velocity as sound. But they will come under our consideration in a subsequent Section. The following experiment of Mr Pictet indicates a very considerable velocity. 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 †.

Size.

5. As caloric radiates from luminous bodies like light,

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* Pictet, *sur le Feu*, chap. iii.

† See a dissertation on this subject in *Phil. Mag.* xix. 309.

and without any sensible diminution of their weight, it is reasonable to conclude that 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 Herschel's experiments, were it possible to prove by experiment that caloric affects the weight of bodies, the theory founded on Dr Herschel's discoveries would be overturned: But such deductions have been drawn from the experiments of De Luc*, Fordyce †, Morveau ‡, and Chausier §. 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:

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 $\frac{1}{16}$th of a grain heavier than it had been when fluid. A thermometer applied to the globe stood at 10°. When allow-

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* *Sur les Modif. de l'Atmosph.*

† *Phil. Trans.* 1785, part ii.

‡ *Jour. de Phys.* 1785, Oct.

§ *Jour. de Scavans*, 1785, p. 493.

ed to remain till the thermometer rose to 32°, it weighed $\frac{2}{10}$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 1797, 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 agrees with light 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 a very great velocity;

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* *Phil. Trans.* 1799, p. 179.

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.

Upon the whole, we are authorised by the above statement of facts, to conclude that the solar light is composed of three distinct substances, in some measure separable by the prism on account of the difference of their refrangibility. The *calorific* rays are the least refrangible, the *deoxidizing* rays are most refrangible, and the *colorific* rays possess a mean degree of refrangibility. Hence the rays in the middle of the spectrum have the greatest illuminating power, those beyond the red end the greatest heating power, and those beyond the violet end the greatest deoxidizing power; and the heating power on the one hand, and the deoxidizing power on the other, gradually increase as we approach that end of the spectrum where the maximum of each is concentrated. These different bodies resemble each other in so many particulars, that the same reasoning respecting refrangibility, reflexibility, &c. may be applied to all; but they produce different effects upon those bodies on which they act. Little progress has yet been made in the investigation of these effects; but we may look forward to this subject as likely to correct many vague and unmeaning opinions which are at present in vogue among chemists.

SECT. II.

OF THE MOTION OF CALORIC.

FROM the preceding account of the nature of caloric, we learn that it is capable, like light, of radiating in all directions from the surfaces of bodies; and that when thus radiated, it moves with a very considerable velocity. Like light, too, it is liable to be absorbed when it impinges against the surfaces of bodies. When it has thus entered, it is capable of making its way through all bodies; but its motion in this case is comparatively slow. Heat then moves at two very different rates. 1. It escapes from the surfaces of bodies. 2. It is *conducted*, or passes through bodies. It will be proper to consider each of these separately.

I. ESCAPE OF HEAT FROM SURFACES.

WHEN bodies artificially heated are exposed to the open air, they immediately begin to emit heat, and continue to do so till they become nearly of the temperature of the surrounding atmosphere. That different substances when placed in this situation cool down with very different degrees of rapidity, could not have escaped the most careless observer; but the influence of the surface of the hot body in accelerating or retarding the cooling process, was not suspected till lately. For this curious and important part of the doctrine of heat, we are indebted to the sagacity of Mr Leslie, who has already brought it to a great degree of perfection. His

Inquiry into the Nature of Heat, published in 1804, contains a great number of original experiments and views on this subject. It is remarkable, that a few weeks after the publication of this work, a dissertation by Count Rumford on the same subject, and containing similar experiments, appeared in the Philosophical Transactions. This dissertation displays, in a remarkable degree, that ingenuity and happy talent of illustration for which the Count is so remarkable. But as Mr Leslie informs us that his leading experiments had been made in 1801, and as his work appeared first, he is certainly entitled to the merit of priority and originality.

Effect of the surface in cooling.

1. Mr Leslie filled with hot water a thin globe of bright tin, four inches in diameter, having a narrow neck, and placed it on a slender frame in a warm room without a fire. The thermometer inserted in this globe sunk half way from the original temperature of the water to that of the room in 156 minutes. The same experiment was repeated, but the outside of the globe was now covered with a thin coat of lamp black. The time elapsed in cooling to the same temperature as in the last case was now only 81 minutes *. Here the rate of cooling was nearly doubled; yet the only difference was the thin covering of lamp black. Nothing can afford a more striking proof than this of the effect of the surface of the hot body on the rate of its cooling.

Count Rumford took two thin cylindrical brass vessels of the same size and shape, filled them both with

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* Leslie's *Inquiry into the Nature of Heat*, p. 268.

hot water of the same temperature, and clothed the one with a covering of Irish linen, but left the other naked. The naked vessel cooled ten degrees in 55 minutes, but the one covered with linen cooled ten degrees in $36\frac{1}{2}$ minutes *. In this experiment, the linen produced a similar effect with the lamp black in the preceding. Instead of retarding the escape of heat, as might have been expected, they produced the contrary effect. The same acceleration took place when the cylinder was coated with a thin covering of glue, of black or white paint, or when it was smoked with a candle.

Greatest in still air.

2. The variation in the rate of cooling occasioned by coating the hot vessel with different substances is greatest when the air of the room in which the experiments are made is perfectly still. The difference diminishes when the atmosphere is agitated, and in very strong winds it disappears almost entirely. Thus two globes of tin, one bright, the other covered with lamp black, being filled with hot water, and exposed to winds of various degrees of violence, were found by Mr Leslie to lose half their heat in the following times †:

	Clean Globe.	Blackened Globe.
In a gentle gale............	44′	35′
In a pretty strong breeze	23′	$20\frac{1}{4}$′
In a vehement wind......	9·5′	9′

This is sufficient to convince us, that the effect of the lamp black in accelerating cooling cannot be owing to any power which it has of *conducting* heat, and com-

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* Nicholson's *Jour.* ix. 60.

† *Inquiry into the Nature of Heat*, p. 271.

municating it to the air, but to the property which it has of radiating heat (to use the common expression) in a greater degree than clear metallic bodies. That this is in reality the case is easily shown.

3. When a canister of tin, of a cubic shape and considerable size, is placed at the distance of a foot or two from a concave mirror of bright polished tin, having a delicate thermometer in the focus, the thermometer experiences a certain elevation. If the canister be coated with lamp black, the thermometer rises much higher than when the metal is left bright. Here we perceive that more heat radiates from the lamp black than the clear metal; since the elevation of the thermometer is in some degree the measure of the radiation. A common thermometer does not answer well in similar experiments, because it is affected by every change of temperature in the room in which the experiments are made. But Mr Leslie has invented another, to which we are indebted for all the precision that has been introduced into the subject. He has distinguished it by the name of the *differential thermometer*. It was employed also by Count Rumford in his researches.

Differential thermometer.

This thermometer consists of a small glass tube bent into the shape of the letter U, and terminating at each extremity in a small hollow ball, nearly of the same size; the tube contains a little sulphuric acid tinged red with carmine, and sufficient to fill the greatest part of it. The glass balls are full of air, and both communicate with the intermediate tube. To one of the legs of the tube is affixed a small ivory scale divided into 100 degrees; and the sulphuric acid is so disposed, that in the graduated leg its upper surface stands opposite to the part of the scale marked 0. The glass ball attached to the leg of the instrument to which the scale is attached, is, by way of distinction, called the *focal ball*. Suppose this thermometer brought into a warm room, the heat will act equally upon both balls, and expanding the included air equally in each, the liquor in the tube will remain stationary. But suppose the focal ball exposed to heat while the other ball is not, in that case the air included in the focal ball will expand, while that in the other is not affected. It will therefore press more upon the liquid in the tube, which will of course advance towards the cold ball, and therefore the liquid will rise in the tube above 0, and the rise will be proportional to the degree of heat applied to the focal ball. This thermometer, therefore, is peculiarly adapted for ascertaining the degree of heat accumulated in a particular point, while the surrounding atmosphere is but little affected, as happens in the focus of a reflecting mirror. No change in the temperature of the room in which the instrument is kept is indicated by it, while the slightest alteration in the spot where the focal ball is placed is immediately announced by it.

In making experiments on the radiation of heat, Mr Leslie employed hollow tin cubes, varying in size from three inches to ten, filled with hot water, and placed before a tin reflector, having the differential thermometer in the focus. The reflector employed was of the parabolic figure, and about 14 inches in diameter. This apparatus afforded the means of ascertaining the effect of different surfaces in radiating heat. It was only necessary to coat the surface of the canister with the various substances whose radiating properties were to be tried, and expose it, thus coated and filled with hot water, before the reflector. The heat radiated in each case would be collected into the focus where the focal ball of the differential thermometer was placed, and the rise of this instrument would indicate the proportional radiation of each surface. These experiments were conducted with much address. The following are the principal results obtained.

Radiation as the difference between the temperature of the hot body and the air.

4. When the nature and position of the canister is the same, the rise of the differential thermometer is always proportional to the difference between the temperature of the hot canister and that of the air in the room in which the experiment is made *.

Effect on the thermometer inversely as the distance from the reflector.

5. When the temperature of the canister is the same, the effect upon the differential thermometer diminishes as the distance of the canister increases from the reflector, the focal ball being always understood to be placed in the focus of the mirror. Thus if the rise of the thermometer, when the canister was three feet from the mirror, be denoted by 100, it will amount only to 57 when the canister is removed to six feet. On substituting a glass mirror for the reflector, and a charcoal fire for the canister, when the fire was at the distance of 10 feet the thermometer rose 37°, and at the distance of 30 feet it rose 21 †. From Mr Leslie's experiments it follows, that the effect on the thermometer is very nearly inversely proportional to the distance of the canister from the reflector. He found likewise that when canisters of different sizes were used, heated to the same point, and placed at such distances that they all subtended the same angle at the reflector; in that case the effect of each upon the differential thermometer was nearly the same. Thus a canister of

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* Leslie, p. 14.

† Ibid. p. 51.

3 inches at	3 feet distance raised the thermometer	50°
4 inches -	4 feet	54
6 inches -	6 feet	57
10 inches	10 feet	59

From these experiments we learn, that the effect of the canister upon the thermometer is nearly proportional to the angle which it subtends, and likewise that the heat radiated from the canister suffers no sensible diminution during its passage through the air.

Proportional to the sine of the inclination of the hot surface to the reflector.

6. Heat radiates from the surface of hot bodies in all directions; but from Mr Leslie's experiments we learn, that the radiation is most copious in the direction perpendicular to the surface of the hot body. When the canister is placed in an oblique position to the reflector, the effect diminishes, and the diminution increases with the obliquity of the canister. Mr Leslie has shown, that the effect in all positions is proportional to the visual magnitude of the canister as seen from the reflector, or to its orthographic projection. Hence the action of the heated surface is proportional to the sine of its inclination to the reflector.

Such are the effects of the temperature, the distance, and position of the canister with respect to the reflector. None of these, except the first, occasion any variation in the quantity of heat radiated, but merely in that portion of it which is collected by the mirror and sent to the focal ball; but the case is different when the surface of the canister itself is altered.

Radiating power of different bodies.

7. Mr Leslie ascertained the power of different substances to radiate, by applying them in succession to a side of the canister, and observing what effect was produced upon the differential thermometer. The following Table exhibits the relative power of the different

Book I.
Division II.

substances tried by that philosopher, expressed by the elevation of the differential thermometer produced.

Lamp black	100
Water by estimate	100+
Writing paper	98
Rosin	96
Sealing wax	95
Crown glass	90
China ink	88
Ice	85
Minium	80
Isinglass	80
Plumbago	75
Tarnished lead	45
Mercury	20+
Clean lead	19
Iron polished	15
Tin plate	12
Gold, silver, copper	12

From this Table it appears, that the metals radiate much worse than other substances, and that tin plate is one of the feeblest of the metallic bodies tried. Lamp black radiates more than eight times as much as this last metal, and crown glass 7·5 times as much. The experiments of Count Rumford do not coincide exactly with those of Mr Leslie respecting the radiating power of the metals. The Count found all that he tried equal in this respect; while the preceding table indicates a considerable difference in power. But the method adopted by the Count was not susceptible of the same precision with that of Mr Leslie; the latter therefore has a much greater chance of being correct.

8. Such are the radiating powers of different substances. But even when the substance continues the same, the radiation is very considerably modified by apparently trifling alterations on its surface. Thus metals radiate more imperfectly than other bodies; but this imperfection depends upon the brightness and smoothness of their surface. When, by exposure to the air, the metal acquires that tarnish which is usually ascribed at present to oxidizement, the power of radiating heat is greatly increased. Thus it appears from the preceding table, that the radiating power of lead while bright is only 19; but when its surface becomes tarnished, its radiating power becomes no less than 45. The same change happens to tin, and to all the metals tried.

Increased by tarnishing,

When the smoothness of the surface is destroyed by scratching the metal, its radiating power is increased. Thus if the effect of a bright side of the canister be 12, it will be raised 22 by rubbing the side in one direction with a bit of fine sand paper *. But when the surface is rubbed across with sand paper, so as to form a new set of furrows intersecting the former ones, the radiating power is again somewhat diminished.

And scratching the surface of metals.

9. The radiating power of the different substances examined, was ascertained by applying a thin covering of each to one of the sides of the canister. Now this coat may vary in thickness in any given degree. It becomes a question of some importance to ascertain, whether the radiating power is influenced by the thickness to a given extent, or whether it continues the same

Increases or diminishes as the thickness of the coat increases.

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* Leslie, p. 81.

Book I. Division II.

whatever be the thickness of the covering coat. This question Mr Leslie has likewise resolved. On a bright side of a canister he spread a thin coat of liquified jelly, and four times the quantity upon another side; both dried into very thin films. The effect of the thinnest film was 38, that of the other 54. In this case the effect increased with the thickness of the coat. The augmentation goes on till the thickness of the coat of jelly amounts to about $\frac{1}{1000}$th of an inch; after which it remains stationary. When a surface of the canister was rubbed with olive oil, the effect was 51: a thicker coat of oil produced an effect of 59. Thus it appears that when a metallic surface is covered with a coat of jelly or oil, the effect is proportional to the thickness of the coat, till this thickness amounts to a certain quantity; but when a vitreous surface is covered by very thin coats of metal, no such change is perceived. A canister was employed, one of the sides of which was a glass plate. Upon this plate were applied, in succession, very fine coats of gold, silver, and copper leaf. But notwithstanding their thinness, the effect was only 12, or the same that would have been produced by a thick coat of these very metals. But when glass enamelled with gold is used, the effect is somewhat increased; a proof that varying the thickness of the metallic coats, would have the same effect as varying the thickness of jelly, provided they could be procured of sufficient tenuity*. As long as an increase of thickness alters the radiating power of the coat, it is obvious that the surface of the canister below exerts

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* Leslie, p. 110.

a certain degree of energy. And the action exerted by metallic bodies appears to be greater than that exerted by vitreous bodies.

10. Such are all the circumstances connected with the radiating surface hitherto observed, which influence its power. For hitherto it has been impossible to ascertain the efficacy of *hardness* and *softness*, or of *colour*, upon radiation; though it appears, from Mr Leslie's experiments, not unlikely that softness has a tendency to promote radiation [*]. But as the effect, as far at least as measured by the differential thermometer, depends not only upon the radiating surface, but likewise upon the surface of the focal ball, and likewise of the reflector; it will be necessary also to consider the modifications produced by alterations in the surface of these bodies. This inquiry, for which, like the preceding, we are indebted to Mr Leslie, will throw considerable light on the nature of radiation.

Surfaces rad absorb heat in the same proportion.

11. When the focal ball is in its natural state, that is to say, when its surface is vitreous, it has been already observed, that the side of the hot canister coated with lamp black raises the thermometer 100°. If the experiment be repeated, covering the focal ball with a smooth surface of tinfoil, instead of rising to 100°, the thermometer will only indicate 20°. A bright side of the canister will raise the thermometer, when the focal ball is naked, 12°; but when the ball is covered with tinfoil, the elevation will not exceed $2\frac{1}{2}$ degrees [†]. From these experiments it is obvious, that metal not only radiates heat worse than glass, but like-

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[*] Leslie, p. 90.

[†] Ibid. p. 19.

wise that it is not nearly so capable of imbibing it when the rays strike against its surface. If the surface of the tinfoil be furrowed by rubbing it with sand paper, the effect produced when the focal ball is exposed in the focus will be considerably increased*. It has been already observed that the radiating power of tin is likewise increased by scratching it. These facts entitle us to conclude, that those surfaces which radiate heat most powerfully, likewise absorb it most abundantly when it impinges against them.

Reflection inversely as radiation.

12. The very contrary holds with respect to the reflectors, as might indeed have been expected. Those surfaces which *radiate* heat best, *reflect* it worst; while the weakest *radiating* surfaces are the most *powerful* reflectors. Metals of course are much better reflectors than glass. When a glass mirror was used instead of the tin reflector, the differential thermometer rose only one degree; upon coating the surface of the mirror with lamp black, all effect was destroyed; when covered with a sheet of tinfoil the effect was 10° †.

Reflecting power of various bodies.

To compare the relative intensity of different substances as reflectors, Mr Leslie placed thin smooth plates of the substances to be tried before the principal reflector, and nearer than the proper focus. A new reflection was produced, and the rays were collected in a focus as much nearer the reflector than the plate as the old focus was farther distant. The comparative power of the different substances tried was as follows ‡.

Brass	100
Silver	90

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* Leslie, p. 81.

† Ibid. p. 20.

‡ Ibid. p. 98.

Tinfoil	85
Block-tin	80
Steel	70
Lead	60
Tinfoil softened by mercury	10
Glass	10
Do. coated with wax or oil	5

When the polish of the reflector is destroyed by rubbing it with sand paper, the effect is very much diminished. When the reflector is coated over with a solution of jelly, the effect is diminished in proportion as the thickness of the coat increases, till its diameter amounts to $\frac{1}{1000}$th part of an inch. The following Table exhibits the intensity of the reflector coated with jelly of various degrees of thickness *.

Thickness of coat.	Effect.
Naked reflector	127
$\frac{1}{400000}$	98
$\frac{1}{100000}$	93
$\frac{1}{50000}$	87
$\frac{1}{20000}$	61
$\frac{1}{10000}$	39
$\frac{1}{5000}$	29
$\frac{1}{2000}$	21
$\frac{1}{1000}$	15

All these phenomena are precisely what might have been expected, on the supposition that the intensity of reflection is inversely that of radiation. Mr Leslie has shown that it is the anterior surface of reflectors only

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* Leslie, p. 106.

that acts. For when a glass mirror is employed, its power is not altered by scraping off the tin from its back, nor by grinding the posterior surface with sand or emery *.

13. Such are the phenomena of the radiation of heat as far as the radiating surface, the reflector, and the focal ball are concerned. It cannot be doubted from them, that heat is actually radiated from different surfaces, and that bodies vary considerably in their radiating power. We have seen also that substances differ no less from each other in their power of reflecting heat, and that the intensity of the latter power is always the inverse of the intensity of the former. Before we can be able to form a judgment of the way in which the heat is conveyed in these cases, it will be necessary to examine the effect of the different mediums in which the radiation may take place, and the obstructions occasioned by putting different substances between the radiating surface and the reflector. Both of these points have been examined by Mr Leslie with his usual acuteness.

Radiation takes place only in elastic mediums.

14. In all common cases, the medium through which the heat is radiated is the air; and from Mr Leslie's experiments it appears, that no sensible radiation can be observed when the canister, reflector, and differential thermometer, are plunged into water. Hence he concludes, that no radiation takes place except when the radiating body is surrounded with an elastic medium. But the experiments which he adduces are scarcely sufficient to decide the point. Substances cool so fast

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* Leslie, p. 21.

when plunged into water, that there is scarcely time for the thermometer to be affected; and, besides, the heat could scarcely accumulate in the focal ball in such quantity as to occasion a sensible rise*.

Heat radiates through all the gaseous bodies tried; and from Mr Leslie's experiments, it does not appear that the rate of radiation is much influenced by altering the surrounding medium. The rate is the same, at least, in air and hydrogen gas; and oxygen and azotic gas appear to have the same properties in this respect as air. Mr Leslie has shown also that the rarefaction of the surrounding air diminishes somewhat the radiating energy of surfaces; but the radiation diminishes at different rates in different gases. The following Table, calculated from his trials, shows, according to him, the diminution of the power of radiation in air and hydrogen gas of different degrees of rarity.

Diminished by rarefaction.

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* We shall find, however, hereafter, that other experiments of Mr Leslie leave no doubt that heat does not radiate through solid bodies.

Rarity.	Air.		Hydrogen.	
	Radiation of Glass.	Metal.	Radiation of Glass.	Metal.
1	5714	714	5714	714
2	5519	690	5584	698
4	5332	667	5456	682
8	5150	644	5331	666
16	4975	622	5210	651
32	4805	601	5091	637
64	4641	580	4974	622
128	4483	560	4861	608
256	4331	542	4750	594
512	4183	523	4641	580
1024	4041	505	4538	567

Such is the effect of different mediums as far as they have been examined by Mr Leslie; but the experiments on which his conclusions were founded would require to be repeated.

Interceptive power of a screen.

15. When a substance is interposed by way of screen between the hot canister and the reflector, the effect is either diminished or destroyed altogether, according to circumstances. These circumstances have been examined by Mr Leslie with great sagacity. Indeed, the developement of the effect of screens constitutes perhaps the most curious and important part of his

whole work. A screen may affect the radiation of heat three ways: 1. By its distance from the hot canister; 2. By its thickness; and, 3. By the nature of the substance of which it is composed. Let us take a view of each of these in succession.

Increases with its distance from the hot body,

First, From all Mr Leslie's trials, it appears that a screen diminishes the effect of radiation upon the differential thermometer situated in the focus of the reflector, in proportion to its distance from the canister. When placed very near the canister, the effect is comparatively small; but it increases rapidly as the screen is drawn away from the canister; so that the elevation of the differential thermometer is soon prevented altogether. When the canister is at the distance of three feet from the reflector, if the side painted with lamp black produce an effect equivalent to 100, this effect upon interposing a pane of glass at the distance of two inches from the canister will be diminished to 20. When the pane is advanced slowly forward towards the reflector, the effect of the radiation gradually diminishes; and when it has got to the distance of one foot from the screen, the radiation is completely intercepted *.

And with its thickness.

Second, When a screen of thin deal board is used instead of the pane of glass, and placed at the distance of two inches from the canister, the radiation is diminished, and the diminution is proportional to the thickness of the board.

With a board $\frac{1}{8}$ inch thick the effect is 20
.... $\frac{3}{8}$ inch 15
.... 1 inch 9

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* Leslie, p. 28.

Radiated heat intercepted by all solids.

Thus the radiation diminishes very slowly as the thickness increases *.

Third, When a sheet of tinfoil is substituted for the glass pane, and put into the same position, the effect, instead of 20, is reduced to 0; and this happens however thin the tinfoil is; even gold leaf of the thickness of $\frac{1}{100000}$th part of an inch, though pervious to light, completely stops the progress of radiating heat. When a sheet of writing paper is substituted for tinfoil, the effect is 23 †. Thus it appears, that substances vary considerably from each other in their property of intercepting radiating heat; and likewise that the power of intercepting heat is inversely as the power of radiating it. Those substances which radiate most heat, intercept the least of it when in the situation of screens; and those which radiate the least heat, on the contrary, intercept the most. But it was formerly observed, that the power of absorbing heat was the same with that of radiating it. Hence those substances which absorb least heat are the most powerful interceptors of it, and the contrary.

These facts lead naturally to the opinion, that the property of absorbing heat depends upon the *surface* of the substance which is interposed as a screen; an opinion which Mr Leslie has established by the following experiments. He took two panes of glass, and coated one side of each with tinfoil, leaving the other side bare. These two panes were pressed together; the tinned side of each being outmost, and applied as a screen at two inches distance from the canister. The whole of the rays of heat appeared to be intercepted,

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* Leslie, p. 38.

† Ibid.

for the thermometer was not acted upon at all. But when the glass side of the screen was outmost, the effect of radiation was equivalent to 18. Here we find the very same screen, in the very same position, intercepting very different proportions of the radiated heat, according to the nature of its external surface. When the tin was outmost, the whole heat was stopped; but when the glass was outmost, about $\frac{1}{5}$th passed on to the reflector. The effect was analogous when two sheets of tin, each painted on one side with a thin coat of lamp black, were employed as a screen, and placed two inches from the canister. Pressed together, and having their metal sides outmost, the radiation produced no effect upon the thermometer; but when the blackened sides were outmost, the effect was equivalent to 23. When only one of the plates is used, and its blackened side turned to the canister, the effect is equal to 4. If the two plates be used with their blackened sides outmost, and at the distance of two inches from each other, all effect is destroyed *.

Radiation of caloric not similar to that of light.

16. Such are the phenomena of the radiation of heat as far as they have been ascertained. Let us see how far they will enable us to ascertain its nature. The only other radiation with which we are familiarly acquainted is that of light. This seems to have induced philosophers to consider them both as similar, without any minute examination; but the facts ascertained by Mr Leslie, supposing them correct, demonstrate that there is no such similarity between them as has been supposed. Light passes through diaphanous bodies, as glass, with only a small diminution of its intensity;

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* Leslie, p. 35.

and the effect is the same in whatever part of the course the glass pane is placed. But with radiating heat the case is very different; when the pane is placed very near the canister, a portion of the effect still takes place; but as the pane is removed towards the reflector, the intensity gradually diminishes, and at last disappears. Neither does the intensity of surfaces radiating heat vary at the same rate as that of luminous bodies; the first being very nearly inversely as the distance, the second inversely as the square of the distance. These, and several other particulars pointed out in the preceding pages, indicate a decided difference between the radiation of heat and of light.

Mr Leslie's experiments on the effect of screens leave no doubt that every solid body interposed between the canister and the reflector, however diaphanous or thin, completely intercepts all the rays of heat. For when such bodies are interposed, the remaining intensity is always proportional to the disposition of the screen to receive and radiate heat; and the effect constantly diminishes as the screen is removed to a greater distance from the canister: that is to say, that the screen imbibes a certain portion of heat from the canister, and radiates again the excess which it has thus acquired. Thus a screen is precisely the same as another canister heated to a smaller temperature. The rays of heat then cannot pass through solid bodies, however thin and transparent, in the state of rays. They enter the screen, are retained by it, and only a small portion sent off from the other surface, in proportion as its heat is greater than that of the air. In this respect the radiation of heat differs materially from that of light. Hence the reason why radiation takes place only when the hot body is surrounded with an elastic medium.

But provided the medium be elastic, it does not appear that its chemical nature occasions any difference; at least in the few trials made by Mr Leslie, the radiation in air was nearly the same as in other gases. But when the medium is artificially rarefied, the effect is diminished.

It does not appear that the rays of heat suffer a diminution during their passage through air, how great soever the distance be through which they pass; for the effect on the thermometer is proportional to the visual magnitude of the canister. In this respect they resemble the rays of light, and seem to differ in several circumstances from the aerial pulses which constitute sound.

Thus it appears, that rays of heat are sent off in different quantities from different surfaces; that they can pass only through aerial bodies, being intercepted by all solids; that their intensity diminishes inversely as their distance; and that no part of them is lost during their journey. So far seems to be sufficiently established; but beyond it every thing is still hypothetical. Mr Leslie supposes that the heat is conveyed from one surface to another by means of the air, and that the supposed radiation is nothing else than a series of aerial undulations. The radiation of heat, according to this hypothesis, is analogous to the propagation of sound. A hot body, according to him, communicates a certain portion of heat to the stratum of air immediately in its neighbourhood; the stratum immediately expands, and the vibration into which it is thrown occasions a similar vibration in the next stratum, which is propagated in

Ascribed to aerial undulations.

the usual manner, and with the velocity of sound. The portion of heat which produced the first vibration, passes from the first stratum of air to the second, and from the second to the third, with the same rapidity as the undulations themselves. The amount of the effect will depend upon the portion of heat communicated at each successive moment to the stratum of air in the neighbourhood of the hot body; and this will depend upon the nearness of the air to that substance. Those bodies to which air approaches the closest will therefore radiate heat more powerfully than those to which it cannot approach so near. Hence glass, and those other bodies which radiate best, have the greatest affinity for air; and metals, which radiate worst, have the least affinity for air. Hence, also, those bodies which radiate heat best, must absorb it most readily; because the pulses of air loaded with heat will approach them more nearly. Scratching the surface of a metal increases its radiating power by allowing the particles of air to approach more nearly in consequence of the prominences produced; and the same reason accounts for the increasing effect produced by repeated coats of jelly applied to metallic surfaces.

Such is an imperfect sketch of Mr Leslie's ingenious hypothesis. For a fuller detail it will be necessary to consult his work. Several objections naturally present themselves to this view of the subject; but as the author has not hitherto advanced any proof in confirmation of his peculiar opinions, except their conveniience in accounting for the phenomena, it is not necessary to enter upon a particular examination of them. They cannot be admitted without direct proof; especially as they do not appear consistent with the experiments of

Herschel, Wollaston, Ritter, and Bockmann. Count Rumford has advanced an hypothesis not very dissimilar, but has not succeeded so well in giving it an imposing aspect.

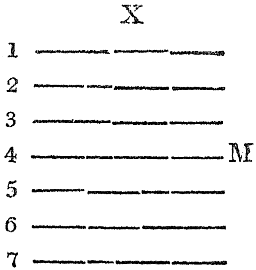
II. PASSAGE OF CALORIC THROUGH BODIES.

1. CALORIC, we have seen, is incapable of moving in rays through solid bodies. Yet it is well known that all bodies whatever are pervious to it. Through solids, then, it must pass in a different manner. In general its passage through them is remarkably slow. Thus if we put the end of a bar of iron, twenty inches long, 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°. In this case, the caloric takes four minutes to pass through a bar of iron 20 inches. When caloric passes in this slow manner, it is said to be *conducted* through bodies. It is in this manner alone that it passes through non-elastic bodies; and though it often moves by radiation through elastic media, yet we shall find afterwards that it is capable of being conducted through them likewise.

Conducting power explained.

2. As the velocity of caloric, when it is *conducted* through bodies, is greatly 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:

Book I.
Division II.



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 doze 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 another 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 doze of caloric, and forms compound B.

Chap. II.

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 a new 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.

3. 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.

4. 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. Hence the measure of the heat transmitted must always be proportional to the excess of temperature communicated to that side of the conductor which is nearest the source of heat.

Has a limit.

5. 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.

6. As to the rate at which bodies conduct caloric, that depends upon the specific nature of each particular body; the best conductors conducting most rapidly, and to the greatest distance. The goodness of bodies as conductors appear to be in some measure dependent upon their density; but not altogether, as the specific affinity of each for caloric must have considerable influence. When bodies are arranged into sets, we may lay it down as a general rule that the densest set conduct at the greatest rate. Thus the metals conduct at a greater rate than any other bodies. But in considering the individuals of a set, it is not always the densest that conducts best.

7. 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.

8. 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 218°, 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.

9. 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 make 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

Book I. Division II.

transporting caloric; in consequence of which they acquire heat independent altogether of any conducting power.

10. 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

Chap. II.

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, potash 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 grains, had 192 grains 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 grains 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. ll 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 comon 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 source 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 $\frac{1}{4}$th 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 accounting 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 about 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*

Book I.
Division II.

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 four and at seven 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 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 the conical projection of the ice, was distant from it only $\frac{2}{10}$ths of an inch. The end of the sheath descended $\frac{1}{10}$th 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 was filled about half way;

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* Rumford, Essay vii. Part ii. chap. i.

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 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 *.

These experiments have been since confirmed by a very ingeniously contrived and convincing experiment made by Mr Murray. To prevent the possibility of any heat being conducted by the vessel, he employed a vessel of ice, which is incapable of conducting any degree of heat greater than 32°. In this vessel he made experiments of the same nature with those that I have just mentioned, and the result was the same. The thermometer constantly rose upon the application of a hot body to the surface of the liquid in which the thermometer was standing †. Mr Dalton has likewise published lately a set of experiments almost exactly of the

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* Nicholson's *Journal*, iv. 529.

† Ibid. 8vo. 1.

same nature with mine, and with the same result. From the date affixed to his paper we learn, that his experiments had been made, and an account of them read to the Manchester Society just about the same time that I was drawing up an account of mine; though they were not published till about two years after*.

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.

11. 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 subject, however, is of the highest importance, and deserves a thorough investigation.

Of metals.

12. Metals are the best conductors of caloric of all the solids hitherto tried. 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

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* *Manchester Memoirs*, v.

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, } much inferior to the others.
Steel, }
Lead. }

Stones,

13. 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,

14. 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.

Woods.

15. Next to these come dried woods. Mr Meyer † has made a set of experiments on the conducting power of 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

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* *Jour. de Phys.* 1789, p. 68.

† *Ann. de Chim.* xxx. 32.

Bodies.	Conducting Power.
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, feathers, &c.

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 substances †. He ascertained that their conducting power is inversely as the fineness of their texture.

Relative conducting powers of liquids.

16. The conducting power of liquid bodies has not been examined with any degree of precision. I find

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* *Ann. de Chim.* xxvi, 225.

† *Phil. Trans.* 1792.

by experiment, that the relative conducting powers of mercury, water, and linseed oil, are as follow:

I. EQUAL BULKS.

Water .... = 1
Mercury .... = 2
Linseed oil ...... = 1·111

II. EQUAL WEIGHTS.

Water .... = 1
Mercury .... = 4·8
Linseed oil .... = 1·085

Of gases.

17. With respect to gaseous bodies, it is well known that bodies cool much more slowly in them than in liquids. But as the cooling of hot bodies in gases is produced by a variety of causes besides the conducting power of these fluids, it is difficult to form an estimate of their relative intensities as conductors from the time that elapses during the cooling of bodies in them. Count Rumford found that a thermometer cooled nearly four times as fast in water as in air of the same temperature; but no fair inference can be drawn from that experiment, as it is known that the rate of cooling varies with the temperature much more in water than in air*. The same philosopher ascertained, that rarefaction diminished the conducting power of air, and that hot bodies cool slowest of all in a Torricellian vacuum. Mr Leslie was enabled, by the delicacy of his instruments, to examine the conducting power of gases with

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* *Phil. Trans.* 1786.

more precision than had been previously done. The following are the facts which he ascertained.

The conducting power of all gases is diminished by rarefaction. He has endeavoured to deduce from his experiments, that the conducting power of air is nearly proportional to the fifth root of its density. But Mr Dalton has rendered it probable that it varies nearly as the cube root of its density.

Vapours of all kinds, and every thing that has a tendency to dilate air, diminish its conducting power.

The conducting powers of common air, oxygen, and azote, are nearly equal. The conducting power of carbonic acid gas is rather inferior to that of air; but bodies cool in hydrogen gas more than twice as fast as in common air. By analysing the process of cooling, and ascertaining that the radiation is the same in air and hydrogen gas, Mr Leslie has rendered it probable that the conducting power of this gas is four times as great as that of air *.

Mr Dalton has lately investigated the rate of cooling of hot bodies in different gases. He filled a strong phial with the gas to be examined; introduced into it a delicate thermometer through a perforated cork, and observed the time it took to cool 15° or 20°. The following Table exhibits the result of his trials †.

Gases.	Time of Cooling.
Carbonic acid, ...	112″
Sulphureted hydrogen,	...100+
Nitrous oxide,	
Olefiant gas,	

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* Leslie's *Inquiry into the Nature of Heat*, p. 473.

† Dalton's *New System of Chemical Philosophy*, p. 117.

Gases	Time of Cooling.
Common air,	100
Oxygen,	
Azotic gas,	
Nitrous gas	90
Gas from pit-coal	70
Hydrogen gas	40

SECT. III.

OF THE EQUAL DISTRIBUTION OF TEMPERATURE.

We have seen, in the preceding Section, that caloric is capable of moving through all bodies, though with different degrees of facility. The consequence of this property is a tendency which it has to distribute itself among all contiguous bodies in such a manner, that the thermometer indicates the same temperature in all.

Contiguous bodies assume the same temperature.

1. 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.

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.*

Law of the heating and cooling of bodies.

2. From the experiments of Kraft and Richmann *, made with much precision, and upon a great number of bodies, the following general conclusion has been drawn. " When a body is suspended in a medium of a temperature different from its own, the difference be-

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* *Nov. Comm. Petrop.* i. 195

Book I.
Division II.

tween the temperature of the body and the medium diminishes in a geometrical ratio, while the time increases in an arithmetical ratio." Or, "In given small times the heat lost is always proportional to the heat remaining in the body." This law had been first suggested by Sir Isaac Newton, who calculated by means of it several temperatures above the scale of thermometers †.

The caloric which leaves hot bodies till they are reduced to the temperature of the substances around them, is partly conducted away by the surrounding medium, partly abstracted by currents produced in that medium (supposing it fluid), and, in the atmosphere,

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† This proposition applies, perhaps, strictly only to bodies cooling in air. Let H be the temperature of a hot body above the atmosphere, and d its loss of heat in one minute. It follows from the law stated in the text, that at the end of m minutes, the temperature will be $H\left(\frac{H-d}{H}\right)^m$; and at the end of n minutes $H\left(\frac{H-d}{H}\right)^n$. Supposing these two temperatures found by experiment, and that the first is $= A$, and the second $= B$; from these two equations we obtain

$$1.\ H = \frac{A^{\frac{n}{n-m}}}{B^{\frac{m}{n-m}}}, \text{ or Log. } H = \frac{1}{n-m}\,(n \text{ Log. } A - m \text{ Log } B).$$

$$2.\ d = H\left(1 - \overline{\frac{B}{A}}\Big|^{\frac{1}{n-m}}\right)$$

$$3.\ r = \text{rate of cooling} = \left(\frac{B}{A}\right)^{\frac{1}{n-m}}$$

$$4.\ m = \frac{\text{Log. } A - \text{Log. } H.}{\text{Log. } \overline{H-d} - \text{Log. } H.}$$

See Nicholson's *Quarto Jour.* i. 187.

Cooling pends

partly radiates from the surface of the hot body. The process of cooling, both in air and in water, has been analysed with much address and success by Mr Leslie, though he has neglected to notice the labours of his predecessors in that investigation. The following facts have been ascertained.

The conducting power,

The effect of the conducting power depends upon the medium, and is therefore constant, supposing the temperatures and the medium constant; but it gradually diminishes as the temperature of the hot body approaches that of the medium.

The radiation,

The effect of radiation depends upon the surface of the hot body, and is therefore constant when the same surface is heated to the same degree: but, like the conducting power, it diminishes as the hot body approaches to the temperature of the medium. Radiation, being confined to cooling in elastic mediums, does not operate when the hot body is surrounded by liquids.

And currents.

That portion of the medium which is in contact with the hot body receiving a certain portion of its heat, acquires a different density, and in consequence gives place to a new portion, which, being heated in its turn, follows the preceding portion; and in this manner a current is produced, which very much accelerates the rate of cooling. It is obvious, that the velocity of this current will be the greater the higher the temperature of the hot body is. Hence the effect of these artificial currents will diminish as the temperature of the hot body approaches that of the medium.

If these currents be artificially increased, it is obvious that the rate of cooling will be proportionably accelerated. Hence the effect of winds in cooling hot bodies. From Mr Leslie's experiments it appears that, other things being the same, the rate of cooling is always proportional to the velocity of the current, or, which is the same thing, to the velocity with which the hot body moves through the cold medium. Thus a hot ball, that in calm air cooled down a certain number of degrees in 120′, when moved in the same air with different velocities, lost the same quantity of heat in times which diminished as the velocity increased, as will be obvious from the following Table:

Velocity.	Time of cooling.
$6\frac{2}{3}$ feet per second	60′
20	30
60	12

When the ordinary influence of cooling is deducted, the acceleration of cooling in these degrees is found to increase exactly as the velocity *.

Attempts to explain the equilibrium of heat.

4. As soon as it was discovered that contiguous bodies assume the same temperature, various attempts were made by philosophers to account for the fact. 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 too 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

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* *Leslie*, p. 281.

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 is equally inconsistent with the nature of caloric; which has been shown in the first Section of this Chapter, to be a body very different from the hypothetical fluid of De Mairan.

Hypothesis of Pictet.

5. 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 [*].

But this theory, notwithstanding its ingenuity, is inconsistent with the phenomena of the heating and cooling of bodies, and has accordingly been abandoned by the ingenious author himself.

Of Prevost.

6. The opinion at present most generally received, and which accounts for the phenomena in the most satisfactory manner, is that of Prevost, first published in the *Journal de Physique* for 1791, in an essay on *the equilibrium of caloric*; and afterwards detailed at greater length in his *Recherches sur la Chaleur* [†]. It was soon after adopted by Mr Pictet [‡], and has been lately applied by Prevost with much address to the experiments of Herschel and Pictet [§]. According to him, caloric is a *discrete* fluid, each particle of which moves with enormous velocity when in a state of liberty. Hot bodies emit calorific rays in all directions; but its particles are at such a distance from each other, that various currents may cross each other without disturbing one another, as is the case with light. The consequence of this must be, that if we suppose two neighbouring spaces in which caloric abounds, there must be a continual exchange of caloric between these two spaces. If it abounds equally in each, the interchanges will balance each other, and the temperature will continue the same. If one contains more than the other, the exchanges must be unequal; and by a continual repetition of

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[*] See Pictet, *sur le Feu*, chap. i.

[†] Geneva, 1792.

[‡] *Biblioth. Britan.* iv. 30.

[§] *Phil. Trans.* 1802, p. 408.

this inequality, the equilibrium of temperature must be restored between them.

If we suppose a body placed in a medium hotter than itself, and the temperature of that medium constant, we may consider the caloric of the medium as consisting of two parts; one equal to that of the body, the other equal to the difference between the temperature of the two. The first part may be left out of view, as its radiations will be counterbalanced by those of the body. The excess alone requires consideration; and relatively to that excess the body is absolutely cold, or contains no caloric whatever. If we suppose that in one second the body receives $\frac{1}{10}$th of this excess, at the end of the first second the excess will be only $\frac{9}{10}$ths. One tenth of this excess will pass into the body during the next second, and the excess will be reduced to $\frac{9}{10}$ of $\frac{9}{10}$, or $(\frac{9}{10})^2$. At the end of the third second, the excess will be $(\frac{9}{10})^3$; at the end of the fourth, $(\frac{9}{10})^4$; and so on: the time increasing in an arithmetical ratio, while the excess diminishes in a geometrical ratio, according to Richmann's rule.

Such is a sketch of Prevost's theory. It is founded altogether upon the radiation of caloric, and leaves the effect of the conducting power of bodies out of sight. The reality of the radiation cannot be doubted; and it is exceedingly probable that the equal distribution of temperature is the consequence of it. Were caloric merely conducted, its progress would be excessively slow, and indeed absolute equality of temperature would scarcely ever take place. At the same time, it must be allowed that this property of bodies has very considerable influence in regulating the time which elapses before the temperature of contiguous bodies is brought to equality; and in so far as Mr Prevost's hypothesis overlooks this circumstance, which obviously depends upon the affinity existing between caloric and other bodies, it must be considered as imperfect.

SECT. IV.

OF THE EFFECTS OF CALORIC.

Having in the preceding Sections considered the nature of caloric, the manner in which it moves through other bodies, and distributes itself among them; let us now examine, in the next place, the effects which it produces upon other bodies, either by entering into them or separating from them. The knowledge of these effects we shall find of the greatest importance, both on account of the immense additional power which it puts into our possession, and of the facility with which it enables us to comprehend and explain many of the most important phenomena of nature. The effects which caloric produces on bodies may be arranged under three heads, namely, 1. Changes in bulk; 2. Changes in state; and, 3. Changes in combination. Let us consider these three sets of changes in their order.

I. Of Changes in Bulk.

Expansion. It may be laid down as a general rule to which there is no known exception, that every addition or abstraction of caloric makes a corresponding change in the bulk of the body which has been subjected to this alteration in the quantity of its heat. In general, the addition of heat increases the bulk of a body, and the abstraction of it diminishes its bulk; but this is not uniformly the case, though the exceptions are not numerous. Indeed these exceptions are not only confined to a very small number of bodies, but even in them they do not hold, except at certain particular temperatures; while at all other temperatures these bodies are increased in bulk when heated, and diminished in bulk by being cooled. We may therefore consider *expansion* as one of the most general effects of heat. It is certainly one of the most important, as it has furnished us with the means of measuring all the others. Let us, in the first place, consider the phenomena of expansion, and then turn our attention to the exceptions which have been observed.

Differs in different bodies.

1. Though all bodies are expanded by heat and contracted by cold, and this expansion in the same body is always proportional to some function of the quantity of caloric added or abstracted; yet the absolute expansion or contraction has been found to differ exceedingly in different bodies. In general, the expansion of gaseous bodies is greatest of all; that of liquids is much smaller, and that of solids the smallest of all. Thus, 100 cubic inches of atmospheric air, by being heated from the temperature of 32° to that of 212°, are increased to 137·5 cubic inches; while the same augmentation of temperature only makes 100 cubic inches of water assume the bulk of 104·5 cubic inches: and 100 cubic inches of iron, when heated from 32° to 212°, assume a bulk scarcely exceeding 100·1 cubic inches. From this example, we see that the expansion of air is more than eight times greater than that of water; and the

expansion of water about 45 times greater than that of iron.

Expansion of gases.

2. An accurate knowledge of the expansion of gaseous bodies being frequently of great importance in chemical researches, many experiments have been made to ascertain it; yet, till lately, the problem was unsolved. The results of philosophers were so various and discordant, that it was impossible to form any opinion on the subject. This was owing to the want of sufficient care in excluding water from the vessels in which the expansion of the gases was measured. The heat which was applied converted portions of this water into vapour, which, mixing with the gas, totally disguised the real changes in bulk which it had undergone. To this circumstance we are to ascribe the difference in the determinations of Deluc, General Roy, Saussure, Divernois, &c. Fortunately this point has lately engaged the attention of two very ingenious and precise philosophers; and their experiments, made with the proper precautions, have solved the problem. The experiments of Mr Dalton of Manchester were read to the Philosophical Society of Manchester in October 1801, and published early in 1802 [*]. To him therefore the honour of the discovery of the law of the dilitation of gaseous bodies is due; for Mr Gay Lussac did not publish his dissertation on the expansion of the gases [†] till more than six months after. Mr Dalton's experiments are distinguished by a simplicity of apparatus, which adds greatly to their value, as it puts it in the power of others to repeat them without difficulty. It consists merely of a glass tube, open at one end, and

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[*] *Manchester Memoirs*, v. 593.

[†] *Ann. de Chim.* xliii, 137.

divided into equal parts; the gas to be examined was introduced into it after being properly dried, and the tube is filled with mercury at the open end to a given point; heat is then applied, and the dilatation is observed by the quantity of mercury which is pushed out. Mr Guy Lussac's apparatus is more complicated but equally precise; and as his experiments were made on larger bulks of air, their coincidence with those of Mr Dalton adds considerably to the confidence which may be placed in the results.

The same in all,

From the experiments of these philosophers it follows, that all gaseous bodies whatever undergo the *same* expansion by the same addition of heat, supposing them placed in the same circumstances. It is sufficient, then, to ascertain the law of expansion observed by any one gaseous body, in order to know the exact rate of dilatation of them all. Now, from the experiments of Gay Lussac we learn, that air, by being heated from 32° to 212°, expands from 100 to 137·5 parts: the increase of bulk for 180° is then 37·5 parts; or, supposing the bulk at 32° to be unity, the increase is equal to 0·375 parts: this gives us 0·00208, or $\frac{1}{480}$th part, for the expansion of air for 1° of the thermometer. Mr Dalton found that 100 parts of air, by being heated from 55° to 212°, expanded to 132·5 parts: this gives us an expansion of 0·00207, or $\frac{1}{483}$d part, for 1°; which differs as little from the determination of Lussac as can be expected in experiments of such delicacy.

And nearly equable.

From the experiments of Mr Dalton, it appears that the expansion of air is almost perfectly equable; that is to say, that the same increase of bulk takes place by the same addition of caloric at all different temperatures. It is true, indeed, that the rate of diminution appears to

Book I.
Division II.

diminish as the temperature increases. Thus the expansion from 55° to 133½°, or for the first 77½ degrees, was 167 parts; while the expansion from 133° to 212°, or for the next 77½°, was only 158 parts, or nine parts less than the first. But this difference, in all likelihood, is chiefly apparent; for Deluc has demonstrated, that the thermometer is not an accurate measure of the increase of heat. Indeed Mr Dalton has shown that the expansion of air follows a regular geometrical progression, if we suppose that mercury expands as the square of the temperature from the freezing point.

From the experiments of Gay Lussac, it appears that the steam of water, and the vapour of ether, undergo the same dilation with air when the same addition is made to their temperature. We may conclude, then, that all elastic fluids expand equally and uniformly by heat; The following Table gives us nearly the bulk of a given quantity of air at all temperatures from 32° to 212°.

Expansion of air.

Temp.	Bulk.	Temp.	Bulk.	Temp.	Bulk.
32°	100000	59°	105616	86°	111232
33	100208	60	105824	87	111440
34	100416	61	106032	88	111648
35	100624	62	106240	89	111856
36	100832	63	106448	90	112064
37	101040	64	106656	91	112272
38	101248	65	106864	92	112480
39	101456	66	107072	93	112688
40	101664	67	107280	94	112896
41	101872	68	107488	95	113104
42	102080	69	107696	96	113312
43	102288	70	107904	97	113520
44	102496	71	108112	98	113728
45	102704	72	108320	99	113936
46	102912	73	108528	100	114144
47	103120	74	108736	110	116224
48	103328	75	108944	120	118304
49	103536	76	109152	130	120384
50	103744	77	109360	140	122464
51	103952	78	109568	150	124544
52	104160	79	109776	160	126624
53	104368	80	109984	170	128704
54	104576	81	110192	180	130784
55	104784	82	110400	190	132864
56	104992	83	110608	200	134944
57	105200	84	110816	210	137024
58	105408	85	111024	212	137440

Expansion of liquids,

3. The expansion of liquid bodies differs from that of the elastic fluids, not only in quantity, but in the want of uniformity with which they expand when equal additions are made to the temperature of each. This difference seems to depend upon the fixity or volatility of the component parts of the liquid bodies; for in general, those liquids expand most by a given addition of heat, whose boiling temperatures are lowest, or which

Not uniform.

contain in them an ingredient which readily assumes the gaseous form. Thus mercury expands much less when heated to a given temperature than water, which boils at a heat much inferior to mercury; and alcohol is much more expanded than water, because its boiling temperature is lower. In like manner, nitric acid is much more expanded than sulphuric acid; not only because its boiling point is lower, but because a portion of it has a tendency to assume the form of an elastic fluid. This rule holds at least in all the liquids whose expansion I have hitherto tried. We may consider it therefore as a pretty general fact, that the higher the temperature necessary to cause a liquid to boil, the smaller the expansion is which is produced by the addition of a degree of heat; or, in other words, the expansibility of liquids is nearly inversely as their boiling temperature.

Increases with the temperature.

4. Another circumstance respecting the expansion of liquids deserves particular attention: The expansibility of every one seems to increase with the temperature; or, in other words, the nearer a liquid is to the temperature at which it boils, the greater is the expansion produced by the addition of a degree of caloric: and, on the other hand, the farther it is from the boiling temperature, the smaller is the increase of bulk produced by the addition of a degree of caloric. Hence it happens, that the expansion of those liquids approaches nearest to equability whose boiling temperatures are highest; or, to speak more precisely, the ratio of the expansibility increases the more slowly the higher the boiling temperature is.

Unconnected with their density.

5. These observations are sufficient to show us, that the expansion of liquids is altogether unconnected with

p.78- of Mercury water be [illegible] of boiling
afterwards separately heated to the point
water the water will be found to have ~~[illegible]~~ required
3 times the caloric that the mercury did - to
bring it to that point -

p.34 - take ice at 32° & mix it with an equal weight
of water at 172° the ice melts immediately & the
temperature of the water is 32° - which proves that
140° of caloric have been absorbed in rendering the
water liquid - hence the latent caloric required to
keep it in that state is equal to 140° -

p.100 - water { 85 parts Oxygen } weight
15 " - hydrogen
- 101 - a cubic foot of water = 62½ ℔

Mode of refining Sugar - see Sugar Rees's encyclopaedia -
the account may be relied on -

Davy's paper on the effects of positive & negative electricity
in acids & alkalies in regard to causing them unite
- phil. Trans. for 1807 - p. 1 -
acids are naturally negative
metals & alkalies - positive -

p.199 mode of procuring citric acid in salts - annales
de Chim. tome 22 -

p.205 - process of making Prussian Blue { Newman's Chemistry
Shaw's lectures on Arts
Bouillon la Grange
Journal de Physique for 1788

209 - Common salt { 53 soda
39 acid muriatic
8 water }

280 Carbonic acid ——— by wt. { 72 parts Oxygen
28 Carbon

287 - Lavoisier having analysed sugar found it contained
Hydrogen 8 lb
Ox. — 64 "
Carbon — 28 "

Alcohol - Carbon — 30 parts
Hydrogen — 7.5
Wat. — 62.5 —

Wedderburn — Wedderburn

their density. It depends upon the quantity of heat necessary to cause them to boil, and to convert them into elastic fluids. But we are altogether ignorant at present of the reason why different liquids require different temperatures to produce this change.

Table of expansion.

6. The following Table will give the reader a precise notion of the rate of expansion of those liquids which have been hitherto examined by chemical philosophers.

Temp.	Mercury *.	Linseed oil †.	Sulphuric Acid ‡.	Nitric Acid ‡.	Water §.	Oil of Turpen. ‡.	Alcohol §.
32°	100000	100000	—	—	—	—	100000
40	100081	—	99752	99514	—	—	100539
50	100183	—	100000	100000	100023	100000	101105
60	100304	—	100279	100486	100091	100460	101688
70	100406	—	100558	100990	100197	100993	102281
80	100508	—	100806	101530	100332	101471	102890
90	100610	—	101054	102088	100694	101931	103517
100	100712	102760	101317	102620	100908	102446	104162
110	100813	—	101540	103196	—	102943	—
120	100915	—	101834	103776	101404	103421	—
130	101017	—	102097	104352	—	103954	—
140	101119	—	102320	105132	—	104573	—
150	101220	—	102614	—	102017	—	—
160	101322	—	102893	—	—	—	—
170	101424	—	103116	—	—	—	—
180	101526	—	103339	—	—	—	—
190	101628	—	103587	—	103617	—	—
200	101730	—	103911	—	—	—	—
212	101835	107250	—	—	104577	—	—

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* This is the result of De Luc's experiments. Philosophers have given very different statements of the expansion of mercury from 32° to 212°. According to General Roy it is 0·0168. Haellstroem makes it 0·017583 (Gilbert's *Annalen. der Physik*, xvii. 107). Lalande affirms

7. Mr Dalton has rendered it probable that the expansion of water and mercury is as the square of the temperature of each, reckoning from their respective freezing points. He finds, if this law be supposed, that

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that the experiments of Delisle and his own make it 0·0150 (Ibid. p. 102.) Mr Deluc has shown, that the expansion of mercury from 32° to 122° is to its expansion from 122° to the temperature of boiling water as 14 to 15.

† The expansion of linseed oil was determined by Sir Isaac Newton.

‡ The expansion of these three liquids is given from my experiments. They were made by filling thermometers with the liquids, and noting down the degrees at which the liquids stood at the different temperatures marked. The weight of liquid equivalent to one degree of the tube was then ascertained, and the weight of the whole liquid whose expansion was tried. From these data, it was easy to ascertain the rate of expansion. The degrees were marked corresponding to a good mercurial thermometer. But as the expansion of mercury is not equable, it is obvious that the numbers gradually deviate from accuracy in proportion to the temperature. It was the consciousness of this that induced me to omit the higher parts of the scale altogether. The correction for the expansion of the glass was not inserted.

§ The expansion of these liquids was ascertained by Sir Charles Blagden and Mr Gilpin. My experiments give the expansion of both considerably less. Thus I found the expansion of water as follows:

Temp.	Expansion.	Temp.	Expansion.
42·5°	100000	112·°	100777
52·5	100030	122·5	101006
62·5	100106	132·5	101220
72·5	100182	142·5	101495
82·5	100273	152·5	101755
92·5	100471	162·5	102040
102·5	100624	172·5	10226

The strength of the alcohol in the Table was 0·825. Mr Dalton found 1000 parts of alcohol of 0·817 at 50° became 1039 at 110°, and 1079 at 170°. The expansion diminishes when the alcohol is made weaker.

Mr Deluc, by mixing together equal quantities of water at 32° and boiling water, ascertained the medium temperature between that of boiling and freezing water. Suppose the whole expansion from the

the expansions of water and mercury correspond. Hence he infers that all liquids follow the same law, or that they expand as the square of the temperature from the freezing point of each §.

Expansion of solids.

8. The expansion of solid bodies is so small, that a micrometer is necessary to detect the increase of bulk. As far as is known, the expansion is equable, at least the deviation from perfect equality is insensible. The following Table exhibits the expansion of most of the solids which have hitherto been examined. Most of the experiments were made by Smeaton.

Temp.	Platinum ¶.	Gold *.	Antimony.	Cast Iron ‡.	Steel †.
32°	100000	100000	100000	100000	100000
212	100087	100094	100109	100111	100112

Temp.	Iron.	Bismuth.	Copper.	Cast Brass ‖.	Silver §.
33°	100000	100000	100000	100000	100000
212	100126	100139	100170	100188	100189

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temperature of freezing water to that of boiling water to be divided into 80 parts; he found that the expansion from 32° to that medium temperature (which would be 122°, if the expansion of mercury were equable), and from that temperature to that of boiling water, in different liquids, to be as follows:

	From 32° to M. Temp.	From M. Temp. to boiling Water.	Ratios.
Mercury	38·6	41·4	14 : 15
Olive and linseed oil	37·8	42·2	13·4 : 15
Oil of camomile	37·2	42·8	13 : 15
Water saturated with salt	34·9	45·1	11·6 : 15
Rectified spirit of wine	33·7	46·3	10·9 : 15
Water	19·2	60·8	4·7 : 15

§ *New System of Chemical Philosophy*, p. 10.

¶ Borda.

* Bouguer.

† The expansion of blistered steel from 32° to 212°, was found by

Temp.	Brass Wire	Tin.	Lead.	Zinc.	Hammered Zinc.
32°	100000	100000	100000	100000	100000
212	100194	100238	100287	100296	100308

Temp.	Zinc 8 Tin 1	Lead 2 Tin 1	Brass 2 Zinc 1	Pewter.	Copper 3 Tin* 1
32°	100000	100000	100000	100000	100000
212	100259	100251	100205	100228	100182

Expansion of glass.

The expansion of glass is a point of great importance, as it influences the result of most experiments on temperature. It has been examined with much precision by Mr Deluc. The rate of its expansion, as settled by that philosopher, may be seen in the following Table:

Temp.	Bulk.	Temp.	Bulk.	Temp.	Bulk.
32°	100000	100°	100023	167°	100056
50	100006	120	100033	190	100069
70	100014	150	100044	212	100083

From this Table, it appears, that when glass is heated one degree, it undergoes an expansion which amounts

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Smeaton 100115. Gen. Roy found that of a steel rod 1·0011499. By the late very precise trials of Mr Dalby, 100 feet of blistered steel expanded 0·007492 inches when heated 1° of Fahrenheit. *Phil. Trans.* 1795, p. 428.

‡ Ramsden. § Herbert.

‖ Ramsden found the expansion of a brass scale from 32° to 212°, 0·0222646; of English plate brass, in form of a rod, 0·0227136; of the same in form of a trough, 0·0227386. The original bulk being 12·0000.

* 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.

nearly to $\frac{1}{200000}$ of the whole bulk. The glass examined by Deluc was of the kind employed for making barometer and thermometer tubes. But the expansion of this substance must vary considerably according to circumstances. Thus a solid glass rod expanded, according to Ramsden, 0·0096944 when heated from 32° to 212°, and a glass tube 0·0093138. Smeaton found a barometer tube, exposed to the same degree of heat, 0·0100 *. The original bulk in these was 12·000. Mr Dalton has rendered it probable that thin glass bulbs expand nearly as much as iron when heated.

Nature of the thermometer.

9. 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.

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* On the supposition that metals expand equably, the expansion of a mass of metal, 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 $x = 3\,b\,a\,s$.

To facilitate observation, the tube is divided into 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 is supposed by some 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 rendered it really useful, by pointing out the method of constructing thermometers capable of being compared together.

How graduated.

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 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†. From the different methods followed by philosophical instrument makers in determining the boiling point, it was found, that thermometers very seldom agreed with each other, and that they often deviated several degrees from the truth. This induced Mr Cavendish to suggest to the Royal Society the importance of publishing rules for constructing these very useful instruments. A committee of the society was accordingly appointed to consider the subject. This committee published a most valuable set of directions, which may be consulted in the Philosophical Transactions‡. The most important of these directions is, to expose the whole of the tube as well as the ball of the thermometer to steam, when the boiling water point is to be determined. They recommend this to be done when the barometer stands at 29·8 inches.

Different thermometers used.

Mercury is the liquid which answers best for thermometers, because its expansion is most equable, owing to the great distance from its boiling and freezing points. 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 De Lisle's.

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* *Phil. Trans.* Abr. iv. 1.

† *On the Construction and Graduation of Thermometers.*

‡ *Phil. Trans.* 1777. p. 816.

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 centigrade*. 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°[‡].

De Lisle'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,

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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 $F = \frac{9C}{5} + 32$.

[‡] Consequently 180 F = 80 R, or 18 F = 8 R, or 9 F = 4 R; therefore $F = \frac{9R}{4} + 32$.

and increases towards the freezing point. The boiling point is marked 0, the freezing point 150° *.

Does not measure the increase of heat.

10. In making experiments with the thermometer, we ought always to remember that, when graduated in the common way, it does not give us an exact measure of the increase of heat: For as the expansion of mercury for every degree of temperature increases with the temperature, it is obvious that, unless allowance be made for that increase, the degree indicated by the thermometer will not mark the number of degrees of heat added to or abstracted from a body, but another number, deviating more and more from the true one the higher the temperature indicated happens to be. Thus suppose the medium temperature between that of boiling and freezing water to be denoted by 122°; if we extend the scale upwards, the boiling water point will not be 212°, as it would be if the scale were equable, but 218·4°. On the other hand, if we fix the boiling and freezing points, as is commonly done, and mark them 212° and 32°, then the medium temperature between these two will not be 122°, but 118·8°.

If Mr Dalton's opinion, that the expansion of mercury is as the square of the temperature, reckoning from its freezing point, be correct, it is obvious, that the thermometer, to indicate equal measurements of temperature, ought to be graduated differently; the present de-

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* Hence 180 F = 150 D, or 6 F = 5 D. To reduce the degrees of De Lisle's thermometer under the boiling point to those of Fahrenheit, we have $F = 212 - \frac{6\,D}{5}$; to reduce those above the boiling point, $F = 212 + \frac{6\,D}{5}$.

grees are too large at the beginning of the scale, and too small at its upper extremity. The following Table shows the degrees of Mr Dalton's *new thermometer* corresponding with those of the common, supposing the freezing point to be 32°, and the boiling water point to be 212°.

Dalton's new graduation.

New therm.	Com. therm.	New therm.	Com. therm.
—175°	—40·00	172	163·2
— 68	—21·12	182	175—
— 58	—17·06	192	186·9
— 48	—12·96	202	199·2
— 38	— 8·52	212	212
—28	—3·76	222	225
—18	+1·34	232	238·6
— 8	6·78	242	252·6
+ 2	12·63	252	266·8
12	18·74	262	281·2
22	25·21	272	296·2
32	32	282	311·5
42	39·3	292	327
52	47—	302	342·7
62	55—	312	359·2
72	63·3	322	375·8
82	72—	332	392·7
92	81	342	409·8
102	90·4	352	427·3
112	100·1	362	445·3
122	110—	372	463·6
132	120·1	382	482·2
142	130·4	392	501
152	141·1	402	520·3
162	152—	412	539·7

New therm.	Com. therm.	New therm.	Com. therm.
422	559·8	452	621·6
432	580·1	462	642
442	600·7		

Exceptions to expansion,

11. Having now considered the phenomena and laws of expansion as far as they are understood, it will be proper to state the exceptions to this general effect of heat, or the cases in which expansion is produced, not by an increase, but by a diminution of temperature. These exceptions may be divided into two classes. The first class comprehends certain liquid bodies which have a maximum of density corresponding with a certain temperature; and which, if they be heated above that temperature, or cooled down below it, undergo in both cases an expansion or increase of bulk. The second class comprehends certain liquids which suddenly become solid when cooled down to a certain temperature; and this solidification is accompanied by an increase of bulk.

Of two kinds.

1. Water has its maximum density at 40°.

12. Water is considered at present, by the greater number of chemists, as furnishing a remarkable example of the first class of bodies. This liquid is supposed to be at its maximum of density when nearly at the temperature of 40°. If it be cooled down below 40°, it expands as the temperature diminishes; if it be heated above 40°, it in like manner expands as the temperature increases. Thus two opposite effects are produced by heat upon water, according to the temperature of that liquid. From 40° to 32°, and downwards, heat diminishes the bulk of water; but from 40°, to 212°, and upwards, it increases its bulk. Such is the opinion at present received by most persons, and which is considered as the result of the most exact experiments.

History of the discovery.

The facts which led to this conclusion were first observed by the Florentine academicians. An account of their experiments was published in the Philosophical Transactions for 1670[*]. They filled with water a glass ball, terminating in a narrow graduated neck, and plunged it into a mixture of snow and salt. The water started suddenly up into the neck, in consequence of the construction of the vessel, and slowly subsided again as the cold affected it. After a certain interval it began to rise again, and continued to ascend slowly and equably, till some portion of it shot into ice, when it sprung up at once with the greatest velocity. The attention of the Royal Society was soon afterwards called to this remarkable expansion by Dr Croune, who, in 1683, exhibited an experiment similar to that of the Florentine philosophers, and concluded from it, that water begins to be expanded by cold at a certain temperature above the freezing point. Dr Hooke objected to this conclusion, and ascribed the apparent expansion of the water to the contraction of the vessel in which the experiment was made. This induced them to cool the glass previously in a freezing mixture, and then to fill it with water. The effect, notwithstanding this precaution, was the same as before[†]. Mr De Luc was the first who attempted to ascertain the exact temperature at which this expansion by cold begins. He placed it at 41°, and estimated the expansion as nearly equal, when water is heated or cooled the same number of degrees above or below 41°. He made his experiments

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[*] *Phil. Trans.* No. 66. or vol. v. p. 2020. *Abridgement*, i. 540.

[†] Birche's *Hist. of the Royal Society*, iv. 253.

in glass thermometer tubes, and neglected to make the correction necessary for the contraction of the glass; but in a set of experiments by Sir Charles Blagden and Mr Gilpin, made about the year 1790, this correction was attended to. Water was weighed in a glass bottle at every degree of temperature from 32° to 100°, and its specific gravity ascertained. They fixed the maximum of density at 39°, and found the same expansion very nearly by the same change of temperature either above or below 39°. The following Table exhibits the bulk of water at the corresponding degrees on both sides of 39°, according to their experiments*.

Rate of expansion.

Specific Gravity.	Bulk of Water.	Temperature.		Bulk of Water.	Sp. Gravity of Ditto.
	100094	39		1·00094	
1·00000	94	38	40	94	1·00000
0·99999	93	37	41	93	0·99999
0·99998	92	36	42	92	0·99998
0·99996	90	35	43	90	0·99996
0·99994	88	34	44	88	0·99994
0·99991	85	33	45	86	0·99992
0·99988	82	32	46	83	0·99989

Mr Dalton, in a set of experiments published in 1802, obtained nearly the same result as De Luc. He placed

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* *Phil. Trans.* 1792, p. 428.

the maximum density at 42·5°, not making any correction for the contraction of the glass; and observed, as Blagden had done before him, that the expansion is the same on both sides of the maximum point, when the change of temperature is the same, and continues however low down the water be cooled, provided it be not frozen *.

All these experiments had been made by cooling water in glass vessels; but when the French were forming their new weights and measures, the subject was investigated by Lefebvre-Gineau in a different manner. A determinate bulk of water at a given temperature was chosen for the foundation of their weights. To obtain it, a cylinder of copper, about nine French inches long, and as many in diameter, was made, and its bulk measured with the utmost possible exactness. This cylinder was weighed in water of various temperatures. Thus was obtained the weight of a quantity of water equal to the bulk of the cylinder; and this, corrected by the alteration of the bulk of the cylinder itself from heat or cold, gave the density of water at the temperatures tried. The result was, that the density of the water constantly increased till the temperature of 40°, below which it as constantly diminished †. These experiments seem to have been made about the year 1795. More lately a set of experiments were tried by Haellstroem exactly in the same way; but he substituted a cylinder of glass for the one of metal. The result which he obtained was the same. The ne-

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* *Manchester Mem.* v. 374.

† *Jour. de Phys.* xlix. 172; and Hauy's *Traité de Physique*, i. 55. and 181.

cessary corrections being made, he found the maximum density of water lie between 4° and 5° of Celsius, or nearly at 40° of Fahrenheit ‡.

Still more lately, a set of experiments have been published by Dr Hope, which lead to the same result in a different way. He employed tall cylindrical glass jars filled with water of different temperatures, and having thermometers at their top and bottom. The result was as follows; 1. When water was at 32°, and exposed to air of 61°, the *bottom* thermometer rose fastest till the water became of 38°, then the top rose fastest. Just the reverse happened when the water was 53°, and exposed to the cold water surrounding the vessel; the *top* thermometer was *highest* till the water cooled down to 40°, then the bottom one was highest. Hence it was inferred, that water when heated towards 40° sunk down, and above 40° rose to the top, and *vice versa*. 2. When a freezing mixture was applied to the top of the glass cylinder (temp. of air 41°), and continued even for several days, the bottom thermometer never fell below 39°; but when the freezing mixture was applied to the bottom, the top thermometer fell to 34° as soon as the bottom one. Hence it was inferred, that water when cooled below 39° cannot sink, but easily ascends. 3. When the water in the cylinder was at 32°, and warm water applied to the middle of the vessel, the bottom thermometer rose to 39° before the top one was affected; but when the water in the cylinder was at 39·5°, and cold was applied to the middle of the vessel, the top

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‡ Gilbert's *Annalen der Physik*, xvii. 107.

thermometer cooled down to 33° before the bottom one was affected [*].

Count Rumford has lately published a set of experiments conducted nearly on the same principles with those of Dr Hope, and leading to the same results. They are contrived with his usual ingenuity; but as they are of posterior date, and add nothing to the facts above stated, I do not think it necessary to detail them[†]. Dr Hope's experiments and those of Count Rumford coincide with those above related, in fixing the maximum density of water at between 39° and 40°.

Ascribed to the contraction of the vessels.

Such are the experiments upon which the belief of this remarkable property of water is founded, and they seem at first sight to leave no doubt respecting its reality. Doubts, however, have been entertained by men of acknowledged candour and capacity; and it will now be necessary to state the grounds upon which these doubts have been founded.

Liquids, as is obvious from the preceding part of this Section, expand when heated at a much greater rate than solids. It has been the opinion of many philosophers, that the expansion of liquids is proportional to the squares of the temperatures measured from the freezing point of each; and that the deviations from this law are only apparent, and owing to the thermometer not being an exact measurer of the increase of heat. Among others, Mr Dalton has stated this opinion as coinciding with his experiments, and Mr Leslie has made it the foundation of some of his mathematical

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[*] See *Edin. Trans.* vol. vi. The paper was published before October 1804.

[†] See *Nicholson's Journal*, xi. 228. Aug. 1805.

reasonings, without any explanation whatever of the grounds of his conviction of its truth. On the other hand, the expansion of solids is sensibly only proportional to the temperature, setting out from any given point. When cold is applied to solids and liquids, their contractions will follow the same rate as their expansions [*]. But as the diminution of bulk, when cold is applied to water, is as the difference between the squares of the temperatures, and the diminution of solids simply as the difference of the temperatures, it is obvious, that the contraction which water experiences when cooled a degree is constantly diminishing as we approach the freezing point, while that of solids continues sensibly the same. Therefore, at some particular point, the contraction of water will be precisely equal to the contraction of a given solid, and below that point, the contraction of the solid will be greatest. Suppose water to be exposed to cold in a glass ball and tube,

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[*] With respect to the expansions of water, it certainly follows, pretty nearly at least, the law stated in the text. From the table given in page 494, it appears that the expansion of water, the original bulk being 10000, may be expressed pretty nearly by the following numbers:

Temp.	Expan.
82·5°	6^2
102·5°	8^2
122·5°	10^2
142·5°	12^2
162·5°	14^2

The greatest deviation from these numbers is towards the beginning of the scale, when, owing to the smallness of the expansion, it is difficult to measure it with precision. It leads us to this remarkable conclusion, that the squares of the natural numbers beginning at 6 indicate the increase of bulk which 10000 parts of water experience for every ten degrees they are heated above 82·5°.

Book I.
Division II.

it will continue to sink in the tube as long as the contraction which it suffers by cooling is greater than that of the glass; but when it comes to the point at which the contraction of both is the same, it will not sink farther though cooled, because the diminution of bulk in the water will be just counterbalanced by the contraction of the vessel. When we pass that point, the water will rise in the tube by the application of cold, because the contraction of the glass will now surpass that of the water. The rise of the water then may be only apparent, and occasioned by this cause; but an easy method occurs to ascertain the point. Make the experiment in vessels of different kinds, which are differently contracted by heat, the point of the greatest density of the water ought to vary with the vessel. This accordingly has been done by Mr Dalton. The following Table exhibits the result of his experiments. The first column contains the substances in which the water was contained, and the second the degree of the thermometer at which the water began to rise when cooled in these substances, or its apparent point of greatest density.

Brown earthen ware	38°
Queen's ware	40
Flint glass	41½
Iron	42½
Tin plate	42½
Copper	45½
Brass	46
Pewter	46
Zinc	48
Lead	49½

These experiments coinciding with what would happen if the supposed expansion of water were only apparent, have been considered by Mr Dalton as decisive of the point; and Mr Leslie has advanced a similar opinion. This coincidence, however, is merely apparent. If we calculate, from the table of expansion given in a preceding part of this Section, the temperatures at which the expansion of the various bodies in the table coincide with the expansion of water, we obtain the following results:

But this does not account for it.

	Lowest Point by Calculation.	Do. by Dalton's Experiments.	Difference.
Glass	41·5	41·5	0
Iron	46	42·5	3.5
Copper	52	45·5	6·5
Brass	54	46	8
Pewter	59	46	13
Lead	64	49·5	14·5

The glass indeed coincides with Mr Dalton's experiments, but the other bodies deviate as their expansion increases. This destroys all the consequences that have been drawn from similar experiments, and points out, besides, some error in the data from which the calculations were drawn. The error no doubt consists in setting out from the supposition that water expands from the freezing point.

The experiments of Lefebvre-Gineau and Haellstroem, above related, were in some measure free from the uncertainty resulting from the contraction of the vessels in which the bulk of the water was estimated. The copper cylinder, weighed by the former, was hollow, and every possible precaution was taken to estimate the change of bulk occasioned by heat and cold; and as the instruments were delicate, and the object of

Book I.
Division II.

great importance, it seems unreasonable to conclude that he allowed himself to be deceived.

The experiments of Dr Hope and Count Rumford appear at first sight to lead to the same result in a still less ambiguous manner; but it must be acknowledged that there are circumstances connected with them sufficiently puzzling. I shall mention one. If different strata of coloured watery liquids be put into tall glass jars, they will remain separate, if not agitated (as Count Rumford himself observed long ago), for at least a month, notwithstanding all the vicissitudes of temperature to which they are exposed; vicissitudes often greater than those to which the liquids were exposed in the trials of Dr Hope and Count Rumford. Now, how can the currents, which their experiments indicate, take place without mixing these strata together in the course of a few hours? This is a difficulty which I at least have not been able to solve in a satisfactory manner.

Mr Dalton has lately reconsidered the subject, and has shown by arguments, which to me appear convincing, that the real temperature at which the density of water is a maximum is 36°. Thus the singular anomaly of the expansion of water by cold seems to be completely made out; but no satisfactory explanation of the cause of this expansion has been yet offered. We might ascribe it to a commencement of congelation, were it not that in glass tubes water may be cooled down almost to zero before it begins to freeze, and during the whole progress it expands with the utmost regularity.

I tried a considerable number of liquids, to ascertain whether any of them, like water, have a temperature in which their density is a maximum, and which expand when cooled below that temperature. Sulphuric acid has no such point, neither have the oily bodies; but I thought I could perceive some solutions of salt in water beginning to expand before they became solid. But these solutions, when cooled down sufficiently, crystallize with such rapidity, that it is extremely difficult to be certain of the fact, that they really do begin to expand before they crystallize.

2. Many liquids expand in crystallizing.

13. That class of bodies which undergo an expansion when they change from a liquid to a solid body by the diminution of temperature, is very numerous. Not only water when converted into ice undergoes such an expansion, but all bodies which by cooling assume the form of crystals.

Expansion of ice.

The prodigious force with which water expands in the act of freezing has been long known to philosophers. Glass bottles filled with water are commonly broken in pieces when the water freezes. The Florentine academicians burst a brass globe, whose cavity was an inch in diameter, by filling it with water and freezing it. The force necessary for this effect was calculated by Muschenbroeck at 27720 lbs. But the most complete set of experiments on the expansive force of freezing water are those made by Major Williams at Quebec, and published in the second volume of the Edinburgh Transactions. This expansion has been explained by supposing it the consequence of a tendency which water, in consolidating, is observed to have to arrange its particles in one determinate manner, so as to form prismatic crystals, crossing each other at angles of 60° and 120°. The force with which they arrange themselves in this manner must be enormous, since it enables small quantities of water to overcome so great mechanical pressures. I tried various methods to assertain the specific gravity of ice at 32°; the one which succeeded best was, to dilute spirits of wine with water till a mass of solid ice put into it remained in any part of the liquid without either sinking or rising. I found the specific gravity of such a liquid to be 0·92; which of course is the specific gravity of ice, supposing the specific gravity of water at 60° to be 1. This is an expansion much greater than water experiences even when heated to 212°. We see from this, that water, when converted into ice, no longer observes an equable expansion, but undergoes a very rapid and considerable augmentation of bulk.

The very same expansion is observed during the crystallization of most of the salts; all of them at least which shoot into prismatic forms. Hence the reason that the glass vessels in which such liquids are left usually break to pieces when the crystals are formed. A number of experiments on this subject have been published by Mr Vauquelin *.

Several of the metals have the property of expanding at the moment of their becoming solid. Reaumur was the first philosopher who examined this point. Of all the metallic bodies that he tried, he found only three that expanded, while all the rest contracted on becoming solid. These three were, *cast iron*, *bismuth*, and *antimony* †. Hence the precision with which cast iron takes the impression of the mould.

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* *Ann. de Chim.* xiv. 286.

† *Mem. Par.* 1726. Berthollet's *Statique Chimique*, ii. 348.

This expansion of these bodies cannot be considered as an exception to the general fact, that bodies increase in bulk when heat is added to them; for the expansion is the consequence, not of the diminution of heat, but of the change in their state from liquids to solids, and the new arrangement of their particles which accompanies or constitutes that change.

Some bodies contract in freezing.

14. It must be observed, however, that all bodies do not expand when they become solid. There are a considerable number which diminish in bulk; and in these the rate of diminution in most cases is rather increased by solidification. When liquid bodies are converted into solids, they either form prismatic crystals, or they form a mass in which no regularity of arrangement can be perceived. In the first case, expansion accompanies solidification; in the second place, contraction accompanies it. Water and all the salts furnish instances of the first, and tallow and oils are examples of the second. In these last bodies the solidification does not take place instantaneously, as in water and salts, but slowly and gradually; they first become viscid, and at last quite solid. Most of the oils, when they solidify, form very regular spheres. The same thing happens to honey and to some of the metals, as mercury, which Mr Cavendish has shown from his own experiments, and those of Mr Macnab, to lose about $\frac{1}{23}$d of its bulk in the act of solidification [*]. When sulphuric acid congeals, it does not perceptibly expand, nor does it in the least alter its appearance. Sulphuric acid, of the specific gravity 1·8, may be cooled down in thermometer tubes

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[*] *Phil. Trans.* 1783, p. 23.

to —36° before it freezes; and during the whole process it follows exactly the rate of expansion given in the table of expansions. At —36°, or about that temperature, it freezes; but its appearance is so little altered, that I could not satisfy myself whether or not the liquid was frozen till I broke the tube. It was perfectly solid, and displayed no appearance of crystallization. On the other hand, cast iron, and probably sulphur also, expands in the act of congealing.

II. CHANGES IN THE STATE OF BODIES.

ALL substances in nature, as far as we are acquainted with them, occur in one or other of the three following states; namely, the state of solids, of liquids, or of elastic fluids or vapours. It has been ascertained, that in a vast number of cases, the same substance is capable of existing successively in each of these states. Thus sulphur is usually a solid body; but when heated to 218°, it is converted into a liquid; and at a still higher temperature (about 570°), it assumes the form of an elastic vapour of a deep brown colour. Thus also water in our climate is usually a liquid; but when cooled down to 32°, it is converted into a solid body, and at 212° it assumes the form of an elastic fluid.

Bodies change their state by heat.

All solid bodies, a very small number excepted, may be converted into liquids by heating them sufficiently; and, on the other hand, every liquid, except spirit of wine, is convertible into a solid body by exposing it to a sufficient degree of cold. All liquid bodies may, by heating them, be converted into elastic fluids, and a great many solids are capable of undergoing the same change; and, lastly, the number of elastic fluids which by cold are condensible into liquids or solids is by no means inconsiderable. These facts have led philosophers to form this general conclusion, "That all bodies, if placed in a temperature sufficiently low, would assume a solid form; that all solids become liquids when sufficiently heated; and that all liquids, when exposed to a certain temperature, assume the form of elastic fluids." The state of bodies then depends upon the temperature in which they are placed; in the lowest temperatures they are all solid, in higher temperatures they are converted into liquids, and in the highest of all they become elastic fluids. The particular temperatures at which bodies undergo those changes, are exceedingly various, but they are always constant for the same bodies. Thus we see that heat produces changes on the state of bodies, converting them all, first into liquids, and then into elastic fluids.

Conversion of solids into liquids.

I. When solid bodies are converted by heat into liquids, the change in some cases takes place at once, There is no interval between solidity and liquidity; but in other cases a very gradual change may be perceived: the solid becomes first soft, and it passes slowly through all the degrees of softness, till at last it becomes perfectly fluid. The conversion of ice into water is an instance of the first change; for in that substance there is no intervening state between solidity and fluidity. The melting of glass, of wax, and of tallow, exhibits instances of the second kind of change; for these bodies pass through every possible degree of softness before they terminate in perfect fluidity. In general, those solid bodies which crystallize or assume regular prismatic figures, have no interval between solidity and fluidity; while those that do not usually assume such

Instantaneous or slow.

shapes, have the property of appearing successively in all the intermediate states.

Takes place at a particular temperature.

1. Solid bodies never begin to assume a liquid form till they are heated to a certain temperature: this temperature is constant in all. In the first class of bodies it is very well defined; but in the second class, though it is equally constant, the exact temperature of fluidity cannot be pointed out with such precision, on account of the infinite number of shades of softness through which the bodies pass before they acquire their greatest possible fluidity. But even in these bodies we can easily ascertain, that the same temperature always produces the same degree of fluidity. The temperatures at which this change from solidity to liquidity takes place, receive different names according to the usual state of the body thus changed. When the body is usually observed in a liquid state, we call the temperature at which it assumes the form of a solid its *freezing point*, or *congealing point*. Thus the temperature in which water becomes ice, is called the *freezing point* of water; on the other hand, when the body is usually in the state of a solid, we call the temperature at which it liquifies its *melting point:* thus 218° is the melting point of sulphur; 442° the melting point of tin.

2. The following Table contains a list of the melting points of a considerable number of solid bodies:

Table of melting points.

Substance.	Melting Point.	Substance.	Melting Point.
Lead	594°	Sulphur	218
Bismuth	476	Wax	142*
Tin	442	Spermaceti	112

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* Bleached wax, 155°. Nicholson.

Substance.	Melting Point.	Substance.	Melting Point.
Phosphorus	100°	Blood	25
Tallow	92	Oil of Bergamot	23
Oil of anise	50	Wines	20
Olive oil	36	Oil of turpentine	14
Ice	32	Mercury	—39
Milk	30	Liquid ammonia	—46
Vinegar	28	Ether	—46

Water may be cooled under the freezing point.

3. Though the freezing point of water be 32°, yet it may be cooled down in favourable circumstances considerably below that temperature, before it begins to shoot into crystals. Experiments were made on this subject by Mairan and Fahrenheit; but it is to Sir Charles Blagden that we are indebted for the fullest investigation of it. He succeeded in cooling water down to 22° before it froze, by exposing it slowly to the action of freezing mixtures. The experiment succeeds best when the water tried is freed from air. It ought also to be transparent; for opaque bodies floating in it cause it to shoot into crystals when only a few degrees below the freezing point. When a piece of ice is thrown into water thus cooled, it causes it instantly to shoot out into crystals. The same effect is produced by throwing the liquid into a tremulous motion; but not by stirring it. It freezes also when cooled down too suddenly *.

Freezing of saline solutions.

4. When salts are dissolved in water, it is well known that its freezing point is in most cases lowered. Thus sea-water does not freeze so readily as pure water. The experiments of Sir Charles Blagden have given us the point at which a considerable number of these solutions

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* Blagden, *Phil. Trans.* 1788, p. 125.

congeal. The result of his trials may be seen in the following Table. The first column contains the names of the salts; the second the quantity of salt, by weight, dissolved in 100 parts of water; and the third, the freezing point of the solution *.

Names of Salts.	Proportion.	Freezing point.
Common salt	25	4
Sal ammoniac	20	8
Rochelle salt	50	21
Sulphate of magnesia .	41·6	25·5
Nitre.............	12·5	26
Sulphate of iron	41·6	28
Sulphate of zinc	33·3	28·6

From this table it appears that common salt is by far the most efficacious in lowering the freezing point of water. A solution of 25 parts of salt in 100 of water freezes at 4°. These solutions, like pure water, may be cooled down considerably below their freezing point without congealing; and in that case the congelation is produced by means of ice just as in common water, though more slowly.

When the proportion of the same salt held in solution by water is varied, it follows from Sir Charles Blagden's experiments, that the freezing point is always proportional to the quantity of the salt. For instance, if the addition of $\frac{1}{10}$th of salt to water lowers its freezing point 10 degrees, the addition of $\frac{2}{10}$ths will lower it 20°. Hence, knowing from the preceding table the effect produced by a given proportion of a salt, it is easy

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* See *Phil. Trans.* 1788, p. 277.

to calculate what the effect of any other proportion will be. The following Table exhibits the freezing points of solutions of different quantities of common salt in 100 parts of water, as ascertained by Blagden's trials, and the same points calculated on the supposition that the effect is as the proportion of salt.

Quantity of salt to 100 water.	Freezing point by experim.	Do. by calculation.
3·12	8+	28·5
4·16	27·5	27·3
6·25	25·5	25
10·00	21·5	20·75
12·80	18·5	17·6
16·1	13·5	14
20	9·5	9·8
22·2	7·2	7
25	4	4

Of strong acids.

5. The strong acids, namely, sulphuric and nitric, which are in reality compounds containing various proportions of water according to their strength, have been shown by Mr Cavendish, from the experiments of Mr Macnab, to vary in a remarkable manner in their point of congelation according to circumstances. The following are the most important points respecting the freezing of these bodies that have been ascertained.

When these acids diluted with water are exposed to cold, the weakest part freezes, while a stronger portion remains liquid; so that by the action of cold they are separated into two portions differing very much in strength. This has been termed by Mr Cavendish the *aqueous* congelation of these bodies.

When they are very much diluted, the whole mixture, when exposed to cold, undergoes the *aqueous* congelation; and in that case, it appears from Blagden's experiments, that the freezing point of water is lowered by mixing it with acid rather in a greater ratio than the increase of the acid. The following Table exhibits the freezing point of mixtures of various weights of sulphuric acid, of the density 1·837 (temperature 62°), and of nitric acid of the density 1 454, with 100 parts of water.

SULPHURIC ACID.		NITRIC ACID.	
Proportion of acid.	Freezing point.	Proportion of acid.	Freezing point.
10	24·5	10	22
20	12·5	20	10·5
25	7·5	23·4	7[*]

The concentrated acids themselves undergo congelation when exposed to a sufficient degree of cold; but each of them has a particular strength at which it congeals most readily. When either stronger or weaker, the cold must be increased. The following Table, calculated by Mr Cavendish from Mr Macnab's experiments, exhibits the freezing points of nitric acid of various degrees of strength[†].

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[*] *Phil. Trans.* 1788, p. 308.

[†] The strength is indicated by the quantity of marble necessary to saturate 1000 parts of the acid. *Phil. Trans.* 1788, p. 174.

Chap. II.

Strength.	Freezing point.	Difference.
568	—45·5	+15·4
538	—30·1	+12
508	—18·1	+ 8·7
478	— 9·4	+ 5·3
448	— 4·1	+ 1·7
418	— 2·4	— 1·8
388	— 4·2	— 5·5
358	— 9·7	— 8
328	—17·7	—10
298	—27·7	

The following Table exhibits the freezing points of sulphuric acid of various strengths ‡.

Strength.	Freezing point.
977	+ 1
918	—26
846	+42
758	—45

Mr Keir had previously ascertained that sulphuric acid of the specific gravity 1·780 (at 60°) freezes most easily, requiring only the temperature of 46°. This agrees nearly with the preceding experiments, as Mr Cavendish informs us that sulphuric acid of that specific gravity is of the strength 848. From the preceding table we see, that besides this strength of easiest freezing, sulphuric acid has another point of contrary flexure at a superior strength; beyond this, if the strength be increased, the cold necessary to produce congelation begins again to diminish.

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‡ ibid. p. 181.

Dr Black's opinion,

6. Before Dr Black began to deliver his chemical lectures in Glasgow in 1757, it was universally supposed that solids were converted into liquids by a small addition of heat after they have been once raised to the melting point, and that they returned again to the solid state on a very small diminution of the quantity of heat necessary to keep them at that temperature. An attentive view of the phenomena of liquefaction and solidification gradually led this sagacious philosopher to observe their inconsistence with the then received opinions, and to form another, which he verified by direct experiments; and drew up an account of his theory, and the proofs of it, which was read to a literary society in Glasgow on April 23d, 1762*; and every year after he gave a detailed account of the whole doctrine in his lectures.

That fluidity is occasioned by latent heat,

The opinion which he formed was, that when a solid body is converted into a liquid, a much greater quantity of heat enters into it than is perceptible immediately after by the thermometer. This great quantity of heat does not make the body apparently warmer, but it must be thrown into it in order to convert it into a liquid; and this great addition of heat is the principal and most immediate cause of the fluidity induced. On the other hand, when a liquid body assumes the form of a solid, a very great quantity of heat leaves it without sensibly diminishing its temperature; and the state of solidity cannot be induced without the abstraction of this great quantity of heat. Or, in other words, whenever a solid is converted into a fluid, it combines with

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* Black's *Lectures*, Preface, p, 38.

a certain dose of caloric without any augmentation of ts 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 eaves 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.

Such is the opinion concerning the cause of fluidity, taught by Dr Black as early as 1762. Its truth was established by the following experiments:

Proved by experiment.

First. 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?

Dr Black took two thin globular glasses four inches in diameter, and very nearly of the same weight. Both were filled with water; the contents of the one were frozen into a solid mass of ice, the contents of the other were cooled down to 33°; the two glasses were then suspended in a large room at a distance from all other bodies, the temperature of the air being 47°. In half an hour the thermometer placed in the water glass rose from 33° to 40°, or seven degrees: the ice was at first four or five degrees colder than melting snow; but in a few minutes the thermometer applied to it stood at 32°. The instant of time when it reached that temperature was noted, and the whole left undisturbed for ten hours and a half. At the end of that time the whole ice was melted, except a very small spongy mass, which floated at the top and disappeared in a few minutes. The temperature of the ice-water was 40°.

Thus 10½ hours were necessary to melt the ice and raise the product to the temperature of 40°. During all this time it must have been receiving heat with the same celerity as the water glass received it during the first half-hour. The whole quantity received then was 21 times 7, or 147°; but its temperature was only 40°: therefore 139 or 140 degrees had been absorbed by the melting ice, and remained concealed in the water into which it had been converted, its presence not being indicated by the thermometer *.

That heat is actually entering into the ice, is easily ascertained by placing the hand or a thermometer under the vessel containing it. A current of cold air may be perceived descending from it during the whole time of the process.

But it will be said, perhaps, that the heat which en-

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* Black's *Lectures*, i. 120.

ters into the ice does not remain there, but is altogether destroyed. This opinion is refuted by the following experiment.

Second. 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 the heat which it had absorbed during its liquefaction; and that this evolution maintains the temperature of the water at 32°, notwithstanding what it parts with to the air during the whole process? We may easily satisfy ourselves that the water while congealing is constantly imparting heat to the surrounding air; for a delicate thermometer suspended above it is constantly affected by an ascending stream of air less cold than the air around *. The following experiment, first made by Fahrenheit, and afterwards often repeated by Dr Black and others, affords a palpable evidence, that such an evolution of caloric actually takes place during congelation.

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* Black's *Lectures*, i. 127.

Book I.
Division II.

Third. 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?

From a good many experiments which I have made on water in these circumstances, I have found reason to conclude, that the quantity of ice which forms suddenly on the agitation of water, cooled down below the freezing point, bears always a constant ratio to the coldness of the liquid before agitation. Thus I find that when water is cooled down to 22°, very nearly $\frac{1}{14}$ of the whole freezes *; when the previous temperature is 27°, about $\frac{1}{28}$ of the whole freezes. I have not been able to make satisfactory experiments in temperatures lower than 22°; but from analogy I conclude, that for every five degrees of diminution of temperature below the freezing point, without congelation, $\frac{1}{28}$ of the liquid freezes suddenly on agitation. Therefore, if water could be cooled down 28 times five degrees below 32° without congelation, the whole would congeal instantaneously on agitation, and the temperature of the ice would be 32°,

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* A medium of several experiments.

Now it deserves attention, that 5 × 28 = 140; gives us precisely the quantity of heat which, according to Dr Black's experiments, enters into ice in order to convert it into water. Hence it follows, that in all cases when water is cooled down below 32°, it loses a portion of the caloric which is necessary to constitute its liquidity. The instant that such water is agitated, one portion of the liquid seizes upon the quantity of caloric in which it is deficient at the expence of another portion, which of course becomes ice. Thus when water is cooled down to 22°, every particle of it wants 10° of the caloric necessary to keep it in a state of liquidity. Thirteen parts of it seize ten degrees each from the fourteenth part. These thirteen of course acquire the temperature of 32°; and the other part being deprived of 10 × 13 = 130, which with the ten degrees that it had lost before constitute 140°, or the whole of the caloric necessary to keep it fluid, assumes of consequence the form of ice.

Fourth. If these experiments should not be considered as sufficient to warrant Dr Black's conclusion, the following, for which we are indebted to the same philosopher, puts the truth of his opinion beyond the reach of dispute. He mixed together given weights of ice at 32° and water at 190° of temperature. The ice was melted in a few seconds, and the temperature produced was 53°. The weight of the ice was 119 half-drams;

That of the hot water, ...	135
of the mixture, ...	264
of the glass vessel, ...	16

Sixteen parts of glass have the same effect in heating cold bodies as eight parts of equally hot water. There-

Book I.
Division II.

fore, instead of the 16 half-drams of glass, eight of water may be substituted, which makes the hot water amount to 143 half-drams.

In this experiment there were 158 degrees of heat contained in the hot water to be divided between the ice and water. Had they been divided equally, and had the whole been afterwards sensible to the thermometer, the water would have retained $\frac{143}{262}$ parts of this heat, and the ice would have received $\frac{119}{262}$ parts. That is to say, the water would have retained 86°, and the ice would have received 72°: and the temperature after mixture would have been 104°. But the temperature by experiment is found to be only 53°; the hot water lost 137°, and the ice only received an addition of temperature equal to 21°. But the loss of 18° of temperature in the water is equivalent to the gain of 21° in the ice. Therefore $158° - 18° = 140°$ of heat have disappeared altogether from the hot water. These 140° must have entered into the ice, and converted it into water without raising its temperature *.

In the same manner, if we 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

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* Black's *Lectures*, i. 123.

irresistibly, that ice, when it is converted into water, absorbs and combines with caloric.

It is rather difficult to ascertain the precise number of degrees of heat that disappear during the melting of ice. Hence different statements have been given. Mr Cavendish, who informs us that he discovered the fact before he was aware that it was taught by Dr Black, states them at 150° ; Wilke at 130°[*] ; Black at 140° ; and Lavoisier and Laplace, at 135°. The mean of the whole is very nearly 140°.

Latent heat of water.

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 the caloric necessary to give fluidity to ice is equal to 140°.

To the quantity of caloric which thus occasions the fluidity of solid bodies by combining with them, Dr Black gave the name of *latent heat*, because its presence is not indicated by the thermometer: a term sufficiently expressive, but other philosophers have rather chosen to call it *caloric of fluidity*.

Dr Black and his friends 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.

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[*] *Phil. Trans.* 1783, p. 313.

[†] *Jour. de Phys.* xxvi.

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.

Latent heat of other bodies.

7. The only experiments to determine the latent heat of other bodies besides water, that have been hitherto published, are those of Dr Irvine † and his son Mr William Irvine ‡. The following Table exhibits the result of their trials.

Bodies.	Latent heat.	Do. reduced to the specific heat of water
Sulphur	143·68	27·14
Spermaceti.....	145	
Lead	162	5·6
Bees wax	175	
Zinc	493	48·3
Tin	500	33
Bismuth	550	23·25

The latent heat of spermaceti, wax, and tin, were determined by Dr Irvine, that of the rest by his son. The latent heat in the second column expresses the degrees by which it would have increased the temperature of each of the bodies respectively when solid, except in the case of spermaceti and wax; in them it expresses the increase of temperature which would have been produced upon them while fluid.

Softness and ductility owing to the same cause.

8. Dr Black has rendered it exceedingly probable also, or rather he has proved by his experiments and observations, that the softness of such bodies as are rendered plastic by heat, depends upon a quantity of la-

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† Black's *Lectures*, i. 187.

‡ Nicholson's *Jour.* ix. 45.

tent heat which combines with them. Metals also owe their malleability and ductility to the same cause. Hence the reason that they become hot and brittle when hammered.

II. Thus it appears, that the conversion of solids into liquids is occasioned by the combination of a dose of caloric with the solid. But there is another change of state still more remarkable, to which bodies are liable when exposed to the action of heat. Almost all liquids, when raised to a certain temperature, gradually assume the form of an elastic fluid, invisible like air, and possessed of the same mechanical properties. Thus water, by boiling, is converted into steam, an invisible fluid, 1800 times more bulky than water, and as elastic as air. These fluids retain their elastic form as long as their temperature remains sufficiently high; but when cooled down again, they lose that form, and are converted into liquids. All liquids, and even a considerable number of solids, are capable of undergoing this change when sufficiently heated.

Some bodies become vapour at all temperatures, others not.

2. With respect to the temperatures at which liquids undergo this change, they may be all arranged under two divisions. There are some liquids which are gradually converted into elastic fluids at every temperature; while others again never begin to assume that change till their temperature reaches a certain point. Water is a well known example of the first class of bodies. If an open vessel, filled with water, be carefully examined, we find that the water diminishes in bulk day after day, and at last disappears altogether. If the experiment be made in a vessel sufficiently large, and previously exhausted of air, we shall find, that the water will fill the vessel in the state of invisible vapour, in whatever

temperature it be placed: alcohol likewise, and ether and volatile oils, gradually assume the form of an elastic fluid in all temperatures. But sulphuric acid and the fixed oils never begin to assume the form of vapour till they are raised to a certain temperature. Though left in open vessels they lose no perceptible weight; neither does sulphuric acid lose any weight though kept ever so long in the temperature of boiling water. When liquids gradually assume the form of elastic fluids in all temperatures, they are said to *evaporate* spontaneously. The second class of liquids want that property altogether.

Boiling explained.

3. When all other circumstances are the same, the evaporation of liquids increases with their temperature; and after they are heated to a certain temperature, they assume the form of elastic fluids with great rapidity. If the heat be applied to the bottom of the vessel containing the liquids, as is usually the case, after the whole liquid has acquired this temperature, those particles of it which are next the bottom become an elastic fluid first: they rise up, as they are formed, through the liquid, like air-bubbles, and throw the whole into violent agitation. The liquid is then said to *boil*. Every particular liquid has a fixed point at which this boiling commences (other things being the same); and this is called the boiling point of the liquid. Thus water begins to boil when heated to 212°. It is remarkable, that after a liquid has begun to boil, it never becomes any hotter, however strong the fire be to which it is exposed. A strong heat indeed makes it boil more rapidly, but does not increase its temperature. This was first observed by Dr Hooke,

Chap. II.

Boiling points.

4. The following Table contains the boiling point of a number of liquids.

Bodies.	Boiling Point.	Bodies.	Boiling Point.
Ether	98°	Muriate of lime	264‡
Ammonia	140*	Sulphuric acid	590*
Alcohol	174	Phosphorus	554
Water	212	Sulphur	570
Nitric acid	248	Linseed oil	600
Carbonate of potash	260†	Mercury	660

Vary with the Pressure.

5. It was observed, when treating of the melting point of solids, that it is capable of being varied considerably by altering the situation of the body. Thus water may be cooled down considerably lower than 32° without freezing. The boiling point is still less fixed, depending entirely on the degree of pressure to which the liquid to be boiled is exposed. If we diminish the pressure, the liquid boils at a lower temperature; if we increase it, a higher temperature is necessary to produce ebulition. From the experiments of Professor Robison, it appears that, in a vacuum, all liquids boil about 145° lower than in the open air, under a pressure of 30 inches of mercury; therefore water would boil in vacuo at 67° and alcohol at 34°. In a Papin's digester, the temperature of water may be raised to 300°, or even 400°, without ebulition: But the instant that this great pressure is removed, the boiling commences with prodigious violence.

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* Dalton.

† When so much concentrated as to become nearly solid, 280°.

‡ By my trials.

Elasticity of vapours increases with the temperatures.

6. The elasticity of all the elastic fluids into which liquids are converted by heat, increases with the temperature; and the vapour formed, when the liquid boils in the open air, possesses an elasticity just equal to that of air, or capable at a medium of balancing a column of mercury 30 inches high. The following very important TABLE, drawn up by Mr Dalton* from his own experiments, exhibits the elasticity of steam or the vapour of water of every temperature, from —40° to 325°. The elasticities of all the temperatures from 32° to 212° were ascertained by experiment; the rest were calculated by observing the rate at which the elasticity increased or diminished according to the temperature.

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* *Manchester Memoirs*, v. 559.

Chap. II.

Table of the elasticity of steam.

Temperature.	Force of Vap. in inches of Mercury.	Temperature.	Force of Vap. in inches of Mercury.	Temperature.	Force of Vap. in inches of Mercury.	Temperature.	Force of Vap. in inches of Mercury.
−40°	·013	31°	·193	66°	·635	102°	1·98
−30	·020			67	·655	103	2·04
−20	·030	32	·200	68	·676	104	2·11
−10	·043	33	·207	69	·698	105	2·18
		34	·214	70	·721	106	2·25
0	·064	35	·221	71	·745	107	2·32
1	·066	36	·229	72	·770	108	2·39
2	·068	37	·237	73	·796	109	2·46
3	·071	38	·245	74	·823	110	2·53
4	·074	39	·254	75	·851	111	2·60
5	·076	40	·263	76	·880	112	2·68
6	·079	41	·273	77	·910	113	2·76
7	·082	42	·283	78	·940	114	2·84
8	·085	43	·294	79	·971	115	2·92
9	·087	44	·305	80	1·00	116	3·00
10	·090	45	·316	81	1·04	117	3·08
11	·093	46	·328	82	1·07	118	3·16
12	·096	47	·339	83	1·10	119	3·25
13	·100	48	·351	84	1·14	120	3·33
14	·104	49	·363	85	1·17	121	3·42
15	·108	50	·375	86	1·21	122	3·50
16	·112	51	·388	87	1·24	123	3·59
17	·116	52	·401	88	1·28	124	3·69
18	·120	53	·415	89	1·32	125	3·79
19	·124	54	·429	90	1·36	126	3·89
20	·129	55	·443	91	1·40	127	4·00
21	·134	56	·458	92	1·44	128	4·11
22	·139	57	·474	93	1·48	129	4·22
23	·144	58	·490	94	1·53	130	4·34
24	·150	59	·507	95	1·58	131	4·47
25	·156	60	·524	96	1·63	132	4·60
26	·162	61	·542	97	1·68	133	4·73
27	·168	62	·560	98	1·74	134	4·86
28	·174	63	·578	99	1·80	135	5·00
29	·180	64	·597	100	1·86	136	5·14
30	·186	65	·616	101	1·92	137	5·29

TABLE *continued.*

Temperature.	Force of Vap. in inches of Mercury.	Temperature.	Force of Vap. in inches of Mercury.	Temperature.	Force of Vap. in inches of Mercury.	Temperature.	Force of Vap. in inches of Mercury.
138°	5·44	171°	12·43	204°	25·61	236°	46·39
139	5·59	172	12·73	205	26·13	237	47·20
140	5·74	173	13·02	206	26·66	238	48·02
141	5·90	174	13·32	207	27·20	239	48·84
142	6·05	175	13·62	208	27·74	240	49·67
143	6·21	176	13·92	209	28·29	241	50·50
144	6·37	177	14·22	210	28·84	242	51·34
145	6·53	178	14·52	211	29·41	243	52·18
146	6·70	179	14·83	212	30·00	244	53·03
147	6·87	180	15·15			245	53·88
148	7·05	181	15·50	213	30·60	246	54·68
149	7·23	182	15·86	214	31·21	247	55·54
150	7·42	183	16·23	215	31·83	248	56·42
151	7·61	184	16·61	216	32·46	249	57·31
152	7·81	185	17·00	217	33·09	250	58·21
153	8·01	186	17·40	218	33·72	251	59·12
154	8·20	187	17·80	219	34·35	252	60·05
155	8·40	188	18·20	220	34·99	253	61·00
156	8·60	189	18·60	221	35·63	254	61·92
157	8·81	190	19·00	222	36·25	255	62·85
158	9·02	191	19·42	223	36·88	256	63·76
159	9·24	192	19·86	224	37·53	257	64·82
160	9·46	193	20·32	225	38·20	258	65·78
161	9·68	194	20·77	226	38·89	259	66·75
162	9·91	195	21·22	227	39·59	260	67·73
163	10·15	196	21·68	228	40·30	261	68·72
164	10·41	197	22·13	229	41·02	262	69·72
165	10·68	198	22·69	230	41·75	263	70·73
166	10·96	199	23·16	231	42·49	264	71·74
167	11·25	200	23·64	232	43·24	265	72·76
168	11·54	201	24·12	233	44·00	266	73·77
169	11·83	202	24·61	234	44·78	267	74·79
170	12·13	203	25·10	235	45·58	268	75·80

TABLE *continued.*

Temperature.	Force of Vap. in inches of Mercury.	Temperature.	Force of Vap. in inches of Mercury.	Temperature.	Force of Vap. in inches of Mercury.	Temperature.	Force of Vap. in inches of Mercury.
269°	76·82	284°	93·23	298°	109·48	312°	125·85
270	77·85	285	94·35	299	110·64	313	127·00
271	78·89	286	95·48	300	111·81	314	128·15
272	79·94	287	96·64	301	112·98	315	129·29
273	80·98	288	97·80	302	114·15	316	130·43
274	82·01	289	98·96	303	115·32	317	131·57
275	83·13	290	100·12	304	116·50	318	132·72
276	84·35	291	101·28	305	117·68	319	133·86
277	85·47	292	102·45	306	118·86	320	135·00
278	86·50	293	103·63	307	120·03	321	136·14
279	87·63	294	104·80	308	121·20	322	137·28
280	88·75	295	105·97	309	122·37	323	138·42
281	89·87	296	107·14	310	123·53	324	139·56
282	90·99	297	108·31	311	124·69	325	140·70
283	92·11						

Elasticity of other vapours.

7. Mr Dalton has shown, that if we consider the expansion of mercury as according to the square of the temperature, then the force of vapour increases in a geometrical progression, by equal increments of temperature, reckoning these increments upon his new thermometric scale. The ratio of the progression he finds to be 1·321. In like manner the force of the vapour of ether increases in a geometrical progression, the ratio of which is 1·2278. But the increase of the force of the vapour of alcohol, of the specific gravity 0·87, he finds to be irregular. He has drawn as a conclusion from his experiments, that the vapour of all pure liquids increases in force in a geometrical progression to the

temperature, but the ratio is different in different fluids. The vapour of alcohol differs from this law, because it is in reality a mixture of two distinct vapours, namely, that of water, and that of alcohol. The following Table exhibits the force of vapour of ether and alcohol, for every ten degrees of Mr Dalton's new thermometer from the freezing to the boiling point of water, as ascertained by that gentleman's experiments *.

New Therm.	Force of Vap. of Ether in inches of Merc.	Force of Vap. of Alcohol in do.	New Therm.	Force of Vap. of Ether in inches of Merc.	Force of Vap. of Alcohol in do.
32° †	6·1	0·80	132°	46·54	8·2
42	7·57	0·93	142	57·03	10·2
52	9·16	1·08	152	69·88	13·9
62	11·22	1·3	162	85·62	17·9
72	13·77	1·6	172	104·91	22·4
82	16·85	2·1	182	128·5	29·3
92	20·65	2·8	192	157·5	
102	25·30	3·6	202	193·—	
112	31·—	4·7	212	236·5	
122	37·98	6·3			

Vapours are liquids combined with caloric.

7. Such are the phenomena of the conversion of liquids into elastic fluids. Dr Black applied his theory of latent heat to this conversion with great sagacity, and demonstrated that it is owing to the very same

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* Dalton's *New System of chemical philosophy*, p. 14.

† The corresponding degrees of the common thermometer will be found in page 502 of this volume. The degrees in the table were preserved to show the geometrical progression in the force of the vapour of ether.

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. The truth of this very important point was established by the following experiments.

First. When a vessel of water is put upon the fire, the water gradually becomes hotter till it reaches 212°; 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.

Dr Black put some water in a tin-plate vessel upon a red hot iron. The water was of the temperature 50°: in four minutes it began to boil, and in 20 minutes it was all boiled off. During the first four minutes it had received 162°, or $40\frac{1}{2}$° per minute. If we suppose that it received as much per minute during the whole process of boiling, the caloric which entered into the water and converted it into steam would amount to $40\frac{1}{2} \times 20 = 810°$ *. This caloric is not indicated by the thermometer, for the temperature of steam is only 212°; therefore Dr Black called it *latent heat*.

Second. Water may be heated in a Papin's digester to 400° without boiling; because the steam is forcibly

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* Black's *Lectures*, i. 157.

compressed, 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 $\frac{1}{5}$th 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 Dr Black, and afterwards, with more precision, by Mr Watt.

Third. When hot liquids are put under the receiver of an air pump, and the air is suddenly drawn off, the liquids boil, and their temperature sinks with great rapidity a considerable number of degrees. Thus water, however hot at first, is very soon reduced to the temperature of 70°; and ether becomes suddenly so cold that it freezes water placed round the vessel which contains it. In these cases the vapour undoubtedly carries off the heat of the liquid; but the temperature of the vapour is never greater than that of the liquid itself: the heat therefore must combine with the vapour, and become latent.

Fourth. 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 × 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 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 which the steam gives out during its condensation. From the experiments of Mr Watt made in this manner, it appears that the latent heat of steam amounts to 940°. The experiments of Mr Lavoisier make it rather more than 1000°.

General law discovered by Dr Black.

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.*

No person will dispute that this is one of the most important discoveries hitherto made in chemistry. Science seems indebted for it entirely to the sagacity of Dr

Black. Other philosophers indeed have laid claim to it; but these claims are either without any foundation, or their notions may be traced to Dr Black's lectures, or their opinions originated many years posterior to the public explanation of Dr Black's theory in the chemical chairs of Glasgow and Edinburgh.

Gases.

III. A very considerable number of bodies, both solids and liquids, may be converted into elastic fluids by heat; and as long as the temperature continues sufficiently high, they retain all the mechanical properties of gaseous bodies. It is exceedingly probable, that if we could command a heat sufficiently intense, the same change might be produced on all bodies in nature. This accordingly is the opinion at present admitted by philosophers. But if all bodies are convertible into elastic fluids by heat, it is exceedingly probable, that all elastic fluids in their turn might be converted into solids or liquids, if we could expose them to a low enough temperature. In that case, all the gases must be supposed to owe their elasticity to a certain dose of caloric: they must be considered as compounds of caloric with a solid or liquid body. This opinion was first stated by Amontons; and it was supported, with much ingenuity, both by Dr Black and by Lavoisier and his associates. It is at present the prevailing opinion; and it is certainly supported not only by analogy, but by several very striking facts.

Supposed to be liquids combined with caloric.

Condensed by cold.

1. If its truth be admitted, we must consider all the gases as capable of losing their elasticity by depriving them of their heat: they differ merely from the vapours in the great cold which is necessary to produce this change. Now the fact is, that several of the gases may be condensed into liquids by lowering their tempe-

ratures. Oxy-muriatic acid gas becomes liquid at a temperature not much under 40°; and at 32° it even forms solid crystals. Ammoniacal gas condenses into a liquid at —45°. None of the other gases have been hitherto condensed.

And pressure.

2. It is well known that the condensation of vapours is greatly assisted by pressure; but the effect of pressure diminishes as the temperature of vapours increases. It is very likely that pressure would also contribute to assist the condensation of gases. It has been tried without effect indeed in several of them. Thus air has been condensed till it was heavier than water; yet it showed no disposition to lose its elasticity. But this may be ascribed to the high temperature at which the experiment was made relative to the point at which air would lose its elasticity.

Objections to the opinion.

3. At the same time it cannot be denied, that there are several phenomena scarcely reconcileable to this constitution of the gases, ingenious and plausible as it is. One of the most striking is the sudden solidification which ensues when certain gases are mixed together. Thus when ammoniacal gas and muriatic acid gas are mixed, the product is a solid salt: yet the heat evolved is very inconsiderable, if we compare it with the difficulty of condensing these gases separately, and the great cold which they endure before losing their elasticity. In other cases, too, gaseous bodies unite, and form a new gas, which retains its elasticity as powerfully as ever. Thus oxygen gas and nitrous gas combined form a new gas, namely, nitric acid, which is permanent till it comes into contact with some body on which it can act.

III. CHANGES IN COMPOSITION.

Caloric decomposes bodies.

CALORIC not only increases the bulk of bodies, and changes their state from solids to liquids and from liquids to elastic fluids; but its action decomposes a great number of bodies altogether, either into their elements, or it causes these elements to combine in a different manner. Thus when ammonia is heated to redness, it is resolved into azotic and hydrogen gases. Alcohol, by the same heat, is converted into carbureted hydrogen and water.

1. This decomposition is in many cases owing to the difference between the volatility of the ingredients of a compound. Thus when weak spirits, or a combination of alcohol and water, are heated, the alcohol separates, because it is more volatile than the water.

2. In general, the compounds which are but little or not at all affected by heat, are those bodies which have been formed by combustion. Thus water is not decomposed by any heat which can be applied to it; neither are phosphoric or carbonic acids.

3. Almost all the combinations into which oxygen enters without having occasioned combustion, are decomposable by heat. This is the case with nitric acid, hyperoxymuriatic acid, and many of the metallic oxides.

4. All bodies that contain combustibles as component parts are decomposed by heat. Perhaps the metallic alloys are exceptions to this rule; at least it is not in our power to apply a temperature high enough to produce their decomposition, except in a few cases.

5. When two combustible ingredients and likewise oxygen occur together in bodies, they are always very

easily decomposed by heat. This is the case with the greater number of animal and vegetable substances.

But it is unnecessary to enlarge any farther on this subject, as no satisfactory theory can be given. The decompositions will all be noticed in describing the different compounds which are to occupy our attention in the subsequent part of this Work.

SECT. V.

OF THE QUANTITY OF CALORIC IN BODIES.

Having, in the second Section of this Chapter, shown that caloric is capable of moving through all bodies; and in the third, that it gradually diffuses itself through all contiguous bodies in such a manner that they assume the same temperature—the next point of discussion which presented itself was the quantity of caloric in bodies. When different bodies have the same temperature, do they contain the same quantity of caloric? Is the same quantity necessary to produce the same change of temperature in all bodies? What is the point at which a thermometer would stand if it were plunged into a body deprived of heat altogether? or what is the commencement of the scale of temperature? But these questions could not be examined with any chance of success while we were ignorant of the effects which caloric produces on bodies; because it is by these effects alone that the quantity of caloric in bodies is measured. This rendered it necessary for us to employ the fourth

Section in the examination of these effects. Let us now apply the knowledge which we have acquired to the investigation of the quantity of caloric in bodies. This investigation naturally divides itself into three parts: 1. The relative quantities of caloric in bodies, or the quantities in each necessary to produce a given change of temperature. This is usually termed *specific caloric.* 2. The absolute quantity of caloric which exists in bodies. 3. The phenomena of *cold,* or the absence of caloric. These three topics shall be examined in order.

I. Of the Specific Caloric of Bodies.

Specific caloric explained.

If equal weights of water and spermaceti oil, 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 oil 50°, it is reasonable to suppose that the water would be cooled 25° and the oil heated 25°, and that the temperature after the 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 83⅓°; consequently the water has only lost 16⅔, while the oil has gained 33⅓. On the other hand, if we mix together equal weights of water at 50°, and oil at 100°, the temperature, after agitation, will be only 66⅓, so that the oil has given out 33⅓, and the water has received only 16⅔. This experiment demonstrates, that the same quantity of caloric is not required to raise spermaceti oil a given number of degrees which is necessary to raise water the same number. The quantity of caloric which raises the oil

$12\frac{2}{3}$, raises water only $6\frac{1}{3}$; consequently the caloric which raises the temperature of water 1° will raise that of the same weight of spermaceti 2°.

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 spermaceti oil 2°, it follows, that the specific caloric of water is two times greater than that of the oil; therefore if the specific caloric of water = 1, that of spermaceti oil must be = 0·5. In this manner may the specific caloric of all bodies be found.

History.

That the specific caloric of bodies is different, was first pointed out by Dr Black in his lectures at Glasgow between 1760 and 1765 *. Dr Irvine afterwards investigated the subject between 1765 and 1770 †; and Dr Crawford published a great number of experiments

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* Black's *Lectures*, i. 504.

† Ibid.

Book. I. Division II.

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 ambiguity, and has introduced confusion into this subject[*].

The experiments of Mr Wilcke were first published in the Stockholm Transactions for 1772, but had been read to the Swedish Academy as early as 1771. 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. From the change of temperature, he deduced, by a very ingenious calculation, the specific caloric of the metal, that of water being considered as unity[†].

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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.

[†] The following is the process of reasoning by which he was led to

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

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his conclusions. He first 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. Therefore 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 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 $C = 32$, 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

Book I. Division II

different temperatures. These were published in his *Treatise on Heat.* In the first edition many errors had crept into his deductions, from his not attending to the chemical changes produced by mixing many of the subjects of his experiments. These were corrected by his

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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 paticles 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, the specific caloric of the water is to that of the metal as 1 to $\frac{N - 32}{c - N}$ *.

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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 a Celsius thermometer, as Mr Wilcke did. In it the freezing point is zero; and consequently, instead of 32 in the formula, 0 is always substituted.

subsequent experiments, and the corrections inserted in his second edition. The method which he employed was essentially the same with that which had been at first suggested by Dr Black. Two substances of different temperatures were mixed uniformly; and the change of temperature produced on each by the mixture was

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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°.	Temperature 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

considered as inversely proportional to its specific caloric *.

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	42·672	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 $\frac{1}{19{\cdot}712}$ 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.

* The specific caloric of water being considered as 1, the formula was as follows: Let the quantity of water (which usually constituted one of the substances mixed) be W, and its temperature *w*. Let the quantity of the other body, whose specific caloric is to be ascertained, be B, and its temperature *b*. Let the temperature after mixture be *m*. The speci-

To the labours of this ingenious and correct experimenter we are indebted for some of the most remarkble facts respecting specific caloric that are yet known*.

Several experiments on the specific caloric of bodies were made also by Lavoisier and Laplace, which from he well-known accuracy of these philosophers cannot but be very valuable.

Their method was exceedingly simple and ingenious; t was first suggested by Mr Laplace. 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 *ffff* (see section of the instrument fig. 11.) 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 *bbbb* is filled with ice. This ice is supported by the grate *mm*, and under the grate is placed a sieve. The external cavity *aaaa* is also filled with ice. We have remarked already, that

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fic caloric of B is $\frac{W \times \overline{m - w}}{B \times \overline{b - m}}$; or, when the water is the hotter of the bodies mixed, the specific caloric of B is $\frac{W \times \overline{w - m}}{B \times \overline{m - b}}$. See Black's *Lectures*, i. 506.

* To form an adequate notion of the delicacy of Dr Crawford's experiments, it will be necessary to peruse his own account of the precautions to which he had recourse. See his *Experiments on Animal Heat and Combustion*, p. 96. Seguin, in his Essay on Heat, *Ann. de Chim.* iii. 148. has done little else than translate Crawford.

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 immediately 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* 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 passes 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 spermaceti oil 0·5 of a pound; the specific caloric of water was one, and that of the oil 0·5. 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

Mr Wedgewood, one would be apt to conclude that is does not happen. He found that the melted ice, far from flowing out, actually *froze* again, and choak- l up the passage.

A Table of the specific caloric of various bodies was kewise drawn up by Mr Kirwan, and published by agellan in his Treatise on Heat. Mr Meyer has late- published a set of experiments on the specific caloric f dried woods; and Mr Leslie, in his Essay on Heat, as given us the result of his experiments on various odies. The experiments of Meyer were made by as- rtaining the rate of cooling of the same bulks of dif- rent bodies. From this he deduced their conducting ower for heat; and he considered the specific caloric s the reciprocal of the product of the conducting pow- r multiplied into the specific gravity of the body [*]. Ir Leslie likewise made his observations by ascertain- ng the time that various bodies of equal bulks took up n cooling in the same circumstances. He then multi- lied the proportional numbers thus got into the speci- ic gravity of the various bodies tried [†].

Mr Dalton has also turned his attention to this import- nt subject, and has lately published a table of the spe- ific heats of different bodies. His method was similar o that employed by Leslie; and Mr Dalton informs us hat he found that method susceptible of considerable recision.

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[*] Let L be the conducting power, A the specific caloric, and M the pecific gravity. According to Meyer we have $A = \frac{1}{LM}$. See *Ann. de* *him.* xxx. 46.

[†] See Leslie on *Heat*, p. 240.

The following Table exhibits a view of the specific heats of various bodies, as they have been obtained by different philosophers §.

Table of specific calorics.

I. GASES.

	Sp. Caloric.
Hydrogen . . .	21·4000*
Oxygen	4·7490*
Common air . .	1·7900*
Carbonic acid .	1·0454*
Azote	0·7936*

II. WATER.

Ice	0·9000† ·800(a)
Water	1·0000
Steam	1·5500*

III. SALINE SOLUTIONS.

	Sp. Caloric.
Carbonate of ammonia	1·851† 0·95 (D)
Sulphuret of amm. (0·818)	0·994†
Sulphate of magnesia . 1 Water . . . 2	0·844†
Common salt 1 Water . . . 8	0·832†
Ditto (1·197)	0·78 (D)
Nitre 1 Water 8	0·8167‡
Nitre 1 Water 3	0·646†
Carbonate of potash (1·30)	0·75 (D)
Muriate of ammonia . . 1 Water . . 1·5	0·798†
Tartar . . 1 Water . 237·3	0·765†
Sulphate of iron . . 1 Water . 2·5	0·734†
Sulphate of soda . 1 Water . 2·9	0·728†
Alum . . 1 Water . . 2·9	0·649†
Nitric acid 9⅓ Lime . . . 1	0·6189‡
Ditto (1·40) . .	0·62 (D)
Solution of br. sugar	0·086†
Ditto (1·17) . .	0·77(D)

IV. ACIDS AND ALKALIES.

Vinegar		0·92(D)
Nitric acid.	pale . . .	0·844†
	(1·20) .	0·76(D)
	(1·2989)	0·6613‡ 0·62(L)
	1·30 . . .	0·66(D)
	(1·355)	0·576†
	(1·36) . .	0·63(D)
Muriatic	(1·122)	0·680†
	1·153	0·60(D)

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§ Instead of giving the average, as in the former edition of this work, it has been thought more useful to insert the result as obtained by each experimenter.

		Sp. Caloric.
Sulph.	(1·885)	0·758†
	(1·872)	0·429† 0·34 (L)
	1·844	0·35(D)
	(1·87)	0·3345‡
		0·333 (a)
Do. 4, Water 5		0·6631‡
Do. 4, do. 3 . . .		0·6031‡
Do. equal bulks		0·52(D)
Aceticacid	(1·056)	0·66(D)
Potash	(1·346)	0·759†
Amm.	(0·997)	0·708†
	(0·948)	1·03(D)

V. INFLAMMABLE LIQUIDS.

		Sp. Caloric.
Alcohol		0·930 (a)
		0·6666*
		0·64 (L)
		0·602*
	(·817)	0·70(D)
		1·086†
	(·848)	·76(D)
Sulphuric ether	(0·76)	0·66(D)
Oil of olives .		0·718† 0·50 (L)
Linseed oil . . .		0·528†
Spermaceti oil		0·5000* 0·52(D)
Oil of turpent.		0·472† 0·400 (a)
Spermaceti . . .		0·399†
Ditto fluid . . .		0.320 (a)

VI. ANIMAL FLUIDS.

	Sp. Caloric.
Arterial blood .	1·0300*
Venous blood .	0·8928*
Cows milk .	0·9999* 0·98(D)

VII. ANIMAL SOLIDS.

	Sp. Caloric.
Ox-hide with hair	0·7870*
Lungs of a sheep	0·7690*
Lean of ox-beef	0·7400*

VIII. VEGETABLE SOLIDS.

	Sp. Caloric.
Pinus sylvestris	0·65¶
Pinus abies . . .	0·60¶
Tilea Europæa .	0·62¶
Pinus picea . . .	0·58¶
Pyrus malus . .	0·57¶
Betula alnus . .	0·53¶
Quercus robur sessilis	0·51¶
Fraxinus excelsior	0·51¶
Pyrus communis	0·50¶
Rice	0·5060*
Horse beans . .	0·5020*
Dust of the pine tree	0·5000*
Peas	0·4920*
Fagus sylvatica .	0·49¶
Carpinus betulus	0·48¶
Betula alba	0·48¶
Wheat	0·4770*
Elm	0·47¶
Quercus robur pedunculata	0·45¶
Prunus domestica	0·44¶
Diaspyrus ebenum	0·43¶
Barley	0·4210*
Oats	0·4160*
Pit-coal	0·28(D) 0·2777*
Charcoal	0·2631*
Cinders	0·1923*

IX. EARTHY BODIES, STONEWARE AND GLASS.

	Sp. Caloric.
Hydrate of lime	0·40(D)
Chalk	0·27(D) 0·2564*
Quicklime . .	0·30(D) 0·2229* 0·2168‡

	Sp. Caloric.
Ashes of pit-coal	0·1855*
Ashes of elm . .	0·1402*
Agate	0·195§
Stoneware . . .	0·195†
Crownglass . .	0·200(a)
Crystal	0·1929‡
Swedish glass . .	0·187§
Flint glass .	0·19(D) 0·174†
X. Sulphur .	0·19(D) 0·183†
Muriate of soda .	0·23(D)

XI. Metals.

	Sp. Caloric.
Platinum . . .	0·13(a)
Iron	0·143(a) 0·13(D) 0·125† 0·1269* 0·126§
Bras	0·1123* 0·116§ 0·11(D)
Copper . . .	0·1111* 0·114§ 0.11(D)
Sheet iron . . .	0·1099‡
Gun metal . . .	0·1100‖
Nickel	0·10(D)
Zinc	0·0943* 0·102§ 0·10(D)
Silver	0·082§ 0·08(D)
Tin	0·068† 0·0704* 0·07(D) 0·060§
Antimony . .	0·086† 0·0645* 0·063§ 0·06(D)
Gold	0·050§ 0·05(D)
Lead	0·050† 0·0352* 0·042§ 0·04(D)
Bismuth . . .	0.043§ 0·04(D)
Mercury . .	0·033† 0·0357* 0·0290‡ 0·0496(D)

XII. Oxides.

	Sp. Caloric.
Oxide of iron . .	0·320†
Rust of iron . .	0·2500*
Ditto nearly free from air	0·1666*
White oxide of antim. washed	0·220† 0·2272*
Do. nearly freed from air	0·1666*
Oxide of copper, do.	0·2272*
Oxide of lead and tin	0·102†
Oxide of zinc, do.	0·1369*
Oxide of tin nearly freed from air	0·0990* 0·096†
Yellow oxide of lead, do.	0·0680* 0·068†

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* Crawford; † Kirwan; ‡ Lavoisier and Laplace; § Wilcke; ¶ Meyer; (L) Leslie; ‖ Count Rumford; (D) Dalton, *New System of Chemical Philosophy*, p. 62. (a) Irvine. *Essays*, p. 84 and 88.

Chap. II.

The specific heats of the gases contained in the preceding table, were determined by Dr Crawford with much ingenuity and patient industry ; yet from the extreme difficulty of the subject, there is little reason for believing that the results which he obtained are very near approximations to the truth. If any confidence can be put in the hypothesis of Gay-Lussac, we are certain that some of the numbers of Crawford must be very erroneous. When the density of any gas is suddenly changed, it always undergoes a corresponding change of temperature. If the gas becomes rarer, a thermometer placed in it sinks ; but if the gas becomes denser, or if it rushes into a vacuum, the thermometer rises. Now Gay-Lussac supposes, that in these cases (other things being equal) the change of temperature will be proportional to the specific heat of the gas. He procured two globular glass vessels of the same capacity, put into each a delicate spirit thermometer, then exhausted each by means of an air-pump, filled one of them with the gas to be examined, and after waiting till they had acquired the temperature of the room, opened a communication between them by means of a stopcock and tube, so contrived that the aperture could be diminished at pleasure, in order that each gas might be made to occupy the same time in passing from the one vessel to the other. The thermometer in the full glass vessel immediately subsided, while that in the vacuum rose; and in Gay-Lussac's experiments the fall of the one thermometer was very nearly the same as the rise in the other. The greatest change of temperature was produced when hydrogen gas was employed: common air produced a smaller change than hydrogen, oxygen gas a smaller change than common air, and carbonic acid a smaller than oxygen gas. From these experiments Gay-Lussac considers it as probable, that the greater the specific gravity of a gas, the less is its specific heat *. Mr Dalton has lately turned his attention to the specific heats of gaseous bodies, and has calculated, from data furnished by a theory of his, to be explained in a subsequent part of this work, that the specific heats of the different gases ought to be as in the following Table, supposing as usual the specific heat of water = 1 †.

Gases.	Sp. Caloric.	Gases.	Sp. Caloric.
Hydrogen gas	9·382	Olefiant gas	1·555
Azotic	1·866	Nitric acid	0·491
Oxygen	1·333	Carbonic oxide	0·777
Air	1·759	Sulphureted hydro.	0·583
Nitrous gas	0·777	Muriatic acid	0·424
Nitrous oxide	0·549	Aqueous vapour	1·166
Carbonic acid	0·491	Ether vapour	0·848
Ammonia	1.555	Alcohol vapour	0·586
Carbureted hydro.	1·333		

If any confidence can be put in the accuracy of this table, it is clear that the hypothesis of Gay-Lussac is without foundation. Indeed, a few simple considerations on the phenomena of combustion, are sufficient to show us that the specific heat of gaseous bodies cannot be inversely as their specific gravity.

The following are the most important points respecting the specific caloric of bodies hitherto investigated.

General results.

1. Dr Crawford made a great many experiments re-

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* *Mem. d'Arcueil*, i. 180.

† *New System of Chemical Philosophy*, p. 74.

lative to the specific caloric of bodies at different temperatures, and the result of them was, that it is nearly permanent in the same body, while that body remains in the same state. His reasoning is founded upon two suppositions, neither of which have been sufficiently proved: 1. That the mercurial thermometer is an accurate measure of heat; 2. That heat does not unite chemically to bodies. With these data he shows, that the specific caloric of water does not vary at different temperatures. And, finally, by mixing bodies at various temperatures with water, he established the permanency of their specific calorics *. As this reasoning is founded on inadmissible suppositions, it is not quite legitimate. Mr Dalton has lately endeavoured to show that the specific heat of all bodies increases with their temperature; and his reasoning, though not quite conclusive, is at least very plausible and probable.

2. Whenever a body changes its state, its specific caloric changes at the same time, according to the following law. When a solid becomes a liquid, or a liquid an elastic fluid, the specific caloric *increases*; when an elastic fluid becomes a liquid, or a liquid a solid, the specific caloric *diminishes*. This very important discovery was made by Dr Irvine, and applied by him, with much sagacity, to the explanation of a great variety of curious and important phenomena.

3. The specific caloric of bodies is increased by combining them with oxygen. Thus the specific caloric of metallic oxides is greater than that of metals, and of acids than of their bases. This fact was discovered by

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* Crawford *on Heat*, p. 53.

Dr Crawford, and constituted the foundation of his theory of animal heat.

4. The specific caloric of oxygen is diminished when it enters into combination with inflammable bodies. This was also established by Dr Crawford, though not n a manner quite so satisfactory.

II. OF THE ABSOLUTE QUANTITY OF HEAT IN BODIES.

THUS we see that the relative quantity of caloric is very different in different bodies, even when they are of the same temperature by the test of the thermometer. It is obvious, therefore, that the thermometer is not capable of indicating the quantity of caloric contained in bodies: since, not to mention the specific caloric, the presence of the caloric which occasions 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?

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.

1 It is obvious, that if the specific caloric of bo-

Hypothesis of Dr Irvine.

ies continues the same at all temperatures, the abso-ute quantity of caloric in bodies must be proportional o the specific caloric. Thus if the specific caloric of permaceti oil be only half of that of water, water must ontain twice as much caloric as spermaceti oil of the ame temperature. Let us suppose both bodies to be otally deprived of caloric, and that we apply to them a hermometer, the zero point of which indicates absolute old or a total deprivation of heat. To raise the oil nd water one degree, we must throw in a certain quantity of heat, and twice as much heat will be ne-cessary to produce the effect upon the water as on the oil. To produce a temperature of two degrees, the same rule must be observed; and so on for three, four, and any number of degrees. Thus at all temperatures the water would contain twice as much caloric as the oil.

2. This supposition, that the specific caloric of bodies continues the same at all temperatures, was the foundation of Dr Irvine's reasoning. He had ascertained, that when a body changes from a solid to a liquid, its specific caloric at the same time increases; and that the same increase is observable when a liquid is converted into an elastic fluid. The constancy of the specific caloric of bodies, on which he founded his theory, was true only while they remained in the same state. He supposed likewise, that when a solid body is converted into a liquid, the caloric absorbed without any increase of temperature, or the latent heat, is merely the consequence of the increase of the specific caloric of the body. Thus when ice is converted into water, 140° of caloric are absorbed, because the specific caloric of water is so much greater than that of ice, as to require

140° additional of caloric to preserve the same temperature which it had when its specific caloric was less. The same supposition accounted for the absorption of caloric when liquids are converted into elastic fluids.

3. Dr Irvine's theory of the absolute caloric of bodies depended upon these two opinions, which he considered as first principles. The first gave him the ratio of the absolute calorics of bodies; the second, the difference between two absolute calorics. Having these data, it was easy to calculate the absolute quantity of caloric in any body whatever. Thus let us suppose that the specific caloric of water is to that of ice as 10 to 9, and that when ice is converted into water the quantity of caloric absorbed is 140°. Let us call the absolute quantity of caloric in ice at 32° x, it is obvious that the absolute caloric in water at 32° is $= x + 140°$. We have then the absolute caloric of ice $= x$, that of water $= x + 140$. But these quantities are to each other as 10 to 9. Therefore we have this proportion $10 : 9 :: x + 140 : x$. By multiplying the extremes and means we get this equation $10\,x = 9\,x + 1260$, from which we deduce $x = 1260$. Thus we obtain the absolute quantity of caloric in ice of 32°, and find it to amount to 1260. Water at 32° of course contains 1400 degrees of caloric. Or, to state the proposition differently; as the specific caloric of water is to that of ice as 10 to 9, it is obvious that the 140 degrees of heat which are evolved when water is frozen are equal to $\frac{1}{10}$th of the whole heat in the water. Therefore the heat of the water is equal to 140×10, or 1400.

Such was the ingenious method proposed by Dr Irvine for ascertaining the real zero, or the degree at which a thermometer would stand when plunged into a body altogether destitute of caloric. We see, that by the above calculation it would be with regard to ice 1260 degrees below 32° of Fahrenheits scale, or 1298 degrees below 0. Dr Crawford, however, who made his experiments upon a different set of bodies, places the real zero at 1500° below 0 of Fahrenheit. Mr Dalton, who has also turned his attention to the same question, has found the mean of his experiments to give 6000° below the freezing point as the real zero *.

4. Unfortunately the truth of the principles on which this theory of Dr Irvine is founded is by no means established. The first proposition, that the specific caloric of bodies continues the same at all temperatures, has by no means been ascertained by experiments; so far from it, that the very contrary has been proved by Dr Irvine himself to hold in the case of spermaceti and wax, and has been observed by Crawford in other cases †. But even if it did hold at all temperatures while bodies continue in the same state, still as every change of state is confessedly attended with a corresponding change of specific caloric, we have no right to affirm that the specific caloric is proportional to the absolute caloric. For instance, though the specific caloric of ice be to that of water as 9 to 10, it does not follow that their absolute calorics bear the same proportion: nor can any reason be assigned for supposing that this ratio ought to hold, unless we suppose that caloric is incapable of uniting chemically to bodies; in which case indeed it might be admitted.

5. The second proposition, namely, that the caloric

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* *New System of chemical philosophy*, p. 97.

† *On Heat*, p. 478.

absorbed by a body, during its change of state, is merely owing to the change of the specific caloric of the body, is equally unsupported by direct proof, and indeed cannot be admitted, if we allow that caloric is capable of combining chemically with bodies. It assigns no reason for the change of state which the body has undergone, while the theory of Dr Black accounts for that change. The 940 degrees of heat which disappear when water becomes steam, according to Dr Irvine, are merely the consequence of the increased specific caloric of steam above that of water. But why does water become steam, and why does it show a tendency to absorb heat before it has actually become steam; a tendency causing it to exert a force which at last overcomes the most powerful obstacles? If the change be produced by the combination of heat, as all the phenomena announce, then the hypothesis of Irvine is inadmissible. Accordingly, both Irvine and Crawford laid it down as an axiom, that heat is incapable of combining with bodies.

6. Another set of phenomena from which Dr Irvine drew his conclusions, is more susceptible of investigation. When bodies unite together chemically, a change of temperature is almost constantly produced; the compound either giving out heat or absorbing it. Dr Irvine ascertained, by a variety of experiments, that the combination is attended with a similar change in the specific heat of the compound *. When the specific caloric increases, the compound generates cold; when the specific caloric diminishes, heat is evolved.

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* Crawford *on Heat*, p. 455.

He inferred, in consequence of his opinion formerly explained, that the heat evolved or absorbed in these cases was proportional to the change of specific caloric, and the consequence of that change. Hence it was easy, knowing the specific caloric of two bodies before combination, the specific caloric of the compound, and the heat evolved or absorbed, to ascertain upon that hypothesis the absolute heat of the body. For example, let the specific caloric of two bodies before combination be $= 2$, and after it $= 1$, it is obvious, that during combination they must have parted with half of their absolute heat. Let the heat evolved be 700; then we know that the whole heat contained in the bodies is twice 700, or 1400. Suppose equal weights of the two bodies A, B to be combined together. Let the specific caloric of A be C, and that of B, c; and let the specific caloric after combination be $\overline{K+k}$, then, according to Dr Irvine, we have $C+c-\overline{K+k} : \overline{K+k} :: l =$ the heat evolved : S = absolute heat. Hence we have $S = \frac{l(K+k)}{C+c-K-k}$. If the weights of the bodies combined be not equal, then let Q be the weight of A, and q that of B; we have as before, $CQ+cq-\overline{KQ+kq} : \overline{KQ+kq} :: l : S$. Hence $S = \frac{l(KQ+kq)}{CQ+cq-KQ-kq}$ This hypothesis can be true only on the supposition that the quantity S, found by mixing substances together in different proportions, turns out always the same quantity. If it does not, the opinion falls to the ground. Thus if we mix together various proportions of water and concentrated sulphuric acid, the heat evolved at each trial, compared with the change of the specific caloric, ought to give us the same value of S. But from the experiments that have been made upon this subject, it does not appear that any such constant value of S is observed. The experiments indeed of Gadolin approach somewhat to it, but those of Lavoisier and Laplace are very anomalous, as will appear from the following statement.

From the experiments of Lavoisier and Laplace on a mixture of water and quicklime, in the proportion of 9 to 16, it follows that the real zero is 3428° below 0.

From their experiments on a mixture of four parts of sulphuric acid and three parts of water, it follows that the real zero is 7262° below 0.

Their experiments on a mixture of four parts of sulphuric acid and five of water place it at 2598° below 0.

Their experiments on $9\frac{1}{3}$ parts of nitric acid and one of lime place it at $\frac{1889}{-0\cdot01783}$ below 32°, = + 23837° *.

The mean result of Gadolin's experiments on mixtures of sulphuric acid and water, place it at 2300° below 0.

Mr Dalton's results vary from 4150° to 1100°; the mean of the whole places the real zero at 6150° below 32° †.

Dr Irvine's own experiments led him to fix the real zero at 900° below 0.

Dr Crawford, from his experiments, placed it at 1500° below 0.

These results differ from one another so enormously, and the last of those obtained by Lavoisier and Laplace,

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* See Seguin, *Ann. de Chim.* v. 231.

† *New System of Chemical Philosophy*, p. 97.

which places the real zero far above a red heat, is so absurd, that if we suppose them accurate, they are alone sufficient to convince us that the data on which they are founded are not true. Nor can the hypothesis be maintained till the anomalies which they exhibit be accounted for.

Mr Dalton's hypothesis.

7. Another method of determining the absolute quantity of caloric in bodies has been lately proposed by Mr Dalton *, a philosopher whose ingenuity and sagacity leave him inferior to none that have hitherto turned their attention to this difficult subject. He supposes that the repulsion which exists between the particles of elastic fluids is occasioned by the caloric with which these particles are combined, and that it is always proportional to the absolute quantity of caloric so combined. Now the diameter of the sphere over which the influence of a particle extends, is the measure of the repulsion, and it is proportional to the cube root of the whole mass. The repulsion exerted by the particles of an elastic fluid, at different temperatures, is proportional to the cube root of the bulk of the fluid in these temperatures. Therefore, according to this hypothesis, the absolute quantity of caloric in elastic fluids, at different temperatures, is proportional to the cube roots of these bulks at these temperatures. To give an example: The bulk of air at 55° being 1000, its bulk at 212° is 1325; therefore the absolute heat in air at 55° is to its heat at 212° as $\sqrt[3]{1000}$ to $\sqrt[3]{1325}$, or nearly as 10 to 11. Let us call the absolute heat of air at 55° x; then the absolute heat of air at 212° is $x +$

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* *Manchester Memoirs*, v.

157. This gives us the following proportion; 10 : 11 : : x : $x + 157$. Hence $11\,x = 10\,x + 1570$, and $x = 1570$. Thus we obtain 1570 for the absolute heat in air at 55°. Subtracting these 55 degrees, we have 1515° below 0 for the point of real zero *.

Such is the hypothesis of Mr Dalton; and the result which he obtained corresponds pretty nearly with Dr Crawford's deductions from some of his experiments: But if it be applied to other temperatures, no such exact coincidence will be observed, as has been very well shown by an anonymous writer in Nicholson's *Journal* †. It appears from the examples there produced, that the higher the temperature at which the comparison is made, the lower is the point obtained for the commencement of the scale of heat. But Mr Dalton has rendered it probable that this is owing to the thermometer not being an accurate measure of the scale of temperature ‡; for when the temperature is corrected by Deluc's experiments, the anomaly in one of the instances disappears.

Insufficient.

This hypothesis of Mr Dalton is founded on a supposition which, though it cannot be demonstrated, is nevertheless exceedingly probable to a certain extent: for if elastic fluids owe their peculiar fluidity to heat, and if their increase of elasticity be proportional to their increase of heat, I do not see how it can be denied that the repulsion between the particles of these bodies is proportional to the caloric combined with them; not, however, to the whole of their caloric, but to that por-

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* *Manchester Memoirs*, v. 601.

† 1803, vol. iv. 223.

‡ *Ibid.* v. 34.

tion of it only which occasions their elasticity, and which increases their elasticity. It is at present believed that the abstraction of heat is capable of converting elastic fluids into liquids, and even into solids. Mr Dalton himself is a supporter of this opinion, which, in the present state of our knowledge, scarcely admits of dispute. But the particles of liquids and solids do not repel one another, but possess a contrary property; they attract one another; yet they all confessedly contain a great deal of heat. Were we then to convert elastic fluids into liquids, by abstracting heat from them, we would deprive their particles of the repulsive force which they exert, and yet leave a considerable quantity of caloric in them. It is not the whole of the caloric, then, which is combined with the particles of elastic fluids, that occasions their repulsion, but only a part of it. Now surely it will not be said, that the repulsive force of the particles of elastic fluids is proportional to that caloric which has no effect in producing the repulsion, and which would remain in combination, though that repulsion were annihilated. It can only be proportional to that portion of the caloric which occasions repulsion. Mr Dalton's hypothesis, then, only enables us to find out the quantity of caloric which occasions the elastic fluidity of the bodies in question, and by no means the whole of the caloric which they contain, unless they were supposed to continue in the state of elastic fluids till deprived of all the heat which they contain except the last particle: which is a supposition that cannot be made. It does not even give us any precise notion of the caloric of elastic fluidity, unless we ascertain the specific caloric of the body in question; and after we have done so, reduce the degrees of caloric of fluidity to a known standard, as to the number of degrees which they would raise the temperature of water, supposing it not to change its state. This indeed is absolutely necessary in all cases when we wish to speak definitely of the real zero: For as more heat is necessary to raise one body a certain number of degrees than to produce the same change on another, suppose we were to deprive these bodies altogether of heat, and then to raise them both to a certain temperature, the number of degrees of heat added to both would be equal; yet the absolute quantity of heat added to both would be very unequal. The term real zero can have no meaning whatever, as far as it alludes to the quantity of heat in bodies, unless we always refer to some particular body, as water, and make it our standard.

Thus it appears that none of the methods hitherto proposed are sufficient to enable us to discover the quantity of heat in bodies. At the same time, I have not the smallest doubt, from the known sagacity and precision of Mr Dalton, that much curious and important information will result from his farther prosecution of the subject.

III. Of Cold.

Having pointed out the methods of ascertaining the relative quantity of heat in bodies of the same temperature, and explained the various hypotheses respecting their absolute heats, it remains for us only to make a few observations on the abstraction of heat from bodies, or on what in common language is called *cold*.

Sensations of heat and cold explained.

When caloric combines with our own bodies, or separates from them, we experience, in the first case, 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 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

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* This experiment, or at least a similar one, was made long ago, and is found in the Essays of the Academy del Cimento, translated by Waller in 1684, p. 103. The ninth experiment, of reflected cold, is thus related: " We were willing to try, if a concave glass, set before a mass of 500 lbs of ice, made any sensible repercussion of cold upon a very nice thermometer of 400 degrees, placed in its focus. The truth is, it immediately began to subside; but, by reason of the nearness of the ice, it was doubtful whether the direct or reflected rays of cold were more efficacious: upon this account, we thought of covering the glass, and (what-

Apparent reflection of cold.

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 recollect that caloric is constantly radiating from all bodies. 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. Such nearly is the explanation of this singular fact offered by Prevost and Dr Hutton. But it cannot be denied that this explanation, ingenious as it is, is very far from

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ever may be the cause) the spirit of wine did indeed presently begin to rise: for all this, we dare not be positive but there might be some other cause thereof, besides the want of the reflection from the glass, since we were deficient in making all the trials necessary to clear the experiment." See *Journals of the Royal Institution*, i. 224.

being satisfactory. If Mr Leslie could prove that the supposed rays of heat are aerial pulses, he would account for the phenomena in a satisfactory manner.

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 various papers published in the Philosophical Transactions from 1787 to 1801. Several curious additions have been made by Professor Lowitz, particularly the introduction of *muriate 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 Tables, which I transcribe from a paper with which I have been lately favoured by Mr Walker.

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* *Ann. de Chim.* xxii. 297. and xxix. 281.

† *Phil. Trans.* 1801, p. 120.

TABLE I.

Frigorific mixtures *without ice.*

Mixtures.	Thermometer sinks.	Degree of cold produced.
Parts. uriate of ammonia ... 5 trate of potash ...... 5 ater 16	From +50° to +10°.	40
uriate of ammonia . 5 itrate of potash ...... 5 lphate of soda .... 8 ater 16	From +50° to +4°.	46
itrate of ammonia ... 1 ater 1	From +50° to +4°.	46
itrate of ammonia ... 1 rbonate of soda ...... 1 ater 1	From +50° to —7°.	57
lphate of soda ...... 3 iluted nitric acid 2	From +50° to —3°.	53
lphate of soda ...... 6 uriate of ammonia .... 4 trate of potash ...... 2 luted nitric acid 4	From +50° to —10°.	60
lphate of soda ...... 6 itrate of ammonia ... 5 iluted nitric acid ... 4	From +50° to —14°.	64
osphate of soda ...... 9 iluted nitric acid 4	From +50° to —12°.	62
hosphate of soda ...... 9 itrate of ammonia ... 6 iluted nitric acid 4	From +50° to —21°.	71
ulphate of soda .... 8 uriatic acid 5	From +50° to 0°	50
ulphate of soda .... 5 iluted sulphuric acid . 4	From +50° to +3°.	47

N. B. If the materials are mixed at a *warmer* temperature than that xpressed in the table, the effect will be proportionably *greater*; thus, if he most powerful of these mixtures be made, when the air is +85°, it will sink the thermometer to + 2°.

TABLE II.

Frigorific Mixtures *with Ice.*

Mixtures.	Parts.	Thermometer sinks.	Degree of cold produced.
Snow, or pounded ice Muriate of soda	2 1	*From any Temperature.* to —5°	*
Snow, or pounded ice Muriate of soda Muriate of ammonia	5 2 1	to —12°	*
Snow, or pounded ice Muriate of soda Muriate of ammonia Nitrate of potash	24 10 5 5	to —18°	*
Snow, or pounded ice Muriate of soda Nitrate of ammonia	12 5 5	to —25°	*
Snow Diluted sulphuric acid	3 2	From +32° to —23°	55
Snow Muriatic acid	8 5	From +32° to —27°	59
Snow Diluted nitric acid	7 4	From +32° to —30°	62
Snow Muriate of lime	4 5	From +32° to —40°	72
Snow Chryst. muriate of lime	2 3	From +32° to —50°	82
Snow Potash	3 4	From +32° to —51°	83

TABLE III.

Combinations of Frigorific Mixtures.

Mixtures.	Parts.	Thermometer sinks.	Degree of cold produced
Phosphate of soda …… Nitrate of ammonia … Diluted nitric acid ……	5 3 4	From 0° to —34°	34
Phosphate of soda …… Nitrate of ammonia … Diluted mixed acids …	3 2 4	From —34° to —50°	16
Snow …………………… Diluted nitric acid ……	3 2	From 0° to —46°	46
Snow …………………… Diluted sulphuric acid Diluted nitric acid …	8 3 3	From —10° to —56°	46
Snow …………………… Diluted sulphuric acid .	1 1	From —20° to —60°	40
Snow …………………… Muriate of lime ………	3 4	From +20° to —48°	68
Snow …………………… Muriate of lime ………	3 4	From +10° to —54°	64
Snow …………………… Muriate of lime ………	2 3	From —15° to —68°	53
Snow …………………… Chryst. muriate of lime	1 2	From 0° to —66°	66
Snow …………………… Chryst. muriate of lime	1 3	From —40° to —73°	33
Snow …………………… Diluted sulphuric acid	8 10	From —68° to —91°	23

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 first freezing mixture in the second 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. III.

OF THE SOURCES OF CALORIC.

Having in the preceding Sections examined the nature, properties, and effects of caloric, as far as the subject has been hitherto investigated, it now only remains

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* Walker, *Phil. Trans.* 1795.

for us to consider the different methods by which caloric may be evolved or made sensible, or the different sources from which it may be obtained. These sources may be reduced to five: It *radiates* constantly from the sun; it is evolved during combustion; and it is extricated in many cases by percussion, friction, and mixture. The sources of heat, then, are the *sun*, *combustion*, *percussion*, *friction*, *mixture*. Let us consider each of these sources in the order in which we have enumerated them.

I. THE SUN.

Nature of the sun.

THE sun, which constitutes as it were the vital part of the whole solar system, is an immense globe, whose diameter has been ascertained by astronomers to be no less than 888,246 miles, and which contains about 333,928 times as much matter as the earth. Philosophers long supposed that this immense globe of matter was undergoing a violent combustion; and to this cause they ascribed the immense quantity of light and heat which are constantly separating from it. But the late very curious and important observations of Dr Herschel leave scarcely any room for doubting that this opinion is erroneous *. From these observations it follows, that the sun is a solid opaque globe, similar to the earth or other planets, and surrounded by an atmosphere of great density and extent. In this atmosphere there float two regions of clouds: The lowermost of the two is opaque and similar to the clouds which form in our

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* *Phil. Trans.* 1801, p. 265.

atmosphere; but the higher region of clouds is luminous, and emits the immense quantity of light to which the splendour of the sun is owing. It appears, too, that these luminous clouds are subject to various changes both in quantity and lustre. Hence Dr Herschel draws as a consequence, that the quantity of heat and light emitted by the sun varies in different seasons; and he supposes that this is one of the chief sources of the difference between the temperatures of different years.

Emits three species of rays.

1. From the experiments of Herschel, Bockman, and Wollaston, it follows that the sun emits three kinds of rays; namely, *calorific*, *colorific*, and *deoxidizing*. The first occasions *heat*, the second *colour*, and the third separates oxygen from various bodies.

These rays heat opaque bodies in proportion to the darkness of their colour.

2. When the solar rays strike transparent bodies, they produce very little effect; but opaque bodies are heated by them. Hence it follows that transparent bodies allow these rays to pass through them; but that they are detained, at least in part, by opaque bodies. The deeper the colour of the opaque body, the greater is the rise of temperature which it experiences from exposure to the sun's rays. 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 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

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* Beddoes's *Contributions*, p. 4.

† *Phil. Trans.* 1792.

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 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†.

Heat produced by the rays of the sun.

3. The temperature produced in bodies by the direct action of the sun's rays seldom exceeds 120°; but a much higher temperature would be produced if we were to prevent the heat communicated from being carried off by the surrounding bodies. Mr Saussure made a little box lined with fine dry cork, the surface of which was charred to make it black and spongy, in order that it might absorb the greatest possible quantity of the sun's rays, and be as bad a conductor of caloric as possible. It was covered with a thin glass plate. When this box was set in the sun's rays, a thermometer laid in the bottom of it rose in a few minutes to 221°; while the temperature of the atmosphere was only 75° ‡. Professor Robison constructed an apparatus of the same kind, employing three very thin vessels of flint glass, which transmit more caloric than any of the other species of glass. They were of the same shape,

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* *Phil. Trans.* 1780.

† *Sur le Feu*, chap. iv.

‡ *Voyages sur les Alpes*, ii. 932.

arched above, with an interval of $\frac{1}{3}$ inch between them. They were set on a cork base prepared like Saussure's, and placed on down contained in a pasteboard cylinder. With this apparatus the thermometer rose often in a clear summer day to 230°, and once to 237°. Even when set before a bright fire, the thermometer rose to 212°[*].

By burning glasses.

4. Such is the temperature produced by the direct rays of the sun. But 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.

Count Rumford has shown by direct experiment, that the heating power of the solar rays is not increased by concentrating them into a focus, but that the intensity of their action is occasioned by a greater number of them being brought to bear upon the same point at once[†].

5. These facts, which have been long known, induced philosophers to infer, that the fixation of light in bodies always raises their temperature. On the other

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[*] Black's *Lectures*, i. 547. When the apparatus was carried to a damp cellar before the glasses were put in their places, so that the air within was moist, the thermometer never rose above 208°. Hence Dr Robison concluded, that moist air conducts better than dry; a conclusion fully confirmed by the subsequent experiments of Count Rumford.

[†] *Jour. de Phys.* lxi. 37.

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.

Owing to the fixation of caloric.

6. But the recent discoveries in this part of chemistry have destroyed all the evidences on which these conclusions were drawn. Not only light, but caloric also, radiates from the sun. We cannot therefore ascribe the rise of temperature to the absorption of light, but to the absorption of caloric; especially as the rays of the moon, though luminous, occasion no rise of temperature. The facts, then, oblige us to conclude, that the sun emits rays of caloric; that these rays are absorbed by opaque bodies, and detained by them; and that the absorption, other things being equal, is proportional to the darkness of the colour of the absorbing body. Thus it appears, that when a body is acted on by rays of caloric, the change of temperature depends upon its opacity and colour. In this respect caloric agrees with light. But when caloric is *conducted* to a body, its opacity or colour does not influence the subsequent change of temperature.

II. COMBUSTION.

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 about 800°, it kindles, becomes intensely hot, and continue to emits 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.

1. 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.

2. A much more ingenious and satisfactory hypothe-

Hooke's theory of combustion.

sis was proposed in 1665 by Dr Hooke. According to this extraordinary man, there exists in common air a certain substance which is like, if not the very same with that which is fixed in saltpetre. 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 *.

Adopted by Mayow.

About ten years after the publication of Hook's *Micrographia*, His theory was adopted by Mayow, without acknowledgement, 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,

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* Hook's *Micrographia*, p. 103. See also his *Lampas*.

† *De Sal-nitro et Spiritu Nitro-aereo.*

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 all 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 Stahl.

3. 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, 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.

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[*] 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.

This substance is precisely the same in all combustibles. These bodies of course owe their diversity to other ingredients which they contain, and 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, is peculiarly disposed to be affected by a violent whirling motion. The heat and the light, which make their appearance during combustion, are merely two properties of phlogiston when in this state of violent agitation.

Improved.

4. The celebrated Macquer, to whose illustrious labours several of the most important branches of chemistry owe their existence, was one of the first persons 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 or 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.

5. 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.

Modified by Priestley,

6. 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 without 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, the origin of the heat and light which appear during combustion remains to be accounted for;

since phlogiston, if it separates from the combustible merely by combining with air, cannot surely act upon those bodies in what state soever we may suppose them.

By Crawford,

7. The celebrated Dr Crawford was the first person who attempted to solve this difficulty, by applying to the theory of combustion Dr Black's doctrine of latent heat. 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

8. 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, Westrumb, Hermbstadt, Karsten, 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

e attempted in a treatise published on purpose, intitled, *An Essay on Phlogiston and the Constitution of Acids* *.

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* I have omitted, in the historical view given in the text, the hypohesis published in 1777 by Mr Scheele, one of the most extraordinary en that ever existed. When very young, he was bound apprentice to n apothecary at Gottenburgh, where he first felt the impulse of that geius which afterwards made him so conspicuous. He durst not indeed evote himself openly to chemical experiments; but he contrived to make imself master of that science by devoting those hours to study which vere assigned him for sleep. He afterwards went to Sweden, and settled s an apothecary at Koping. Here Bergman first found him, saw his nerit, and encouraged it, adopted his opinions, defended him with zeal, nd took upon himself the charge of publishing his treatises. Encouraged nd excited by this magnanimous conduct, the genius of Scheele, though nassisted by education or wealth, burst forth with astonishing lustre; nd at an age when most philosophers are only rising into notice, he had inished a career of discoveries which have no parallel in the annals of hemistry. 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.

In 1777, Scheele published a treatise, entitled *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 tumbled to the ground; but the importance of the materials will always be admired, and the ruins of the structure must remain eternal monuments of the genius of the builder.

Refuted by Lavoisier.

9. 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 of 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 of its existence, excepting only its conveniency in explaining combustion. The proof of 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.

10. 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 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 was 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.

11. 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.

According to the theory of Lavoisier, which is now almost generally received, and considered by chemists as a full explanation of the phenomena, 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. Such is a short historical detail of the improvements gradually introduced into this interesting part of the science of chemistry. Let us now take a more particular view of the subject.

12. By combustion is meant a total change in the nature of combustible bodies, accompanied by the copious emission of heat and light. Every theory of combustion must account for these two things; namely, the change which the body undergoes, and the emission of heat and light which accompanies this change.

Difference between [illegible]ement and combustion.

13. Mr Lavoisier explained completely the first of these phenomena, by demonstrating, that in all cases oxygen combines with the burning body; and that the substance which remains behind, after combustion, is the compound formed of the combustible body and oxygen. But he did not succeed so well in accounting for the heat and the light which are evolved during combustion. Indeed this part of the subject was in a great measure overlooked by him. The combination of oxygen was considered as the important and essential part of the process. Hence his followers considered the terms *oxygenizement* and *combustion* as synonymous: but this was improper; because oxygen often unites to bodies without any extrication of heat or light. In this way it unites to azote, muriatic acid, and mercury; but the extrication of heat and light is considered as essential to combustion in common language. The union of oxygen without that extrication is very different

from its union when accompanied by it, both in the phenomena and in the product; they ought therefore to be distinguished. I employ the term *combustion* in this Work in its usual acceptation.

Difficulty respecting the origin of the heat and light.

14. To account for the emission of heat and light, which constitutes a part of combustion, Mr Lavoisier had recourse to the theory of Dr Crawford. The heat and the light was combined with the oxygen gas, and separated from it, when that gas united to the combustible body. But this explanation, though it answers pretty well in common cases, fails altogether in others. Heat and light were supposed to be combined with the oxygen of the atmosphere, because it is in a gaseous state; and to separate from it, because it loses its gaseous state. But 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 azote; or, according to the language of the French chemists, the azote 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 potash. Here the oxygen is not only already combined with azote, but forms a component part of a solid; yet a greater 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.

15. 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 com-

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* Berthollet, in a note upon this passage in the first edition of this Work, informs us that the subject had been examined long before the period assigned in the text. See *Jour. de Phys.* lx. 289.

bustion 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 [†].

Bodies divisible into supporters, combustibles, and incombustibles.

16. All bodies in nature, as far as combustion is concerned, may be divided into three classes; namely, *supporters*, *combustibles*, and *incombustibles*.

By *supporters* I mean substances which are not themselves, strictly speaking, capable of undergoing combustion; but their presence is absolutely necessary, in order that this process may take place. Combustibles and incombustibles require no definition.

Supporters.

Oxygen gas is the only simple supporter known; but when incombustible bodies are united to oxygen, they also become supporters. The only incombustible bodies which possess this property are azote and muriatic acid [‡]. It was this singularity which induced me to separate these two substances from all the rest, and place them among the simple bodies. The first of these bodies unites with four doses of oxygen, the second with two. Thus we have one simple supporter and six compound; namely,

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[*] *Ann. de Chim.* xxi. 182.

[†] The reader will find this theory very fully detailed in the *Journal de Chimie* of Van Mons, vols. 2d and 3d. I avoid entering into particulars, because I can perceive no evidence whatever for the truth of most of the assertions which constitute this theory.

[‡] Perhaps mercury might be added to this list. I have failed in all my attempts to cause it to undergo combustion.

1. Oxygen gas;
2. Air;
3. Nitrous oxide;
4. Nitric oxide (*nitrous gas*);
5. Nitric acid;
6. Oxymuriatic acid;
7. Hyperoxymuriatic acid.

17. The combustibles are of three kinds; namely, simple, compound, and oxides. The simple are the four simple combustibles described in the second Chapter of the first Division of this Part; and the whole, or at least almost the whole of the metals. The compound are the various bodies formed by the union of these simple substances with each other; most of which are denominated by terms ending in *uret*, as the sulphurets, phosphurets, carburets, &c.; and also the alloys, and some other compounds which will be described hereafter. The combustible oxides consist of combinations of the combustible bodies, or their compounds with oxygen without undergoing combustion. They are very numerous, constituting the greater part of animal and vegetable substances.

Products.

18. During combustion the oxygen of the supporter always unites with the combustible, and forms with it a new substance, which I shall call a *product* of combustion. Hence the reason of the change which combustibles undergo by combustion, as has been sufficiently demonstrated by Lavoisier. Now it deserves attention, that every *product* is always one or other of the three following substances: 1. Water; 2. An acid; 3. A metallic oxide.

Partial supporters.

19. Some of the products of combustion are capable of combining with an additional dose of oxygen; but

this combination is never attended with the phenomena of combustion, and the product by means of it is converted into a *supporter*. This is the case with several of the metallic oxides. Such compounds may be called *partial supporters*, as it is only to a part of the oxygen which they contain that they owe that property. The following oxides are partial supporters:

1. Peroxide of gold;
2. Peroxide of silver;
3. Red oxide of mercury;
4. Peroxide of mercury;
5. Peroxide of iron;
6. Red and brown oxides of lead;
7. Peroxide of manganese.

These bodies, however, never attract oxygen except from supporters.

20. Since oxygen is capable of supporting combustion only when in the supporters and partial supporters, it cannot be doubted that it is in a different state in these bodies from the state in which it exists in other bodies. Now as light and heat are always emitted during combustion, but never when oxygen combines without combustion, it is natural to suppose that the oxygen of supporters contains either the one or the other of these bodies, or both of them; while the oxygen of other bodies wants them altogether.

Oxygen of supporters contains caloric.

I am disposed to believe that the oxygen of supporters contains only caloric, while that body in other cases is wanting, or at least not present in sufficient quantity. My reason for this opinion is, that the caloric which is evolved during combustion is always proportional to the quantity of oxygen which combines with the burning body; but this is by no means the case with respect to light. Thus hydrogen combines with more oxygen than any other body; and it is now known, that the heat produced by the combustion of hydrogen is greater than can be produced by any other method; yet the light is barely perceptible.

Combustibles contain light.

21. It was long the general opinion of chemists, that light exists in a fixed state in all combustible bodies. The discoveries of Lavoisier induced the greater number of them to give up this opinion, on the supposition that combustion could be explained in a satisfactory manner without it. Indeed the followers of that illustrious philosopher considered it as incumbent upon them to oppose it with all their might; because the fixed light, which had been supposed to constitute a part of combustibles, had been unfortunately denominated *phlogiston*; a term which they considered as incompatible with truth. The hypothesis, however, was occasionally revived; first by Richter and Delametherie, and afterwards in a more formal manner by Gren. But little attention has been paid to it in this country till lately. The very curious phenomena observed by Mr Chenevix in his experiments on the hyperoxymuriatic acid, induced him to incline to the same opinion; and I endeavoured to support it in some observations on combustion, which were published in Nicholson's Journal*.

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* Nicholson's *Journal*, 1803, p. 10.—Some very proper remarks were made upon these observations of mine by Mr Portal, and several objections, which certainly deserve to be particularly considered. In prosecuting the subject farther, I have obtained some singular enough results, which have indeed removed several objections that had occurred to me as peculiarly formidable; while they have raised in their own room a greater number of others which I could not have expected.

Book I. Division II.

That the light exists combined with the combustible, will appear exceedingly probable, if we recollect that the quantity which appears during combustion depends altogether upon the combustible. Phosphorus emits a vast quantity, charcoal a smaller, and hydrogen the smallest of all; yet the quantity of oxygen which combines with the combustible during these processes, is greatest in those cases where the light is smallest. Besides, the colour of the light depends in all cases upon the combustible that burns; a circumstance which could scarcely be supposed to take place unless the light were separated from the combustible. It is well known, too, that when vegetables are made to grow in the dark, no combustible substances are formed in them; the presence of light being absolutely necessary for the formation of these substances. These facts, and several others which might be enumerated, give a considerable degree of probability to the opinion that light constitutes a component part of all combustible substances; but they by no means amount to a decisive proof: nor indeed would it be easy to answer all the objections which might be started against this opinion. At the same time, it will be allowed that none of these objections to which I allude amount to a positive proof of the falsehood of the hypothesis. It is always a proof of the difficulty of an investigation, and of the little progress which has been made in it, when plausible arguments can be brought forward on both sides of the question.

22. Were we to suppose that the oxygen of supporters contains caloric as a component part, while combustibles contain light, it would not be difficult to explain what takes place during combustion. The component parts of the oxygen of supporters are two;

Chap. II.

namely, 1. A base; 2. Caloric: The component parts of combustibles are likewise two: namely, 1. A base; 2. Light. During combustion the base of the oxygen combines with the base of the combustible, and forms the product; while at the same time the caloric of the oxygen combines with the light of the combustible, and the compound flies off in the form of fire. Thus combustion is a double decomposition; the oxygen and combustible divide themselves each into two portions, which combine in pairs; the one compound is the *product*, and the other the *fire* which escapes.

Hence the reason that the oxygen of products is unfit for combustion. It wants its caloric. Hence the reason that combustion does not take place when oxygen combines with products or with the base of supporters. These bodies contain no light. The caloric of the oxygen of course is not separated, and no fire appears. And this oxygen still retaining its caloric, is capable of producing combustion whenever a body is presented which contains light, and whose base has an affinity for oxygen. Hence also the reason why a combustible alone can restore combustibility to the base of a product. In all such cases a double decomposition takes place. The oxygen of the product combines with the base of the combustible, while the light of the combustible combines with the base of the product.

23. But the application of this theory to the phenomena of combustion is so obvious, that it requires no particular explanation. It enables us to explain, with equal facility, some curious phenomena which occur during the formation of the sulphurets and phosphurets. Sulphur and phosphorus combine with the metals and with some of the earths. The combination is

Book I.
Division II.

not formed without the assistance of heat. This melts the sulphur and phosphorus. At the instant of their combination with the metallic or earth bases, the compound becomes solid, and at the same time suddenly acquires a strong red heat, which continues for some time. In this case the sulphur and phosphorus act the part of a supporter; for they are melted, and therefore contain a great deal of caloric: the metal or earth acts the part of a combustible; for both contain light as a component part. The instant of combination, the sulphur or phosphorus combines with the metal or earth; while the caloric of the one, uniting to the light of the other, flies off in the form of fire. The process therefore may be called *semicombustion*, indicating by the term that it possesses precisely one half of the characteristic marks of combustion.

To estimate the quantity of heat evolved during the burning of different combustibles is not only important in a philosophical point of view, but of considerable consequence also as an object of economy. A set of experiments on this subject was made by Lavoisier and Laplace. They burnt various bodies in the calorimeter, and estimated the heat evolved by the quantity of ice melted in each experiment. Dr Crawford made a similar set of experiments. He estimated the heat evolved by the increase of temperature which the water experienced with which he contrived to surround the burning bodies *. A still more numerous set of experiments has been made by Mr Dalton, chiefly on the heat evolved during the combustion of gaseous bodies.

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* See his experiments on animal heat, p. 254, 320, 333.

Chap. II.

He filled a bladder capable of holding 30,000 grains of water with the gas: this bladder was fitted with a stopcock and a pipe. A tinned vessel was procured capable of holding 30,000 grains of water; the specific heat of which being ascertained, and as much water added as made the specific heat of both equivalent to that of 30,000 grains of water, the gas was squeezed out of the bladder, lighted, and the extremity of the flame made to play upon the bottom of the tinned vessel. The quantity of heat evolved was estimated by the increase of temperature produced upon the water in the vessel *. The following Table exhibits the result of all these experiments, estimating the heat evolved by the quantity of ice which it would melt. The first column gives the substance burnt, and one pound weight is always supposed to be consumed; the second, the weight of oxygen in lbs. which unites with the combustible during the process; and the third the weight of ice in lbs. which was melted, according to the different experimenters.

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* Dalton's *New System of Chemical Philosophy*, p. 76.

Heat produced by combustion.

Substances burnt, 1 lb.	Oxygen consumed in lbs.	Ice melted in lbs.		
		Lavoisier.	Crawford.	Dalton.
Hydrogen	6	295	480	320
Carbureted hydrogen	4			85
Olefiant gas	3·5			88
Carbonic oxide	0·58			25
Oil	3·5	148	89	104
Wax	3·5	133	97	104
Tallow	3·5			104
Oil of turpentine				60
Alcohol				58
Ether	3			62
Phosphorus	1·5	100		60
Charcoal	2·8	96·5	69	40
Sulphur	1·36			20
Camphor				70
Caoutchouc				42

From the nature of Mr Dalton's experiments, the results which he obtained must be unavoidably rather too low, as a portion of the heat would be dissipated by radiation. But from the simplicity of the method, and the facility of repetition which it afforded, there is reason to believe that the errors are not very material.

From the Table it appears, that much more heat is evolved during the combustion of hydrogen than any other substance. The heat evolved is not proportional to the quantity of oxygen which combines with the combustible; a fact which is rather hostile to the supposition that the whole of the heat evolved in combustion is furnished by the oxygen.

III. 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 colision 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.

Percussion produces condensation.

1. This evolution of caloric by percussion seems to be the consequence of a permanent or temporary condensation of the body struck. 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.

Caloric evolved by condensation.

2. Now condensation seems always to evolve caloric; at least this is the case in those bodies in which we can produce a remarkable and permanent diminution of bulk. When muriatic acid gas is absorbed by water, the liquid soon rises to the temperature of 100°; and a still higher temperature is produced when ammoniacal gas and muriatic acid gas concrete into a solid salt. When limestone is dissolved in sulphuric acid, a considerable heat is produced, notwithstanding the great quantity of carbonic acid which is set at liberty. And if we use pure lime instead of limestone, a very violent heat takes place. Now in this case the acid and the water which it contains are converted partly from liquids to solids, and the bulk is much diminished. It is known also, that when air is suddenly condensed, a ther-

mometer surrounded by it rises several degrees [*]. From the suddenness of the rise in this case, Mr Dalton has shown that a much greater heat is evolved than is indicated by the thermometer. From his experiments it follows, that when air is suddenly condensed to half its bulk, its temperature is raised 50 degrees [†]. The same change takes place when air is suddenly admitted into a vacuum. It can scarcely be doubted that a much greater rise of temperature than 50 degrees is occasioned by the condensation of air, provided the fact mentioned by Mollet be precise, that a small bit of linen, rolled up, takes fire when put into the narrow canal in which the lower extremity of a pump for condensing air generally terminates [‡].

On the other hand, when a body is suddenly rarefied, its temperature is lowered. Mr Dalton has shown, that by pumping the air out of a receiver, its temperature sinks also 50° [§].

And why.

3. It is not difficult to see why condensation should occasion the evolution of caloric, and rarefaction the contrary. 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

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[*] Darwin, *Phil. Trans.* 1788.

[†] *Manchester Memoirs*, v. 515.

[‡] Pictet, *Phil. Mag.* xiv. 364.—Connected with this is the appearance of a small light in the air which surrounds the orifice of an air-gun when discharged in the dark. This curious phenomenon, which has not been explained in a satisfactory manner, was first observed by Mr Fletcher (Nicholson's *Journal*, 1803, iv. 280.), and afterwards by Mr Mollet. See *Phil. Mag.* Ibid.

[§] *Manchester Memoirs*, v. 515.

n has been heated by the hammer, it is much harder d brittler than before. It must then have become nser, and consequently must have parted with caloc. It is an additional confirmation of this, that the me bar cannot be heated a second time by percussion til it has been exposed for some time to a red heat. is too brittle, and flies to pieces under the hammer. ow brittleness seems in most cases owing to the abnce of the usual quantity of caloric. Glass *unanneal*l, or, which is the same thing, that has been cooled ery quickly, is always extremely brittle. When glass in a state of fusion, there is a vast quantity of caloric ccumulated in it, the repulsion between the particles f which must of course be very great; so great indeed, hat they would be disposed to fly off in every direction vith inconceivable velocity, were they not confined by n unusually great quantity of caloric in the surroundng bodies: consequently if this surrounding caloric be emoved, the caloric of the glass flies off at once, and nore caloric will leave the glass than otherwise would eave it, because the velocity of the particles must be greatly increased. Probably then the brittleness of glass 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.

Condensation diminishes specific caloric.

4. It deserves attention, too, that 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

Book I. Division II.

one third *. But we can hardly conceive the specific caloric of a body to be diminished without an evolution of caloric taking place at the same time.

Why heat is occasioned by percussion.

5. These observations are sufficient to explain why caloric is evolved by percussion. It is forced out from the particles of the body struck with which it was formerly combined. But a part of the caloric which is evolved after percussion often originates in another manner. 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 Hawksbee † and others have shown, that iron produces no sparks in the vacuum of an air-pump; but Mr Kirwan affirms, that they are produced under common spring 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. Mr T. Wedgewood found,

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* T. Wedgewood, *Phil. Trans.* 1792.

† Ibid. xxiv. 2165.

hat a piece of window-glass, when brought in contact with a revolving wheel of grit, became red hot at its point of contact, and gave off particles which set fire to gunpowder and to hydrogen gas [*]. 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 luminous appearance which follows the percussion of certain bodies *in vacuo*, or in bodies which are not capable of supporting combustion, seems to be connected with electricity; for Mr Davy has observed that all such bodies are electrics. They are frequently also phosphorescent; which property may likewise contribute to the effect [†].

IV. Friction.

Emission o 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.

Not owin to conden sation,

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

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[*] *Phil. Trans.* 1792. p. 45.

[†] *Jour. of the Royal Instit.* i. 264.

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 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.

Nor to decrease of specific caloric,

Count Rumford took a cannon cast solid and rough as it came from the foundry; 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 lbs. 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 cy-

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* Nicholson's *Journal*, ii. 106.

linder 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 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

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* Nicholson's *Journal*, ii. 106.

0·3°, but did not begin to rise till the friction was over. This shows 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 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 18·77lbs. 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 26·58lbs. avoirdupois of ice cold water boiling hot; and it would have required nine wax-candles of a moderate size, burning with a clear flame all the time the experiment last-

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* Pictet, *sur le Feu*, ch. ix.

ed to have produced as much heat. In this experiment all access of water into the hole of 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 conse quently a present in explicable

The caloric, then, which appears in consequence of friction, is neither produced by an increase of the density, 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.

Indeed there seems to be a very close analogy between caloric and electric matter. Both of them tend

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* Nicholson's *Journal*, ii. 106.

Analogy between caloric and electricity.

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, in the language of Pictet, 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° †.

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* Pictet *sur le Feu*, chap. vi.

† Ibid. chap. ix.

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 another? 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?

V. MIXTURE.

Mixtures change temperature.

IT is well known that in a vast number of cases, when two substances enter into a chemical union, a change of temperature takes place. In some instances the mixture becomes colder than before, while in others it becomes much hotter. In the third division of the preceding Section, a very copious list has been given of the first set of mixtures. It remains for us to consider the nature of the second set, and to endeavour, if possible, to ascertain the cause of the change of temperature.

Water essential.

1. It deserves particular attention, that water constitutes an essential part of almost all mixtures in which a change of temperature takes place. The most remark-

ble exceptions to this rule are some of the gaseous bo- ies, which when united together constitute a solid body, s ammoniacal and muriatic acid gases. At the instant f union a very considerable heat is evolved. But even hese gaseous bodies contain a considerable proportion f water, which in all probability contributes not a little o the effect.

Nature of the change depends on the proportion of water.

2. In many cases the particular change of tempera- ure which is produced by mixture depends upon the roportion of water previously combined with one of he ingredients; for the same ingredients are capable ither of producing heat or cold according to that proportion. It has been ascertained by the experiments of Mr Lowitz and Mr Walker, that when salts which contain a great deal of water in their composition, as *carbonate of soda, sulphate of soda, muriate of lime*, &c. are dissolved in water, the temperature sinks considerably; and the fall is proportional to the rapidity of the solution. But when the same salts, previously deprived of their water by exposure to heat, are dissolved, the temperature of the mixture rises considerably.

An increase of density evolves heat,

3. It may be laid down as a rule to which there is no exception, that when the compound formed by the union of two bodies is more fluid or dense than the mean fluidity or density of the two bodies before mixture, then the temperature sinks; but when the fluidity or the density of the new compound is less than that of the two bodies before mixture, the temperature rises; and the rise is pretty nearly proportional to the difference. Thus when snow and common salt are mixed together, they gradually melt, and assume the form of a liquid. During the whole process of melting, the temperature continues at zero or lower; but whenever the solution is

And the contrary cold.

completed, the temperature rises. On the other hand, when spirits and water are mixed together, a condensation takes place; for the specific gravity is greater than the mean. Accordingly the mixture becomes hot. When four parts of sulphuric acid and one part of water are mixed together, the density is very much increased; accordingly the temperature of the mixture suddenly rises to about 300°.

4. We now see the reason why those salts which contain water in abundance produce cold during their solution: the water, while it constituted a part of them, was in a solid state; but when the salt is dissolved, it becomes liquid. Since these salts, if they be deprived of their water, produce heat during their solution, it cannot be doubted that the water, before it dissolves them, combines first with them, so as to form a solid, or at least a solution of considerably greater density.

Solidification of water evolves heat.

5. Whenever water is solidified, a considerable proportion of heat is evolved. Hence the reason that a great deal of heat is produced by sprinkling water upon quicklime. A portion of the water combines with the lime, and forms with it a dry powder totally destitute of fluidity. For the same reason heat is produced when quicklime is thrown into sulphuric acid.

Depends on latent heat.

6. The whole of these phenomena, and likewise the evolution of heat during putrefaction and fermentation, are sufficiently explained by Dr Black's theory of latent heat. Fluidity, in all cases, is produced by the combination of caloric with the body that becomes fluid. Hence a mixture, when it becomes fluid, must absorb caloric; which is the same as saying that it must produce cold. On the other hand, when a fluid body becomes

soli heat must be evolved; because a fluid can only bec ne solid by parting with its caloric of fluidity. But the pplication of the theory to all cases of changes in tem erature by mixture is so obvious, that it is quite unn essary to give any farther illustration.

In most combinations which evolve heat or cold, a cl nge takes place in the specific caloric of the bodie ombined. To this change Dr Irvine ascribed the hole of the heat or cold evolved. Though he appea to me to have carried this doctrine too far, the cha ge must doubtless be allowed to have considerable effe .

S CH is the present state of our knowledge respecting the ources of caloric, one of the most interesting parts of e science. It is perhaps the most intricate part als Hence the doubt and uncertainty in which it is stil involved, notwithstanding the industry and abilities vhich have been employed in clearing them up. It des ves attention, that the sources of light and heat are ex tly the same; and that these two bodies affect alwa to accompany one another.

CHAP. III.

OF SIMPLE BODIES IN GENERAL.

We have now finished the examination of both divisions of Simple Bodies. Their number amounts to 37. But all the substances which chemists have not yet succeeded in decompounding are by no means included in this first Book. Eleven metallic substances have been omitted for reasons formerly specified, and there are two acids besides, with the bases of which we are not yet acquainted. So that the number of undecompounded bodies at present known amounts to about 50.

The 37 simple substances, in the order in which I have described them, are all concerned in combustion, and contribute to explain it. The knowledge of their properties is necessary to understand that complicated process; and considered in this point of view, they constitute a beautiful whole, which has much more of scientific arrangement than any other part of chemistry is yet capable of assuming. Let us consider them a little in that point of view.

Oxygen is capable of uniting with all the other simple confinable bodies, and it unites with them all in different proportions. With the simple incombustible bodies it unites without the extrication of heat or light;

an th ew compounds are all *supporters* of combusti .. With the simple combustibles it unites, and the ur on is accompanied by the extrication of heat and lig it ; and the compounds are *products* of combustion. W th the metals it unites both with and without the extr ation of heat and light, and two classes of compounds ar formed ; namely, *products* and *supporters*. The si ple unconfinable bodies are always extricated during cc nbustion. Thus *combustion* is occasioned by the m tual action of the simple confinable bodies on each o er ; and the consequence of this action is the extric ion of the simple unconfinable bodies.

May be divided into four classes.

[t deserves attention, that the metals and simple comb stibles approach each other by insensible degrees in t eir properties. Thus the difference between the prop rties of arsenic and sulphur is by no means so great a between those of arsenic and gold : they might theref re, without any great impropriety, be reduced under c e class. In that case we would have the whole conf able bodies divided into three sets ; namely, 1. Sup rters ; 2. Combustibles ; and, 3. Incombustibles. he union of the first and second constitutes products ; the first and third supporters.

Such is the present state of our knowledge of simple ibstances. But it will be worth while to take a view the theories of the ancients, the various modifications hich they underwent, and the steps by which chemists ave been gradually led to the opinions at present reeived.

Elements of the ancients.

It seems to have been an opinion established among hilosophers in the remotest ages, that there are only our simple bodies: namely, *fire*, *air*, *water*, and *earth*. o 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 nine 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 of 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 in 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 gave 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.

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.

Gradually banished from the science.

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 shown, 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 belief in 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.

END OF VOLUME FIRST.

295

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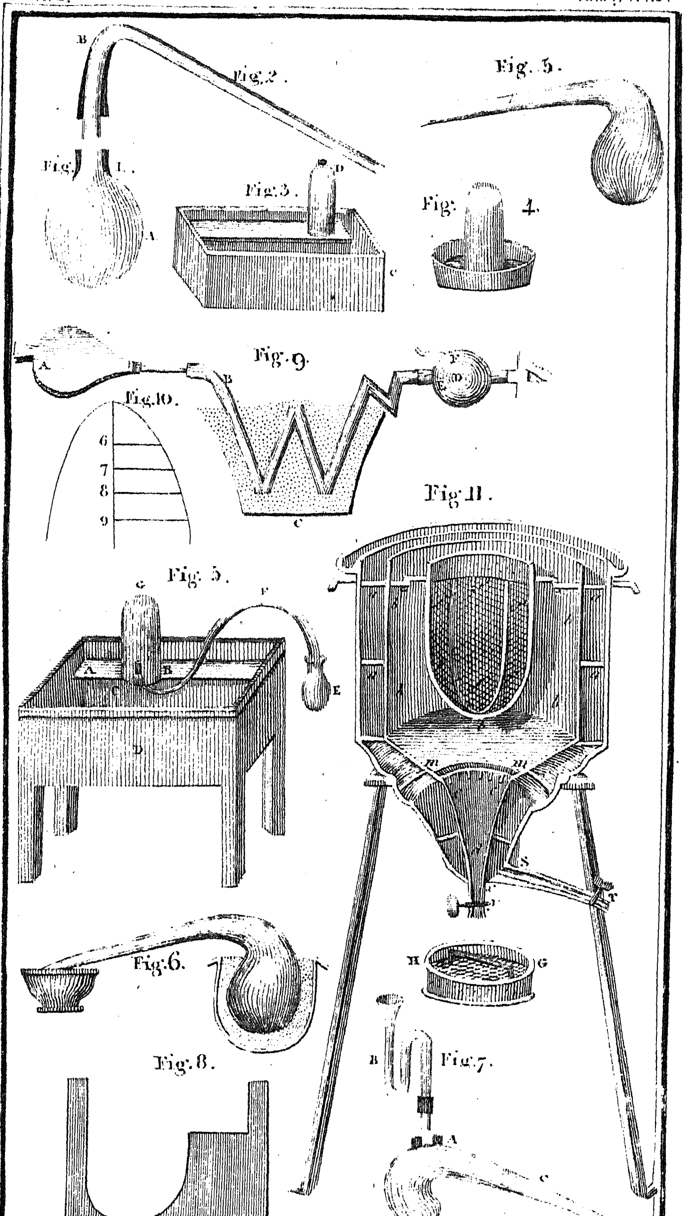
CHEMISTRY

Plate I. *End of Vol. I.*



INDEX.

The Numerals denote the Volume—the Figures the Page.

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