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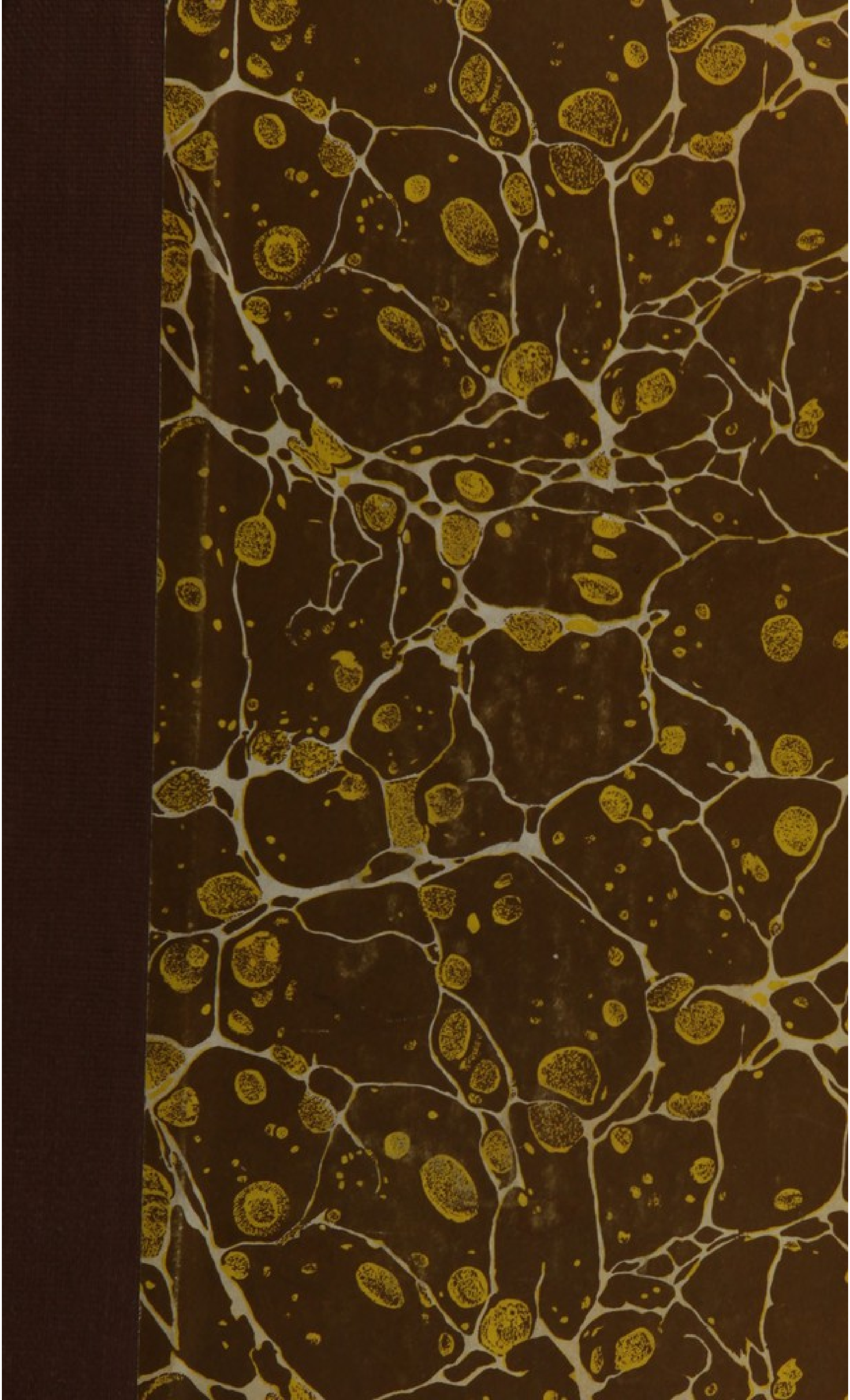

A

SYSTEM

OF

CHEMISTRY,

IN FOUR VOLUMES.

BY THOMAS THOMSON,

M.D. F.R.S.L. AND E.F.L.S. FELLOW OF THE GEOLOGICAL SOCIETY, OF THE WERNERIAN NATURAL HISTORY SOCIETY, OF THE IMPERIAL MEDICO-CHIRURGICAL ACADEMY OF PETERSBURG, OF THE LITERARY AND PHILOSOPHICAL SOCIETY OF NEW-YORK, ETC.

FROM THE FIFTH LONDON EDITION,

WITH NOTES,

BY THOMAS COOPER,

M.D. PROFESSOR OF CHEMISTRY AND MINERALOGY IN THE FACULTY OF ARTS OF THE UNIVERSITY OF PENNSYLVANIA.

VOL. I.

PHILADELPHIA:
PRINTED AND PUBLISHED BY ABRAHAM SMALL,
No. 112, Chesnut Street.
1818.

EASTERN DISTRICT OF PENNSYLVANIA, TO WIT:

Be it remembered, That on the twenty-third day of July, in the forty-third year of
the Independence of the United States of America, A. D. 1818, THOMAS
[L. S.] CLARK, of the said district, hath deposited in this office the title of a book, the
right whereof he claims as proprietor, in the words following, to wit:

A System of Chemistry, in four volumes. By Thomas Thomson, M.D. F.R.S.L. and E.F.L.S. Fellow of the Geological Society, of the Wernerian Natural History Society, of the Imperial Medico-Chirurgical Academy of Petersburg, of the Literary and Philosophical Society of New-York, etc. From the fifth London Edition, with Notes, by Thomas Cooper, M.D. Professor of Chemistry and Mineralogy in the Faculty of Arts of the University of Pennsylvania.

In conformity to the act of the congress of the United States, intituled, "An Act for the Encouragement of Learning, by securing the copies of maps, charts, and books, to the authors and proprietors of such copies, during the times therein mentioned."—And also to the act, entitled, "An act supplementary to an act, entitled, "An act for the encouragement of learning, by securing the copies of maps, charts, and books, to the authors and proprietors of such copies during the times therein mentioned,'' and extending the benefits thereof to the arts of designing, engraving, and etching historical and other prints."

D. CALDWELL,
Clerk of the Eastern District of Pennsylvania.

PREFACE.

SEVERAL circumstances, which it is unnecessary to state to the public, have retarded the appearance of this Edition much longer than was expected or wished for by the Author. Meanwhile the Science of Chemistry has been advancing with unprecedented rapidity; and in consequence of the introduction of the atomic theory and the improvements in analytical precision, which were the natural consequences of that introduction, it has assumed a regularity and simplicity that could hardly have been anticipated. This revolution, together with the great number of new ideas and new names that have been introduced, in consequence of Davy's new views respecting the nature of chlorine and muriatic acid, of the discovery of iodine, and of the knowledge of cyanogen and its compounds by the sagacity of Gay-Lussac, had thrown a certain degree of obscurity over the science, and had given it that unsettled and fluctuating appearance, which is apt to discourage those who are commencing the study.

I thought it necessary, in consequence of these great changes and improvements, to new model this Edition entirely. Indeed almost the whole of the first two volumes, which contain the elementary part of the science, has been written anew. I have been at great pains to introduce every new fact, as far as I was acquainted with it, and to present the science to my readers in its most recent state. The work has passed so rapidly through the press, that it has been unnecessary to add any appendix whatever, no facts of sufficient importance, of which I was ignorant when we began to print, having come to my knowledge since, except such as I was able to introduce at least nearly into their proper places. Thus the *thorina* of Berzelius was unknown to me when the chapter on simple combustibles in the first volume was printing; but I was still able to place it at the end of that chapter. *Morphia* of Sertürner was unknown to me while treating of the *alkalies;* but I have been able at least to place it among the vegetable principles; where it must always continue to figure.

Considerable difference of opinion exists at present respecting the nomenclature of the numerous class of new substances that have been lately introduced into Chemistry. Sir Humphry Davy has invented a nomenclature of his own; but I am not aware that he has obtained hitherto any followers in this country; unless Dr. Davy and Mr. Brande constitute exceptions to the observation. Professor Berzelius, of Stockholm, has given another nomenclature to the public; and he seems to be followed by the Swedish chemists; and a few of his terms appear to have made their way into Germany. A third nomenclature has been contrived by M. Gay-Lussac, and it would appear that it has been adopted by the greater number, if not the whole, of the French chemists. The names, which I have adopted, are all exactly conformable to the laws laid down by Lavoisier and his associates, when they published the new chemical nomenclature. They merely constitute an extension of that nomenclature, and seem to apply so happily to the present state of the science, that I entertain sanguine hopes that they will be found to suit not merely the English language, but that they will be easily intelligible to scientific chemists in every country of Europe.

Concerning the arrangement which I have adopted, it appears unnecessary to say much. It is merely an improvement of the arrangement followed in the preceding Editions of this Work. And it appears to me to be better adapted to convey a clear idea of the present state of the science in all its bearings to the tyro, who is just commencing the study of Chemistry, than any other that I have yet seen.

Mistakes and defects, the consequence of want of sufficient information, may no doubt still be detected in this edition; but I trust that the reader will give me credit when I assure him that they are wholly involuntary; and that neither expense nor pains were spared to avoid them as much as possible.

London, October 1, 1817.

PREFACE OF THE EDITOR.

Four Systems of Chemistry have been published in England, each of them possessing considerable merit. Accum's, Henry's, Murray's, and Thomson's. Accum's and Henry's are each in two volumes, Murray's in four, and the last edition of Thomson's, (that which precedes the fifth London) in five.

Of these Systems, Dr. Thomson's seems ultimately to have obtained the greatest share of public approbation; not only in England but on the European continent; where it has been regarded as an excellent summary of chemical facts and doctrines, so delivered, as to form a proper compendium of the science to be put at once into the hands of a student ignorant of the elements of Chemistry. It was a happy combination of chemical facts and chemical doctrines; very extensively applied to the useful purposes of medicine, the arts, and manufactures.

Since the fourth edition of this work was published, such a number of new facts have been ascertained, and so many new views and doctrines have been proposed, by the increasing number and increasing ardour of chemical votaries, that the science has assumed almost a new character: former explanations have been considered as inadmissible, and exploded; and other theories, founded upon other arrangements, with an oppressive inundation of new terms and phrases, have rendered a modern digest of chemical science absolutely essential to the student. Such a digest, in conformity to public expectation, Dr. Thomson has presented to us, in this his new edition of the System of Chemistry.

Almost every page of the present edition exhibits some dissonance from the former; so that we may almost exclaim in the language of Scripture, "old things are done away, and all things have become new." Whether novelty in this case, be likely to shew itself synonimous with improvement, remains, I apprehend, yet to be ascertained: but whatever may be the name that innovation shall ultimately receive, no student can enter upon the study of chemistry in the present day, without informing himself upon the very important facts and controversies which the last ten years has pressed upon the chemical world; and of which, I know no compendious digest, but the book now offered to the public.

It will be useless to pass in review here, all the novelties of the present edition, which have induced me to comply with a request, to write a few explanatory notes upon it: explanations which, I am well persuaded, are necessary for a student to consider, before he adopts, with implicit deference, the doctrines that mark the present era of chemical science. The leading features of the modern improvements are,

1. A more full developement and illustration of the atomic theory, and the doctrine of definite proportions.

2. The placing of chlorine, fluorine, and iodine, in the same rank with oxygen as supporters of combustion.

3. The introduction of the earths into the class of metals.

4. The introduction of silex as an acid, and of hydrogen as an acidifying principle.

Upon each of these, I would venture to premise a few remarks, although at the hazard of repetition.

1. *Of the Atomic Theory.*—There can be no reasonable doubt about the propriety of adopting practically the opinion, that substances extraneous to us, are the causes and sources of our sensations: that these substances are made up principally of particles apparently homogeneous; but which in fact are composed of particles different in properties, and more simple: that all compound bodies are composed ultimately of particles which admit of no further division or analysis; and which are not only with respect to our knowledge, but which are in themselves, and absolutely, indivisible, and indecomposable. If we do not admit this, we must take for granted that the particles of matter are divisible and decomposable actually, and not merely *ex hypothesi*, ad infinitum: a proposition which seems too absurd to be practically admitted. We must therefore admit the existence of simple undecomposable particles, atoms, monads, or molecules, (by whatever name they may be designated) whereof, in different proportions, all the other particles and masses of matter, of whatever kind, are formed and composed. Here then, the foundations of the atomic theory are laid; and I presume it will thus far be generally admitted.

Suppose the size, the weight, or any other property of these particles, or these particles themselves, to be designated for the purpose of illustration by numbers; as, $\overset{a}{1}\,\overset{b}{2}\,\overset{c}{3}\,\overset{d}{4}$, and so forth:

then it is manifest, that the doctrine of definite proportions must take place in chemical combination; for as by the datum, the particle *d* for instance, is indivisible, then its exponent the number 4, must be indivisible also; and two particles *d d* must be represented, not by 5, 6, or 7, but by the number 8 only; and *d c c* by 10, and so forth.

Admitting this—and admitting also, that too many cases of coincidence of fact with the doctrine, occur, to induce us to believe that coincidence accidental—I think we have admitted almost as much as the present state of chemical knowledge will authorise us to admit. And although I do not pretend to deny that the attempt to illustrate the theory of indivisible atoms and definite proportions by an appeal to experiment, is very desirable in distinct treatises or memoirs, until the truth shall be settled upon an immoveable basis, yet I think that it occupies far more than its due share in the present *elementary* work—that in many instances undue pressure is used by Dr. Thomson, to bring his facts in contact with his theory—that the whole of the illustrations are propounded so abstrusely, as to deter ordinary readers from the study—and to leave an impression of difficulty, and uncertainty, likely to do much harm to the progress of the science—that undue stress is laid upon its present importance, whether considered as facilitating the study of the science, or its application to the objects of common life—and although I have endeavoured from Dr. Prout's papers to furnish some steps of the ladder on which Dr. Thomson has mounted, there still remains an appearance of esoteric mystery in his illustrations and calculations, that may well induce the reader to suppose they are meant only for the initiated. I have endeavoured to make some of them more readily intelligible; but I cannot help thinking that they might in great part have been dispensed with, in an elementary publication.

2. *With respect to Chlorine, Iodine, and Fluorine.*—The whole of Sir Humphry Davy's doctrine respecting the simple nature of chlorine, so well caculated to throw confusion among all our most established notions of chemical theory, has been implicitly adopted by Dr. Thomson, without one intimation of the disputable character of this theory, or any account or even notice of the experiments of Drs. Bostock, Trail, and Murray. This is, I apprehend, a culpable neglect on the part of Dr. Thomson; who ought to have informed us, that men of science in his own country were far from adopting implicitly the doc-

trines he has taken for granted as settled; and to have informed us briefly, of the facts upon which that doctrine was disputed. I think in this omission, he has done injustice to men of great eminence among his cotemporaries; as indeed he did to Dr. Higgins, by omitting that gentleman as the first proposer of the atomic theory: an omission which does no credit to Dr. Thomson, or to his friend Mr. Dalton, who certainly ought to have noticed the prior claims of Dr. Higgins, to be found in his "Comparative View" of the phlogistic and anti-phlogistic theories of Chemistry, that occasioned so much discussion a few years ago.

Since Dr. Thomson published this edition, the experiments of Dr. Murray, and Dr. Ure of Glasgow, seem to me to have completely overthrown the whole system of Sir Humphry Davy on the subject of chlorine; and to have restored the old fashioned explanation of Berthollet; which is likely to prove itself, as true, as it is plain and intelligible.

For the same reason that chlorine seems to combine with oxygen during the process of procuring it, so may iodine and fluorine: and we are likely to be brought back to the elegant simplicity of the Lavoiserian doctrine, that the only supporter of combustion is oxygen; a change by which, if it can be supported, little will be lost.

I have endeavoured to state the argument on both sides, in a way intelligible to the students for whose perusal this edition is designed: and it is manifest, that Dr. Thomson's view of the subject would not be perfectly correct, though Sir Humphry Davy's notions thereon should be considered as true; for even in that case, the modern doctrine ought not to have been stated and propounded in such a way as to induce the reader to suppose, that it had been adopted without opposition.

3. *As to the introduction of the Earths among the Metals.*—I have seen and made potassium too often, not to be aware of the metallic appearance of that substance—of its apparent amalgamation with mercury—of its attraction for oxygen, and the probability that caustic potash is the oxide of potassium. But these characters are not peculiar to these metalloids: the lustre of pyrites and of the Chinese yellow orpiment is as metallic and as brilliant as potassium; but for accuracy's sake, let us settle what we mean by a *metal*, before we call these substances metals. Hitherto, the leading feature of a metal has been its weight; but the alkaline metalloids are the lightest of all solids—hitherto, the oxide of a metal has been deemed with-

out a contradictory instance, lighter than the metal itself; here it is heavier—hitherto we have found every metal apt to combine and form an alloy with almost every other metal; in the present instance we can hardly yet say it has alloyed with any thing but mercury. I am not prepared to deny any of the *facts* stated, but in an elementary work we should alter our definitions at least to suit the case.

4. *The acid character of silex, and the acidifying character of hydrogen.*—I have the same observation to make on this head. Let us alter our definitions, and I agree that silex is an acid. But while people will persuade themselves that acids are sour to the taste, they will not understand the mystery of calling a piece of flint an acid. I hold the talents and industry of Berzelius and Sir H. Davy in high respect: they are men eminent for their ingenuity in devising, their skill in conducting, their patience in pursuing, and their acuteness in deducing conclusions from experiments; but each of them has contrived to acquire a reputation, in which a love of novelty and paradox seems somewhat to intermingle. But I would speak with great deference, of men who have done so much, so well.

With respect to the acidifying character of hydrogen, I am not yet prepared to regard it as irrevocably settled: even though Dr. Murray, in his late paper on the theory of chlorine (Edinb. 5th Jan. 1818), seems willing to suppose that the *elements* of water, and not water itself, enters into the chemical constitution of muriatic acid; and that the water obtained is formed during the process of obtaining it. The theory is ingenious: but I see nothing that is gained by substituting ternary for binary combinations. The facts are as well explained on the latter, as on the former theory; and till new facts inexplicable on the old doctrine be discovered, I see no good reason for embracing a new one.

With respect to sulphureted hydrogen, (the hydrothionic acid), and cyanogen, their acid characters are so dubious, that Dr. Murray certainly talks in too strong language when he says in his late memoir that sulphur forms with hydrogen a substance *unequivocally* acid. It takes away the colour of paper blued by Litmus, but without turning it red. That it combines with alkalies, is no more than sulphur does without the aid of hydrogen; unless indeed water be decomposed during the combination. But a part of the sulphur in obtaining sulphureted hydrogen, may well be oxygenated by the atmospheric air contained in the water employed during the process of making this gas—or even a part of the water itself may be decomposed and furnish its oxygen. These are difficulties in the way of the modern theory, which must be surmounted before Dr. Murray's opinions find full credit. No investigation of them has yet taken place to my knowledge. The same may be said of cyanogen and the other hydrogen acids. Are we sure that the water employed has not furnished oxygen in one or other of the ways just suggested? The perusal of Dr. Murray's very important *Experiments on muriatic acid gas, and his Observations on muriatic acid and on some subjects of chemical theory*, which arrived while this preface was at the press, has led me to make these observations, which otherwise might better have appeared perhaps in the form of notes.

On some or all of these points, Dr. Thomson's work required notes of explanation, notes of doubt, and notes of contradiction. Notes also of addition, where new facts worth registering have occurred since its publication. I have endeavoured to supply these to the best of my ability, though sparingly.* After all, this System of Chemistry is not only the work of one of our most skilful chemists, and ablest compilers, but it is also the only compilation which gives us the present views—the modern facts and doctrines of the science: nor are we likely soon to receive another unless from the same hand, when the additions of some future years of investigation shall require a new summary of the facts. Among the improvements devoutly to be wished, is some regular system of nomenclature, less abstruse than the present one; for if every student of chemistry and mineralogy hereafter is required to be a profound Greek scholar, I fear the votaries of this most engaging science will be often deterred from the pursuit: and we shall be inundated elsewhere as we are threatened to be in this country, with theories fabricated not in the Laboratory but the Lexicon.

I make no apology for differing in opinion from my author. His well earned reputation will not be shaken by these remarks, even in my own opinion. The most able men are liable to error, and acknowledge it generally with a promptitude in direct proportion to their real merit.

THOMAS COOPER, M. D.

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* In classing the new minerals, not having had the opportunity of seeing them, I have been compelled to take their chemical analysis as furnishing the only analogy I could venture to follow.

CONTENTS.

☞ *IN the present Edition the Tables of Contents have been enlarged by placing in them the marginal notes of the last London Edition. This will more perfectly answer the object of reference.*

CONTENTS OF VOLUME I.

A

SYSTEM OF CHEMISTRY.

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

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

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 each other; 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.

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*. The second is known by the name of *Chemistry*.

CHEMISTRY, then, is that science which treats of those events or changes in natural bodies, which are *not* accompanied by *sensible* motions.

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

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

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. 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 great 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 much 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, seems to have been cultivated with considerable eagerness in Egypt and Greece; to have passed from the Greeks to the Arabians, and by the followers of the Caliphs to have been introduced into the west of Europe. Those who professed it gradually assumed the form of a sect under the name of ALCHYMISTS; a term which is supposed to be merely the word *chemist* with the Arabian article *al* prefixed.[†]

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

Chemistry, as the term was used by the alchymists, signified the art of making the philosophers' stone. They affirmed that this art was above the human capacity, and that it was made known by God to those happy sages only whom he peculiarly favoured. The fortunate few, who were acquainted with the philosophers' stone, called themselves *adepti*, "adepts;" that is, persons who had got possession of the secret: this secret they pretended that they were not at liberty to reveal; affirming that dire misfortune would fall

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

[†] I am indebted for the following etymology to my friend, the Rev. Mr. Holme, of St. Peter's, Cambridge, who was supplied with it by the Rev. Mr. Palmer, Professor of Arabic in that University. "AL-CHEMY, or more properly AL-KEMY, *the knowledge of the substance or composition of bodies*, so named from the substantive قياص, (Kiyamon), that is, the *substance* or *constitution* of any thing, from the root قاص, (Kama). See Golius Lexicon."

upon that man's head who ventured to disclose it to any of the sons of men without the clearest tokens of the divine authority.

In consequence of these notions, the alchymists made it a rule to keep themselves as private as possible. They concealed, with the greatest care, their opinions, their knowledge, and their pursuits. In their communications with each other, they adopted a mystical and metaphorical language, and employed peculiar figures and signs that their writings might be understood by the adepts only, and might be 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 proceeded 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 sacred seeds of science. The principal chemical writers among the Arabians, were Geber and Avicenna; and in their writings, at least such of them as I have had an opportunity of perusing, 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 so early, at least, as the 10th 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 in their style and abilities. Some of their books are nearly 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.*

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* Albertus Magnus was a German ecclesiastic. 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 Alchimia*, which contains a 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 chemical writings are studiously obscure; but he generally furnishes us with a key for their explanation. Some

The writings of the greater number of alchymists are remarkable for nothing but obscurity and absurdity. They all boast that they are in possession of the philosophers' stone; they all profess to communicate the method of making it; but their language is enigmatical, that they 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 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 tedious, expensive, and ruinous processes. It was against these men that Erasmus and Ben Jonson directed their well known satires, 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 infinite difficulty, if not the impracticability of the art; men of learning showed that it had never been understood; and men in authority endeavoured, by laws and punishments, to guard their subjects from the talons of alchymistical impostors.

Chemists had for 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 into 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.*

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 so obscure as to be generally unintelligible.

Raymond Lully was born at Barcelona, in 1235. His writings are fully as obscure as 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. Their writings are perfectly plain.

* 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 Ger-

Just about the time that the first of these branches was falling 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 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 utmost height of absurdity, and by exemplifying in his own person their emptiness and uselessness, 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 only to the improvement of chemistry. The chief of them were Agricola, Beguin, Glaser, Erkern, Glauber, Kunkel, Boyle, &c.

The foundations of the alchymistical system being thus shaken,

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many. 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. It was written in German; but there is an elegant Latin translation by Kirkringius.

* I do not mean that he was the only alchymist of his time; but the only man of eminence who published on the subject. Mr. William Oughtred the mathematician, for example, was an alchymist. He used to talk much of the *maiden earth* for the philosophers' stone. It was made of the harshest clear water that he could get, which he let stand to petrify, and evaporated by simmering, "His son Ben," says Mr. Aubrey, "tended his furnaces. He told me that his father would sometimes say that he could make the stone." *Aubrey's Lives of Eminent Men*. Vol. ii. p. 474.

the facts which had been ascertained soon became a heap of rubbish, and chemistry was left without any fixed principle, and destitute of an object. It was then that a man appeared passionately devoted to the study, and thoroughly acquainted with all the facts; who, by a happy hypothesis, connected them together, pointed out the proper objects of chemistry, and demonstrated the important purposes to which it might be applied. This man was BECCHER. He accomplished the arduous task in his *Physica Subterranea*, printed 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 it and improved it so much, that he made it entirely his own: and accordingly it has been ever since distinguished by the name of the *Stahlian theory*.

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 Margraff, Bergman, Scheele, Klaproth, Bucholz, Berzelius, &c.

In France, soon after the establishment of the Academy of Sciences, in 1666, Homberg, Lemery, and Geoffroy, 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 French literary men; and from that moment chemistry became the fashionable study. Men of eminence arose every where, discoveries multiplied, the spirit pervaded the whole nation, extended itself over Italy, and appeared even in Spain. But the most eminent among the French chemists was Lavoisier, who fell a victim to the fury of the Revolution, and died on the scaffold in the year 1794.

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 small number of individuals. The spirit which Newton had infused for the mathematical science was so great, that it drew within its 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 50 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.

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 entitled.

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 kingdom. 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 I.

PRINCIPLES OF CHEMISTRY.

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

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 produces 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.

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

The simple substances at present known amount to about 50, and naturally divide themselves into two classes. Those which belong to the first class are of too subtle a nature to be confined in any of the vessels which we possess. They cannot therefore be exhibited in a separate state, and their existence is merely inferred from certain phenomena exhibited by the second class of bodies in peculiar circumstances. They do not sensibly affect the most delicate balance, and therefore have received the name of *imponderable* bodies. The second class of bodies may be confined in proper vessels, may be exhibited in a separate state, their weight and other properties may be determined. They have received the name of *ponderable* bodies. It will be exceedingly convenient to consider these two classes separately. We shall place the *imponderable* bodies first, because during the account of them we shall have an opportunity of introducing several general facts and doctrines which will serve to elucidate the other departments of chemistry.

DIVISION I.

OF IMPONDERABLE BODIES.

THE imponderable bodies at present supposed to exist are four in number; namely, *light*, *heat*, *electricity*, and *magnetism*. The first three of these are intimately connected with chemistry, and appear to be the agents in many of the most important phenomena connected with the science. But as magnetism has no known connexion with chemistry, it cannot with propriety claim a place in this work.

CHAPTER 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.

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 endeavoured to establish this theory on the firm basis of mathematical demonstration; by showing that all the phenomena of light may be mathematically deduced from it. Huygens and Euler, on the contrary, attempted to support their 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 endeavoured to show, 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. But without attempting to canvass the merits of these different hypotheses, let us proceed to state the properties of light.

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

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* [It is not necessary that the impulse given to light by the action of the sun, or of luminous bodies, should produce an *undulating* motion: it is just as easy to conceive an impulse that shall produce *rectilinear* motion.—C.]

† Phil. Trans. xii. 83.

‡ [2 Smith's Optics, Art. 1120. Roemer's method is this. Let S be the sun, a, b, c, the annual orbit of the earth, J Jupiter, e, f, g, h, the orbit of the innermost satellite, the properest for this inquiry, by reason of the quickness of its revolution; and let this satellite enter the shadow of Jupiter at g, and emerge from it at h. Now supposing the earth at b, some time before the last quadrature, let an emersion of this satellite be observed at h; then if the earth continued in the same place, we should see the next emersion at the end of 24 hours and an half, this being supposed the exact time in which this satellite revolves to the shadow. Likewise if the earth continued at the same place b during any number of revolutions, suppose 30, we should see an emersion at the expiration of 30 times 24 1-2 hours. But the earth in that time being really transferred from b to c, farther from Jupiter, it follows, if light requires time for its propagation, that this emersion will be perceived later at c than it would have been at b, and that to 30 times 24 1-2 hours, we must add the time which the light takes up in describing the space $k\ c$, the difference of $b\ h$ and $h\ c$.

1121. On the contrary, towards the other quadrature, whilst the earth in going from d to a, is approaching towards Jupiter, the emersions of the satellite at g should be perceived sooner at a than they would be, had the earth remained at d.

1122. Now these retardations of the emersions in going from Jupiter, and acceleration of the immersions in going towards him, have been often found to amount to above ten minutes; and from the most accurate consideration of them it is concluded that light describes a line $k\ c$ equal to the semidiameter of the earth's annual orbit, nearly in half a quarter of an hour.

The motion of Jupiter in his orbit during the earth's passage from b to c and from d to a, is considered in that conclusion; and it is at last agreed by astronomers that these equations, of the times of these eclipses, cannot be accounted for either by any inequality in the motion of the satellite, or by any eccentricity or inclination of its orbit; and lastly, that the three other satellites require the same equations of the times of their eclipses.—Phil. Trans. vol. 1. abrid. p. 422. Mr. Bradley's reasoning on the velocity of light from the parallax of the fixed stars may be found in the same book, art. 1196.—C.]

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.*

2. While a ray of light is passing through the same medium, or when it passes *perpendicularly* from one medium to another, it continues to move without changing its direction; but when it passes *obliquely* from one medium to another of a different density, it always bends a little from its old direction, and assumes a new one. It is then said to be *refracted*. When it passes into a denser medium, it is refracted *towards* the perpendicular; but when it passes into a rarer medium, it is refracted *from* the perpendicular. In general, the quantity of refraction is proportional to the density of the medium; but if the medium be combustible, the refraction is greater than it 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.

It has been the general opinion of philosophers since the days of Newton, that the refractive power of the same body in different states is proportional to its density. But M. M. Arago and Petit have lately shown by a set of experiments, that when a liquid body is converted into vapour, its refractive power diminishes at a greater rate than its density. Thus the refractive power of sulphuret of carbon, while liquid, when compared to that of air, is a little greater than 3; while that of the same substance in the state of vapour, being likewise referred to air, does not surpass 2. The liquids tried by these philosophers were sulphuret of carbon, sulphuric ether, and muriatic ether.‡ This newly discovered fact, constitutes one of the strongest objections to the Newtonian theory of light that has yet been advanced.

3. 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.

Newton has explained these phenomena by supposing an attraction to exist between light and the medium through which it is

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* Phil. Trans. xxxv. 637, and xlv. 1. [2 Smith's Optics, ub. sup. and S. Gravesand's Phys. Elem. Math. lib. ii. cap. 1. p. 708.—C.]

† 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.

‡ Ann. de Chimie et Physique, i. 1.

moving, the medium towards which it is approaching, or the bodies in its neighbourhood.

4. Some substances, as water, are *transparent*, or allow light to pass freely through them; other, as iron, are *opaque*, or allow no light to pass through them. Now, it can scarcely be doubted that the component particles of all bodies are far enough distant from each other to allow the free transmission of light; consequently opacity and transparency must depend, not upon the distance of the particles of bodies, but upon something else. Newton has shown, that transparency can only be explained by supposing the particles of transparent bodies uniformly arranged and of equal density. When a ray of light enters such a body, being attracted equally in every direction, it is in the same state as if it were not attracted at all, and therefore passes through the body without obstruction. In opaque bodies, on the contrary, the particles are either not uniformly arranged, or they are of unequal density. Hence the ray is unequally attracted, obliged constantly to change its direction, and cannot therefore make its way through the body.

5. When a ray of light passes through a crystallized body, provided the primitive form of the crystal be neither a cube nor a regular octahedron, it is split into two distinct rays, one of which is refracted in the ordinary way, while the other suffers an extraordinary refraction. Hence, when an object is viewed through such a crystal it appears double. Such bodies are said to *refract doubly*. The laws of this double refraction were first accurately explained by Huygens. Calcareous spar is one of the substances which possesses this property in the most striking degree.

6. If a ray of light fall upon a polished surface of glass at an angle of incidence of 35° 25′, it will be reflected in a straight line, making the angle of reflection equal to the angle of incidence. Let us suppose another plate of glass to be so placed that the reflected ray will fall upon it likewise at an angle of 35° 25′. The second plate may be turned round its axis without varying the angle which it makes with the ray that falls upon it. A very curious circumstance may be observed as this second glass is turned round. Suppose the two planes of reflection to be parallel to each other, in that case the ray of light is reflected from the second glass in the same manner as from the first glass. Let the second glass be now turned round a quadrant of a circle, so as to make the planes of reflection perpendicular to each other. Now the whole of the ray will pass through the second glass, and none of it will be reflected. Turn the second glass round another quadrant of a circle, so as to make the reflecting planes again parallel, the ray will now be reflected by the second glass as at first. When the second glass is turned round three quadrants, the whole light will be again transmitted, and none of it reflected. Thus, when the reflecting planes are parallel, the light is reflected; but when they are perpendicular the light is transmitted. We see that the light can penetrate

through the glass when in one position; but not when in another. Malus, who first observed this curious fact, accounted for it by supposing that the light had bent into another position, just as a needle does when acted upon by a magnet. He therefore called this property of light its *polarization*. Since his death, the phenomena of the polarization of light have been examined with much assiduity, and many new facts discovered by M. M. Biot and Arago, and by Dr. Brewster.

7. 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.

8. 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.

9. 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 consitutes 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.

10. 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.*

11. 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 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 com-

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* Phil. Trans. 1800, p. 255. † Ibid. lxi. 212. ‡ Ibid. lviii. 337.

§ 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.

bustion 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 Canton are also incompatible with the notion of combustion. His pyrophorus shone only in consequence of being exposed to light, and lost that property by being kept in the dark. It is not exposure to light which causes substances capable of combustion at the temperature of the atmosphere to become luminous, but exposure to air. If the same temperature continues, they do not cease to shine till they are consumed; and if they cease, it is not the application of light, but of caloric, which renders them again luminous: but Canton's pyrophorus, on the contrary, when it had lost its property of shining, did not recover it by the application of heat, except it was accompanied by light. The only effect which heat had was to increase the separation of light from the pyrophorus, and of course to shorten the duration of its luminousness. Two glass globes hermetically sealed, containing each some of this pyrophorus, were exposed to the light and carried into a dark room. One of them, on being immersed in a 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.

12. But light does not only enter into bodies, it also combines

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* Jour. de Phys. xx. 270.

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 repeated and carried a great deal farther by Dr. Hulme.† It has been long known that different kinds of meat and fish, just when they are beginning to putrify, become luminous in the dark, and of course give out light. This is the case in particular with the whiting, the herring, and the mackerel. When four drachms of either of these are put into a phial containing two ounces of sea water, or of pure water holding in solution ½ a drachm of common salt, or two drachms 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 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, spirituous 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.

13. 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.

14. 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,

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* Phil. Trans. lix. 446.

† Ibid. 1800. p. 161.

‡ The same experiments succeed with Canton's pyrophorus, as Dr. Hulme has shown.

after their exposure to light, their colour becomes green,[*] their taste is rendered much more intense, and the quantity of combustible matter is considerably increased. These changes are very obvious, and they depend incontestibly upon the agency of light. Another very remarkable instance of the agency of light is the reduction of the metallic 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.[‖]

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 ascertained, that chloride of silver is blackened most rapidly when it is placed beyond the violet ray, and entirely out of the prismatic spectrum.

These observations have been confirmed by M. Berard. He found that the chemical intensity was greatest at the violet end of the spectrum, and that it extended a little beyond that extremity. When he left substances exposed for a certain time to the action of each ray, he observed sensible effects, though with an intensity continually decreasing in the indigo and blue rays. Hence it is very probable that if he had been in possession of more sensible reactives[¶] he would have observed analogous effects, but still more feeble, in the other rays. He concentrated, by means of a lens, all that part of the spectrum which extends from the green to the extreme violet; and likewise, by means of another lens, all that portion which extends from the green to the extremity of the red. The last pencil formed a white point so brilliant that the eye was scarcely able to endure it; yet the chloride of silver remained ex-

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[*] [Hence the process of etiolation, or blanching, used by gardeners; as when they tie up their lettuces, or earth up their celery, to whiten the internal part. It has lately been found at Paris, that the edible mushroom grows more luxuriantly in situations not much exposed to light.—C.]

[†] [In the medico-chirurgical transactions for 1816, p. 284—290, are some cases, furnished by Dr. Albers of Bremen, and Dr. Roget of London, of persons whose skin acquired a permanent blue tinge from persisting in a long course of pills formed of crumb of bread and lunar caustic, which is the fused nitrat of silver. The colour in one case was deepened by exposure to light.—C.]

[‡] 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.

[¶] He employed chloride of silver, which becomes black; guaiac, which passes from yellow to green, as Dr. Wollaston first observed; and a mixture of chlorine and hydrogen, which detonate when exposed to light, as Dalton and Gay-Lussac and Thenard ascertained.

posed to it two hours without undergoing any sensible alteration. But when exposed to the first pencil, which was much less bright and less hot, it was blackened in less than six minutes.*

15. M. Morichini, Professor of Chemistry at Rome, announced, in 1813, that when steel needles are exposed to the action of the violet ray of light they become magnetic.† But when these experiments were carefully repeated by Professor Configliachi of Pavia,‡ and by M. Berard of Montpellier,§ they did not succeed. Hence we may conclude that Morichini deceived himself by using needles already possessed of magnetic properties.

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 properties, of which they are destitute. The first of these properties is the power which it has of exciting in us the sensation of vision, by moving from the object seen, and entering the eye. The phenomena of colours, and the prismatic spectrum, indicate the existence of seven different species of light; but to what the difference of these species is owing, has not been ascertained. We are altogether ignorant of the component parts of every one of these species.

The second peculiar property of light is the prodigious velocity with which it moves whenever it is separated from any body with which it was formerly combined. This velocity, which is but little less than 200,000 miles in a second,‖ it acquires in a moment; 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 at-

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* Annals of Philosophy, ii. 165.

† Gilbert's Annalen der Physick, xlvi. 367.

‡ Ibid. p. 337.

§ Annals of Pilosophy, iv. 228.

‖ [See p. 27, note of the editor.—C.]

¶ [It is very possible that the particles of light repel each other. The following suggestions, however, bear upon this point. 1. The phenomena of mirrors and of lenses, where light, as well as caloric, is so highly concentrated. The attractions of the substances whereof these instruments are formed, are manifestly stronger, than the repulsive spheres that surround the particles of heat and caloric: analogous to this is the electricity accumulated round a main conductor. The repulsive force then, cannot be very strong. 2. By the conclusions drawn by Roemer from the immersion of Jupiter's satellites, and by Bradley from the parallax of the fixed stars, the velocity of light is about 200,000 miles per second of time. When this is compared with M. D'Arcet's experiments on the continuous sensation produced by a ray of light, it will appear, that there may be continuous vision, though the particles of light be 20,000 miles from each other; a distance which renders repulsion between tract each other; and accordingly are found cohering together in masses of more or less magnitude.

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.

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.

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 a supporter. Consequently the light which is emitted during combustion must have existed previously combined either with the combustible or with the supporter. But this subject will be resumed in the next chapter, where the nature of combustion will be particularly considered.

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 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°.

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the luminous particles inadequate to account for this effect. The impression on the optic nerve remains, according to D'Arcet's experiment, from $\frac{1}{450}$ to $\frac{1}{400}$th part of a minute. He made a luminous point (a hot coal) revolve with that velocity which was barely sufficient to keep up a continuous circular image; which he found could not be done unless it revolved in 8 or 9 thirds of a minute. Priestley's History of Light and Colours, 634.

Indeed all bodies repel each other, for as heat expands and cold contracts all bodies, their particles are not in contact really, though seemingly to us, they are so.—C.]

[*] Dr. Irvine has shown that this point is rather too low. For mercury, which he found to boil at 672°, does not become the least luminous at that temperature. Irvine's Essays, p. 32.

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, bent so in the middle that it could be sunk, and make several turns in a large crucible, which was filled with sand. To one end of this tube was fixed a pair of bellows; at the other end was a globular vessel, in which was a passage, furnished with a valve to allow air to pass out, but none to enter. There was another opening in 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 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.

20. 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.

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* T. Wedgewood, Phil. Trans. 1792.

† Id. Ibid.

‡ [All species of fuel used, is vegetable matter: during the combustion, light previously combined with the vegetable during its living state, is set free: may not the light thus set free from the fuel, be absorbed by the heated metal, and occasion its luminous appearance?—C.]

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.

CHAPTER II.

OF HEAT.

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, may lead 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*.

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[*] Lamanon, Jour. de Phys. 1785.

[†] [This seems contradictory to the fact stated in page 254 post. where silica (or quartz) is stated to consist of 100 parts silicon as a base, and 102, 245 oxygen.—C.]

[‡] Ann. de Chim. xvi. 206.

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 will be occupied with the nature of caloric; in the second, I shall 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.

SECTION 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 more probable than the former: and a discovery, made by Dr. Herschel, has at last nearly put an end to the dispute, by demonstrating, that we have the same reason for considering heat to be a substance, as we have for believing light to be material.

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. Herchel 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 were repeated and confirmed by Sir Henry Englefield,† in the year 1802. 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 him. 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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* Phil. Trans. 1800, p. 437.

† Journal of the Royal Institution, i. 202.

		Time.	From	To
Red ray	Black therm. White therm.	3′	58° 55	61° 58
Dark	Black therm. White therm.	3	59 58	64 58½
Confines of red	Black therm. White therm.	3	59 57½	71 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.

In the year 1807, Professor Wünsch, at Frankfort on the Oder, published a set of experiments upon the same subject,* which turned out somewhat different from those of Dr. Herschel. He found that the thermometer was *not affected* when placed either above or below the spectrum. But the rise of temperature was not proportional to the light given by the ray. The blue ray he found gave the most light; but produced the least heat of any of the rays, the violet excepted. When the prism was filled with alcohol, oil of turpentine, or water, the yellow ray raised the thermometer highest; when a prism of green glass was used, the red ray produced most heat: and finally, when a yellow glass prism was used, the colourless tail at the border of the red ray produced the most heat. Professor Wünsch is one of those philosophers who believe that the solar light is only divisible into three coloured rays, and the principal object of his elaborate paper seems to be to show that the heating power of the rays confirm his peculiar hypothesis. It was examined at great length by Ritter, whose opinions were different.† But it is unnecessary to discuss that point here, because, the experiments of Wünsch, though they do not exactly coincide with those of Herschel, are not however inconsistent with them.

The experiments of Herschel were again repeated and confirmed by M. Berard in 1813. He was possessed of an excellent apparatus for the purpose, and his observations appear to have been made with sufficient care. He found, as Herschel had done, that the heating power of the rays decreases from the red to the violet end of the spectrum. It is greatest at the extremity of the red ray while the thermometer is still plunged in the spectrum. When he placed the thermometer quite beyond the visible spectrum in the spot where Herschel fixed the maximum of heat, its elevation above

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* *Versuche uber die vermeinte Sonderung des Lichts der Sonnenstrahlen von der Wärme derselben*, published in the *Der Gesellschaft natur forschender freunde zu Berlin Magazin für die neuesten entdeckungen in der gesammten naturkunde.* Vol. i. p. 207.

† *Gehlen's Journal für die Chemie, Physik und Mineralogie*, vi. 633.

that of the ambient air was only $\frac{1}{5}$th of what it had been in the red ray itself.*

These experiments are sufficient to convince us that the *calorific* and *colorific* power of the rays of light follow quite different laws. Whether two different species of rays exist in the solar spectrum as some have supposed, namely, rays of *light*, and rays of *heat;* or whether certain unknown changes in the velocity or in some other quality of light give it the power of producing heat, are questions which the limited state of our knowledge does not enable us to determine. Some late experiments of Delaroche seem rather favourable to the latter opinion. He found that the higher the temperature of a hot body was raised, the greater was the quantity of rays of heat which became capable of penetrating through a plate of glass.†

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.

3. The rays of caloric are reflected by polished surfaces in the same manner as the rays of light. This was shown long ago by Scheele, who even ascertained that the angle of their reflection is equal to the angle of their incidence. Mr. Pictet also had made a set of very ingenious experiments on this subject, about the year 1790, which led to the same conclusion.‡ He placed two concave mirrors of tin, of nine inches focus, at the distance of 12 feet 2 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.

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* Annals of Philosophy, ii. 163. † Ibid. ii. 100.

‡ A similar set of experiments had been made by Mr. King as early as 1785: See his Morsels of Criticism, vol. i.

The mirrors of tin were now placed at the distance of 90 inches from each other; the matrass with the boiling water in one of the foci, and a very sensible air thermometer in the other, every degree of which was equal to about $\frac{1}{11}$th of a degree of Fahrenheit. Exactly in the middle space between the two mirrors there was placed a very thin common glass mirror, suspended in such a manner that either side could be turned towards the matrass. When the polished side of this mirror was turned to the matrass, the thermometer rose only 0.5°; but when the side covered with tinfoil, and which had been blackened with ink and smoke, was turned towards the matrass, the thermometer rose 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°.*

4. Berard has shown by a set of well contrived experiments that the rays of heat are capable of polarization equally with the rays of light.†

5. As heat radiates from luminous bodies like light, 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 about 1700 grains of water from the New River, London, and then sealed it hermetically. The whole weighed 2150$\frac{31}{32}$ grains at the temperature of 32 degrees. It was put for 20 minutes into a freezing mixture of snow and salt till some of it was frozen; it was then, after being wiped first with a dry linen cloth, next with clean washed dry leather, immediately weighed, and found to be $\frac{1}{60}$th of a grain heavier than before. This was repeated exactly in the same manner five different times. At each, more of the water was frozen, and more weight gained. When the whole water was frozen, it was $\frac{3}{16}$ths of a grain heavier than it had been when fluid. A thermometer applied to the globe stood at 10°. When allowed to remain till the thermo-

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* Pictet, *sur le Feu*, chap. iii.

† Annals of Philosophy, ii. 164.

‡ Sur les Modif. de l'Atmosph.

§ Phil. Trans. 1785, p. 361.

|| Jour. de Phys. 1785, Oct.

¶ Jour. de Sçavans, 1785, p. 493.

meter rose to 32°, it weighed $\frac{2}{16}$ths of a grain more than it did at the same temperature when fluid. It will be seen afterwards that ice contains less heat than water of the same temperature with it. The balance used was nice enough to mark $\frac{1}{1600}$th part of a grain.

This subject had attracted the attention of Lavoisier, and 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 equally decisive. He repeated the experiment of Dr. Fordyce with the most scrupulous caution; and demonstrated that neither the addition nor the abstraction of heat 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; 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. Whether this difference be sufficient to constitute light and heat two specifically distinct bodies; or whether they be merely modifications of one and the same body are questions which the present state of our knowledge does not enable us fully to answer.

SECTION II.

OF THE MOTION OF HEAT.

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

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* Phil. Trans. 1799, p. 179.

† [The heat produced in the focus of a burning mirror, or a burning lens, seems to furnish a difficulty in this case.—C.]

has thus entered, it is capable of making its way through all bodies; but its motion in this case is comparatively slow. In that case it is said to be *conducted* through bodies. Heat then moves at two very different rates. 1. By *radiation*. 2. By *conduction*. It will be proper to consider each of these separately.

1. RADIATION OF HEAT.

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. In the year 1813, a paper on the subject containing some important additions to the experiments of Mr. Leslie was published by M. Delaroche of Geneva.*

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 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 36½ minutes.‡ In this experiment, the linen produced a similar

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* Annals of Philosophy, ii. 100.

† Leslie's Inquiry into the Nature of Heat, p. 268.

‡ Nicholson's Jour. ix. 60.

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.

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:*

	Cleaned Globe.	Blackened Globe.
In a gentle gale	44′	35′
In a pretty strong breeze .	23′	20¼′
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 communicating 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.

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 sur-

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* Inquiry into the Nature of Heat, p. 271.

face 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.

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.*

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

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* Leslie, p. 14.

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

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.

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.

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 substances tried by that philosopher, expressed by the elevation of the differential thermometer produced.

Lamp black	100	Sealing wax	95
Water by estimate .	100+	Crown glass	90
Writing paper . . .	98	China ink	88
Rosin	96	Ice	85

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[*] Leslie, p. 51.

Minium	80	Clean lead	19
Isinglass	80	Iron polished	15
Plumbago	75	Tin plate	12
Tarnished lead	45	Gold, silver, copper	12
Mercury	20+		

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.

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.

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 to 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.

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 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

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* Leslie, p. 81.

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 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.

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 2½ degrees.‡ From these experiments it is obvious, that metal not only radiates heat worse than glass, but likewise 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 entitled us to conclude, that those surfaces which radiate heat most powerfully, likewise absorb it most abundantly when it impinges against them.

12. The very contrary holds with respect to the reflectors, as

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* Leslie, p. 110. † Ibid. p. 90. ‡ Ibid. p. 19. § Ibid. p. 81.

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 lamb black, all effect was destroyed; when covered with a sheet of tinfoil the effect was 10°[*]

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	Lead	60
Silver	90	Tinfoil softened by mercury	10
Tinfoil	85	Glass	10
Block-tin	80	Ditto coated with wax or oil	5
Steel	70		

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 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

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[*] Leslie, p. 20.

[†] Ibid. p. 98.

[‡] Ibid. p. 106.

[§] Ibid. p. 21.

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.

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 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.

Rarity.	AIR.		HYDROGEN.	
	Radiation of Glass.	Radiation of Metal.	Radiation of Glass.	Radiation of 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.

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.

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.*

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

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 $\frac{1}{300000}$ 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

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* Leslie, p. 28.

† Ibid. p. 38.

‡ Ibid.

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, 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.*

16. But the subsequent experiments of M. De la Rôche have somewhat modified the consequences which appeared to follow from the very ingenious experiments of Leslie, and show a much greater analogy between the radiation of light and heat than that philosopher had supposed. De la Roche found that radiant heat in some cases passes directly through glass: that the quantity of radiant heat which passes directly through glass is so much greater relative to the whole heat emitted in the same direction, as the temperature of the source of heat is more elevated: that calorific rays, which have already passed through a screen of glass, experience in passing through a second glass screen of a similar nature a much smaller diminution of their intensity than they did in passing through the first screen: that rays emitted by a hot body differ from each other in their faculty of passing through glass: that a thick glass, though as much or more permeable to light than a thin glass of a worse quality, allows a much smaller quantity of radiant

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* Leslie, p. 35.

heat to pass; but the difference is so much the less as the temperature of the radiating source is more elevated: and that the quantity of heat which a hot body yields in a given time by radiation to a cold body situated at a distance, increases, *cæteris paribus*, in a greater ratio than the excess of temperature of the first body above the second.[*]

These experiments of De la Roche, supposing them correct, destroy the conclusions deduced from Mr. Leslie's observations, that there is an essential difference between the radiation of light and of heat. There would appear on the contrary to be a close analogy between them. The hypothesis of Mr. Leslie that the radiation of heat is owing to aerial vibrations, similar to the propagation of sound, cannot be admitted, because it is inconsistent with the experiments of De la Roche. It would not be surprising if the power of producing *heat* and *light* were properties of the same substance. It may produce light when acting with a certain intensity, or when the particles follow each other at certain limited intervals. When these intervals are changed heat may be produced. It is even conceivable that those rays which are invisible to our eyes, and which therefore we are accustomed to consider as pure caloric, may produce an illuminating effect upon the eyes of some other animals.

II. CONDUCTION OF HEAT.

1. If we put the end of a bar of iron, 20 inches long, into a common fire, while a thermometer is attached to the other extremity, 4 minutes elapse before the thermometer begins to ascend, and 15 minutes by the time it has risen 15°. In this case, the caloric takes 4 minutes to pass through a bar of iron 20 inches long. When caloric passes in this slow manner, it is said to be *conducted* through bodies. It is in this manner that it usually 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.

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.

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.

[†] Annals of Philosophy, ii. 100.

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.

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 appears 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 sets 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 con-

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* [It is just as likely that bodies conduct caloric because they have no affinity for it. The heat that permeates a body does not combine with it. We know as yet nothing of the cause of conducting power.—C.]

sequence, 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.

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.

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

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* [Perfectly dry vegetables are very bad conductors: so is dry charcoal. It can hardly be said to be a conductor of caloric.—C.]

heated particles. The lowest stratum, as soon as it combines with a dose of caloric, becomes specifically lighter, and ascends. New particles approach the source of heat, combine with caloric in their turn, and are displaced. In this manner all the particles come, one after another, to the source of heat; of course the whole of them are heated in a very short time, and the caloric is carried almost at once to much greater distances in fluids than in any solid whatever. Fluids, therefore, have the property of *carrying* or *transporting* caloric; in consequence of which they acquire heat independent altogether of any conducting power.

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 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. These substances retarded the rate of cooling rather more than the starch.

Now the starch and eiderdown diminished the fluidity of the water. It follows from these experiments, that "the more completely the internal motions of a liquid are impeded, the longer is that liquid before it acquires a given temperature." Therefore, when heat is applied to liquids, they acquire the greatest part of their temperature, in common cases, by their carrying power. If liquids then be conductors, their *conducting* power is but small when compared with their *carrying* power.

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

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* [Very slowly. Fill a glass tube of about a quarter of an inch diameter, and 9 inches long, one third full of common water: carefully introduce without mixing, one third more of water coloured by litmus or cochineal. Hold the coloured part over the flame of a spirit lamp till the water boils. The uncoloured water will long remain undisturbed; at least till

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.

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 considerable importance, and deserves a thorough investigation.

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 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,
$$\left.\begin{array}{l}\text{Copper,}\\ \text{Tin,}\end{array}\right\}\text{nearly equal,}$$
$$\left.\begin{array}{l}\text{Platinum,}\\ \text{Iron,}\\ \text{Steel,}\\ \text{Lead,}\end{array}\right\}\text{much inferior to the others.}$$

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.

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.

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.

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the whole tube becomes heated. Again, apply the flame to the bottom of the tube; the liquors will be mixed in a minute's time, the uncoloured water will ascend, the coloured will descend.—C.]

* Jour. de Phys. 1789, p. 68.

† [Hence the practice of *annealing* glass: that is, putting it while hot, immediately after being formed into the required shape, into an oven strongly heated, where the glass remains till it becomes cold, by slow degrees.—C.]

‡ Ann. de Chim. xxx. 32.

Bodies.	Conducting Power.
Water	= 1·00
Diaspyrus ebenum	= 2·17
Pyrus malus	= 2·74
Fraxinus excelsior	= 3·08
Fagus sylvatica	= 3·21
Carpinus betulus	= 3·23
Prunus domestica	= 3.25
Ulmus	= 3·25
Quercus robur pedunculata	= 3·26
Pyrus communis	= 3·32
Betula alba	= 3·41
Quercus robur sessilis	= 3·63
Pinus picea	= 3·75
Betula alnus	= 3·84
Pinus sylvestris	= 3·86
Pinus abies	= 3·89
Tilea Europæa	= 3·90

Charcoal is also a bad conductor: according to the experiments of Morveau, its conducting power is to that of fine sand : : 2 : 3.[*] Feathers, silk, wool, and hair, are still worse conductors than any of the substances yet mentioned. This is the reason that they answer well for articles of clothing. They do not allow the heat of the body to be carried off by the cold external air. Count Rumford has made a very ingenious set of experiments on the conducting power of these substances.[†] He ascertained that their conducting power is inversely as the fineness of their texture.

16. The conducting power of liquid bodies has not been examined with any degree of precision. I find by experiment, that the relative conducting powers of mercury, water, and linseed oil, are as follows:

I. Equal Bulks.		II. Equal Weights.	
Water	= 1	Water	= 1
Mercury	= 2	Mercury	= 4·8
Linseed oil	= 1·111	Linseed oil	= 1·085

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.[‡]

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[*] Ibid. xxvi. 225.

[†] Phil. Trans. 1792.

[‡] Phil. Trans. 1786.

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 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, Nitrous oxide, Olefiant gas,	100+
Common air, Oxygen, Azotic gas,	100
Nitrous gas,	90
Gas from pit-coal,	70
Hydrogen gas	40

SECTION 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

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* Leslie's Inquiry into the Nature of Heat, p. 473.

† Dalton's New System of Chemical Philosophy, p. 117.

has to distribute itself among all contiguous bodies in such a manner, that the thermometer indicates the same temperature in all.

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.*

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 between 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.

From the late experiments of Delaroche, which seem to have been made with very great care, it appears that this law is only an approximation to the truth. At all temperatures below 212° it is sufficiently near; but the error increases as the temperature augments, and at last becomes very great.

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* Nov. Comm. Petrop. i. 195.

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 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 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 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.

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.*

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 ear-

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* Leslie, p. 281.

lier 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 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.

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.

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 was applied by Prevost with much ad-

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* See Pictet, sur le Feu, chap. i. † Geneva, 1792. ‡ Biblioth. Britan. iv. 30.

dress 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 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.

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* Phil. Trans. 1802, p. 403.

SECTION 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.

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.

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 is 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.

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 dilatation 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 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. Gay 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.

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

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* Manchester Memoirs, v. 593.

† Ann. de Chim. xliii. 137.

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.

From the experiments of Gay Lussac it appears that the steam of water, and the vapour of ether, undergo the same dilatation 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°.

Temp.	Bulk.	Temp.	Bulk.	Temp.	Bulk.	Temp.	Bulk.
32°	1000000	53°	1043749	73°	1085416	93°	1127083
33	1002083	54	1045833	74	1087499	94	1129166
34	1004166	55	1047916	75	1089383	95	1131249
35	1006249	56	1049999	76	1091666	96	1133333
36	1008333	57	1052083	77	1093749	97	1135416
37	1010416	58	1054166	78	1095833	98	1137499
38	1012499	59	1056249	79	1097916	99	1139583
39	1014583	60	1058333	80	1099999	100	1141666
40	1016666	61	1060416	81	1102083	110	1162499
41	1018749	62	1062499	82	1104166	120	1183333
42	1020833	63	1064583	83	1106249	130	1204166
43	1022916	64	1066666	84	1108333	140	1224999
44	1024759	65	1068749	85	1110416	150	1245833
45	1027083	66	1070833	86	1112499	160	1266666
46	1029166	67	1072916	87	1114583	170	1287499
47	1031249	68	1074999	88	1116666	180	1308333
48	1033333	69	1077083	89	1118749	190	1329166
49	1035416	70	1079166	90	1120833	200	1349999
50	1037499	71	1081249	91	1122916	210	1370833
51	1039583	72	1083333	92	1124999	212	1374999
52	1041666						

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 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.

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.

5. These observations are sufficient to show us, that the expansion of liquids is altogether unconnected with 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.

6. The following table exhibits the dilatation of various liquids from the temperature of 32° to that of 212°, supposing their bulk at 32 to be 1.

Muriatic acid* (sp. gr. 1·137)	0·0600 = $\frac{1}{17}$
Nitric acid* (sp. gr. 1·40)	0·1100 = $\frac{1}{9}$
Sulphuric acid* (sp. gr. 1·85)	0·0600 = $\frac{1}{17}$
Alcohol*	0·1100 = $\frac{1}{9}$
Water*	0·0466 = $\frac{1}{22}$
Water saturated with common salt*	0.0500 = $\frac{1}{20}$
Sulphuric ether*	0·0700 = $\frac{1}{14}$
Fixed oils*	0·0800 = $\frac{1}{12}$
Oil of turpentine*	0·0700 = $\frac{1}{14}$
Mercury*	0·0200 = $\frac{1}{50}$
Mercury†	0·01872 = $\frac{1}{53}$
Mercury‡	0·0168 = $\frac{1}{59}$
Mercury§	0·01758 = $\frac{1}{56}$
Mercury‖	0·0150 = $\frac{1}{66}$

Doctor Young has observed that if we denote a degree of Fahrenheit's thermometer by f, the expansion of water, reckoning either

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* Dalton, New System of Chemical Philosophy, i. 36.

† Lord Charles Cavendish.

‡ General Roy.

§ Haellstroem, Gilbert's Annalen, xvii. 107.

‖ Lalande and Delisle, Ibid. p. 102.

way from 39°, is nearly represented by $\cdot0000022\,f^2 - \cdot00000000435\,f^3$. He gives the following table of the expansion of this liquid from the experiments of Gilpin and Kirwan.*

Temp.	Expansion		Temp.	Expansion	
	Observed.	Calculated.		Observed.	Calculated.
30° Gilpin	·00020	·00018	74° Gilpin	·00251	·00251
32 G	·00012	·00011	79 G	·00321	·00326
34 G	·00006	·00005	90 G	·00491	·00513
39 G	·00000	·00000	100 G	·00692	·00720
44 G	·00006	·00005	102 Kirwan	·00760	·00763
48 G	·00018	·00018	122 K	·01258	·01264
49 G	·00022	·00022	142 K	·01833	·01859
54 G	·00049	·00048	162 K	·02481	·02512
59 G	·00086	·00084	182 K	·03198	·03219
64 G	·00133	·00130	202 K	·04005	·03961
69 G	·00188	·00186	212 K	·04333	·04332

The following table exhibits the degrees marked upon thermometers filled with different liquids at the same temperature as determined by the experiments of De Luc.† The tubes containing these liquids were of glass; but as he does not mention their capacities, nor the value of a degree, the table does not enable us to determine the expansion of the liquids used.

Mercury.	Olive oil.	Essential oil of camomile.	Essential oil of thyme.	Alcohol capable of setting fire to gunpowder.	Water saturated with common salt.	Water.
80°	80°	80°	80°	80°	80°	80°
75	74·6	74·7	74·3	73·8	74·1	71·0
70	69·4	69·5	68·8	67·8	68·4	62·0
65	64·4	64·3	63·5	61·9	62·6	53·5
60	59·3	59·1	58·3	56·2	57·1	45·8
55	54·2	53·9	53·3	50·7	51·7	38·5
50	49·2	48·8	48·3	45·3	46.6	32·0
45	44·0	43·6	43·4	40·2	41·2	26·1
40	39·2	38·6	38·4	35·1	36·3	20·5
35	34·2	33·6	33·5	30·3	31·3	15·9
30	29·3	28·7	28·6	25·6	26·5	11·2
25	24·3	23·8	23·8	21·0	21·9	7·5
20	19·3	18·9	19·0	16·5	17·3	4·1
15	14·4	14·1	14·2	12·2	12·8	1·6
10	9·5	9·3	9·4	7·9	8·4	0·2
5	4·7	4·6	4·7	3·9	4·2	0·4
0	0·0	0·0	0·0	0·0	0·0	0·0
–5				–3·9	–4·1	
–10				–7·7	–8·0	

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* Young's Lectures on Natural Philosophy ii. 392.

† Recherches sur les Modifications de l'Atmosphere, i. 271.

In these thermometers 0 denotes the temperature at which water freezes, 80° the temperature at which it boils.

Gay Lussac* has lately turned his attention to the phenomena of the expansion of liquids. The following table exhibits the result of his researches. He supposes the volume of each of the liquids at its boiling temperature to be 1000. The table represents the contractions which each liquid experienced when cooled down every five degrees centigrade below its boiling point. The temperatures at which the different liquids tried boiled were as follows :

Water - -	212°	Sulphuret of carbon	116·1
Alcohol - -	173·14	Sulphuric ether -	96·2

Temperature.	Water.	Alcohol.	Sulphuret of carbon.	Ether.
	Contractions.	Contractions	Contractions.	Contractions.
0°	0·00	0·00	0·00	0·00
5	3·34	5.55	6·14	8·15
10	6·61	11·43	12·01	16·17
15	10·50	17·51	17·98	24·16
20	13·15	24·34	23·80	31·83
25	16·06	29·15	29·65	39·14
30	18·85	34·74	35.06	46·42
35	21·52	40·28	40·48	52·06
40	24·10	45·68	45·77	58·77
45	26·50	50·85	51·08	65·48
50	28·56	56·02	56·28	72·01
55	30·60	61·01	61·14	78·38
60	32·42	65·96	66·21	
65	34·02	70·74		
70	35·47	75·48		
75	36·70	80·11		

From the preceding table it appears that alcohol and sulphuret of carbon undergo the same dilatation. Gay Lussac has shown that they likewise form the same volume of vapour when exposed to a boiling temperature.

Alcohol forms 488·3 its volume of vapour.
Sulphuret of carbon 491·1 its volume of vapour.

7. The expansion of solid bodies is so small that many precautions are necessary to measure it with precision. So far as observation has gone it is equable. In this respect resembling the expansion of the gases. I shall introduce here in the first place the table of the expansion of different solid bodies from 32° to 212°, as determined by Lavoisier and Laplace, in 1782. The experiments seem to have been made with very great care. They were supposed to have been lost; but have lately been recovered and published by Biot.†

[*] Ann. de Chim. et Phys. ii. 130.

[†] Traité de Physique, i. 158.

Substances tried.	Length of a rule at 212° which at 32° is 1,00000000.	Dilatation in vulgar fractions.
Glass of Saint Gobain	1,00089089	$\frac{1}{1122}$
Glass tube without lead	1,00087572	$\frac{1}{11\;2}$
Ditto	1,00089760	$\frac{1}{1114}$
Ditto	1,00091751	$\frac{1}{1090}$
English flint glass	1,00081166	$\frac{1}{1248}$
French glass with lead	1,00087199	$\frac{1}{1147}$
Copper	1,00172244	$\frac{1}{581}$
Copper	1,00171222	$\frac{1}{584}$
Brass	1,00186671	$\frac{1}{535}$
Brass	1,00188971	$\frac{1}{529}$
Hammered iron	1,00122045	$\frac{1}{819}$
Iron wire	1,00123504	$\frac{1}{812}$
Hard steel	1,00107875	$\frac{1}{927}$
Soft steel	1,00107956	$\frac{1}{926}$
Tempered steel	1,00123956	$\frac{1}{807}$
Lead	1,00284836	$\frac{1}{351}$
Malacca tin	1,00193765	$\frac{1}{516}$
Tin from Falmouth	1,00217298	$\frac{1}{462}$
Cupelled silver	1,00190974	$\frac{1}{524}$
Silver, Paris standard	1,00190868	$\frac{1}{524}$
Pure gold	1,00146606	$\frac{1}{682}$
Gold, Paris standard, not softened	1,00155155	$\frac{1}{645}$
Ditto, softened	1,00151361	$\frac{1}{661}$

In the year 1754, Mr. Smeaton published a set of experiments on the expansion of different substances measured by means of a very ingenious instrument of his own invention, described by him in the Philosophical Transactions for that year.* The following table shows the expansions which the different substances tried, undergo from 32° to 212° supposing the original bulk to be 1.

White glass barometer tube	0·00083
Antimony	0·001083
Blistered steel	0·001125
Hard steel	0·001225
Iron	0·001258
Bismuth	0·001392
Copper hammered	0·001700
Copper, 8 parts mixed with tin 1	0·0018166
Brass, 16 parts with tin 1	0·001908
Brass wire	0·001933
Speculum metal	0·001933
Spelter solder, viz. brass 2, zinc 1	0·002058

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* Phil. Trans. 1754, p. 598.

Fine pewter - - - - - - -	0·002283
Grain tin - - - - - - -	0·002483
Soft solder, viz. lead 2, tin 1 - - -	0·002508
Zinc, 8 with tin 1, a little hammered -	0·002692
Lead - - - - - - - -	0·002867
Zinc - - - - - - - -	0·002942
Zinc hammered ½ inch per foot - -	0·003011

The following table exhibits the dilatations of different substances as determined by General Roy, the accuracy of whose experiments is well known.

Glass tube - - - -	0·00077615
Glass rod - - - -	0·00080787
Cast-iron prism - - -	0·0011094
Steel rod - - - -	0·0011447
Brass scale, supposed from Hamburg	0·0018554
English plate brass rod - -	0·001875
English plate brass trough - -	0·0018928

In the following table I shall give the result of the trials of some other artists and philosophers on the expansion of some other bodies, reckoning as usual the bulk at 32° to be 1. The expansion given is from 32° to 212°.

Steel - - -	0·0011899.	Troughton.
Silver - - -	0·0020826.	Troughton.
Copper - - -	0·0019188.	Troughton.
Iron wire - -	0.0014401.	Troughton.
Platinum - -	0·0009918.	Troughton.
Platinum - -	0·00085655.	Borda.
Palladium - -	0·0010.	Wollaston.
Iron - - -	0·001446.	Haellstroem.

The expansion of glass being frequently an important point in experiment has been examined with great care. But different kinds of glass differ so much from each other that no general rule can be laid down. Lavoisier and Laplace found that it was the less dilatable by heat the more lead it contained.*† Several determinations will be found in the preceding tables, and I shall add some more here. Ramsden found the expansion between 32° and 212° of a solid glass rod 0·0096944, and that of a glass tube 0·0093138. De Luc's experiments on the expansion of thermometer and barometer tubes 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

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* Biot. Traité de Physique, i. 157.

† [From the finer kind of barometer tubes, I have procured by powdering the glass and mixing it with a small quantity of charcoal, from 1-5th to 1-4th its weight of metallic lead. The lead exists in the glass in the state of an oxyd.—C.]

8. The property which bodies possess of expanding, when heat is applied to them, has furnished us with an instrument for measuring the relative temperatures of bodies. This instrument is the *thermometer*. A thermometer is merely a hollow tube of glass, hermetically sealed, and blown at one end into a hollow globe or *bulb*. The bulb and part of the tube are filled with mercury. When the bulb is plunged into a hot body, the mercury expands, and of course *rises* in the tube; but when it is plunged into a cold body, the mercury contracts, and of course *falls* in the tube. The rising of the mercury indicates an increase of heat; its falling a diminution of it; and the quantity which it rises and falls indicates the proportion of increase or diminution. To facilitate observation, the tube is divided into a 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.

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

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* Phil. Trans. Abr. iv. i.

† On the Construction and Graduation of Thermometers.

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.

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.

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. 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, and increases towards the freezing point. The boiling point is marked 0, the freezing point 150°.[‖]

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[*] Phil. Trans. 1777, p. 816.

[†] 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 $F = \frac{9R}{4} + 32$.

[‖] 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 $F = 212 - \frac{6D}{5}$; to reduce those above the boiling point, $F = 212 + \frac{6D}{5}$.

9. 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.

10. Water furnishes a remarkable example of the first class of bodies. This liquid is 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.

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

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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.

above or below 41°. He made his experiments 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.*

Specific Gravity.	Bulk of Water.	Temperature.		Bulk of Water.	Sp. Gravity of Ditto.
	100000	39		1·00000	
1·00000	00	38	40	00	1·00000
0·99999	01	37	41	01	0·99999
0·99998	02	36	42	02	0·99998
0·99996	04	35	43	04	0·99996
0·99994	06	34	44	06	0·99994
0·99991	08	33	45	08	0·99991
0·99988	12	32	46	12	0·99988

Mr. Dalton, in a set of experiments published in 1802, obtained nearly the same result as De Luc. He placed 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

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* Phil. Trans. 1792, p. 428.

† Manchester Mem. v. 374.

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 was 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 necessary 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 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°.

Such are the experiments by which this very curious and important fact seems perfectly established. The mean of them all makes

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* Jour. de Phys. xlix. 171; and Hauy's Traité de Physique, i. 55. and 181.

† Gilbert's Annalen der Physik, xvii. 207.

‡ See Edin. Trans. vol. vi. The paper was published before October 1804.

§ See Nicholson's Journal, xi. 228. Aug. 1805.

the point at which the specific gravity of water is a maximum 39·81°. We may therefore without much risk of error consider it in round numbers as 40°, which was the temperature selected by the French Philosophers when they fixed their new standard of weights and measures.

11. 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.

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 ascertain 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 (from crystallization.)

The 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 *anti-*

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* Ann. de Chim. xiv. 286.

mony.[*] Hence the precision with which cast iron takes the impression of the mould. [Hence the use of antimony to the type-founder.—C.]

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. [*i. e.* their tendency to crystallization.—C.]

12. 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 to - 36° before it freezes; and during the whole process it continually contracts. 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 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

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[*] Mem. Par. 1726, p. 273. Berthollett's Statique Chimique, ii. 348.

[†] Phil. Trans. 1783, p. 23.

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.

All solid bodies, a very small number excepted, may be converted into liquids by heating them sufficiently; and, on the other hand, every liquid 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.

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 shapes have the property of appearing successively in all the intermediate states.

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:

Substance.	Melting Point.	Substance.	Melting Point.
Lead - -	612°	Ice - -	32
Bismuth - -	476	Milk - -	30
Tin - -	442	Vinegar - -	28
Sulphur - -	218	Blood - -	25
Wax - -	142[*]	Oil of Bergamot -	23
Spermaceti -	112	Wines - -	20
Phosphorus -	108	Oil of turpentine -	14
Tallow - -	92	Mercury - -	—39
Oil of anise -	50	Liquid ammonia -	—46
Olive oil - -	36	Ether - -	—46

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.[†]

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 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.[‡]

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[*] Bleached wax, 155°. Nicholson.

[†] Blagden, Phil. Trans. 1788, p. 125.

[‡] See Phil. Trans. 1788, p. 277.

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	53·3	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 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 of water.	Freezing point by experiments.	Do. by calculation.
3·12	28 +	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

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.[†]

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

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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.

[‡] Ibid. p. 181.

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.

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 23, 1762;* and every year after he gave a detailed account of the whole doctrine in his lectures.

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 a certain dose of caloric without any augmentation of its temperature; and it is this dose of caloric which occasions the change of the solid into a fluid. When the fluid is converted again into a solid, the dose of caloric leaves it without any diminution of its temperature; and it is this abstraction which occasions the change. Thus the combination of a certain dose of caloric with ice causes it to become water, and the abstraction of a certain dose of caloric from water causes it to become ice. Water, then, is a compound of ice and caloric; and in general, all fluids are combinations of the solid to which they may be converted by cold and a certain dose of caloric.

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:

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°;

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* Black's Lectures, preface, p. 38.

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 supended 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 enters 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 4°) 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

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* Black's Lectures, i. 120.

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.

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 they 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°. Now it deserves attention, that $5 \times 28 = 140$, 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 expense 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

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* Black's Lectures, i. 127.

† A medium of several experiments.

= 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-drachms;—that of the hot water 135—of the mixture 254—of the glass vessel 16. Sixteen parts of glass have the same effect in heating cold bodies as eight parts of equally hot water. Therefore, instead of the 16 half-drachms of glass, eight of water may be substituted, which makes the hot water amount to 143 half-drachms.

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 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°.

Water, then, after being cooled down to 32°, cannot freeze till

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* Black's Lectures, i. 123.

† Phil. Trans. 1783, p. 313.

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. 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.

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.

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 latent 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

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* Jour. de Phys. xxv.

† Black's Lectures, i. 187.

‡ Nicholson's Jour. ix. 45.

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.

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.

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.

4. The following table contains the boiling point of a number of liquids.

Bodies.	Boiling Point.	Bodies.	Boiling Point.
Sulphuric ether	96°	Muriate of lime	264‡
Sulphuret of carbon	116	Sulphuric acid (sp. gr. 1·849)	605*
Ammonia	140*		
Alcohol	173	Phosphorus	554
Water	212	Sulphur	570
Nitric acid of 1·54	175*	Linseed oil	600
Nitric acid (sp. gr. 1·42)	248	Mercury	656
Carbonate of potash	260†		

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 ebullition. From the experiments of Professor Robison, it appears that, in a vacuum, all liquids boil about 124° lower than in the open air, under a pressure of 30 inches of mercury; therefore water would boil in vacuo at 88° and alcohol at 49°. In a Papin's digester, the temperature of water may be raised to 300°, or even 400°, without ebullition: but the instant that this great pressure is removed, the boiling commences with prodigious violence.

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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* Dalton.

† When so much concentrated as to become nearly solid, 280°.

‡ By my trials.

§ Manchester Memoirs, v. 559.

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.	Temperature.	Force of Vap. in inches of Mercury.
−40°	·013	36°	·229	78°	·940	120°	3·33	162°	9·91
−30	·020	37	·237	79	·971	121	3·42	163	10·15
−20	·030	38	·245	80	1.00	122	3·50	164	10·41
−10	·043	39	·254	81	1·04	123	3·59	165	10·68
		40	·263	82	1·07	124	3·69	166	10·96
0	·064	41	·273	83	1·10	125	3·79	167	11·25
1	·066	42	·283	84	1·14	126	3·89	168	11·54
2	·068	43	·294	85	1·17	127	4·00	169	11·83
3	·071	44	·305	86	1·21	128	4·11	170	12·13
4	·074	45	·316	87	1·24	129	4·22	171	12·43
5	·076	46	·328	88	1·28	130	4·34	172	12·73
6	·079	47	·339	89	1·32	131	4·47	173	13·02
7	·082	48	·351	90	1·36	132	4·60	174	13·32
8	·085	49	·363	91	1·40	133	4·73	175	13·62
9	·087	50	·375	92	1·44	134	4·86	176	13·92
10	·090	51	·388	93	1·48	135	5·00	177	14·22
11	·093	52	·401	94	1·53	136	5·14	178	14·52
12	·096	53	·415	95	1·58	137	5·29	179	14·83
13	·100	54	·429	96	1·63	138	5·44	180	15·15
14	·104	55	·443	97	1·68	139	5·59	181	15·50
15	·108	56	·458	98	1·74	140	5·74	182	15·86
16	·112	57	·474	99	1·80	141	5·90	183	16·23
17	·116	58	·490	100	1·86	142	6·05	184	16·61
18	·120	59	·507	101	1·92	143	6·21	185	17·00
19	·124	60	·524	102	1·98	144	6·37	186	17·40
20	·129	61	·542	103	2·04	145	6·53	187	17·80
21	·134	62	·560	104	2·11	146	6·70	188	18·20
22	·139	63	·578	105	2·18	147	6·87	189	18·60
23	·144	64	·597	106	2·25	148	7·05	190	19·00
24	·150	65	.616	107	2·32	149	7·23	191	19·42
25	·156	66	·635	108	2·39	150	7·42	192	19·86
26	·162	67	·655	109	2·46	151	7·61	193	20·32
27	·168	68	·676	110	2·53	152	7·81	194	20·77
28	·174	69	·698	111	2·60	153	8·01	195	21·22
29	·180	70	·721	112	2·68	154	8·20	196	21·68
30	·186	71	·745	113	2·76	155	8·40	197	22·13
31	·193	72	·770	114	2·84	156	8.60	198	22·69
		73	·796	115	2·92	157	8·81	199	23·16
32	·200	74	·823	116	3·00	158	9·02	200	23·64
33	·207	75	·851	117	3·08	159	9·24	201	24·12
34	·214	76	·880	118	3·16	160	9·46	202	24·61
35	·221	77	·910	119	3·25	161	9·68	203	25·10

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.	Temperature.	Force of Vap. in inches of Mercury.
204°	25·61	228°	40·30	253°	61·00	278°	86·50	302°	114·15
205	26·13	229	41·02	254	61·92	279	87·63	303	115·32
206	26·66	230	41·75	255	62·85	280	88·75	304	116·50
207	27·20	231	42·49	256	63·76	281	89·87	305	117·68
208	27·74	232	43·24	257	64·82	282	90·99	306	118·86
209	28·29	233	44·00	258	65·78	283	92·11	307	120·03
210	28·84	234	44·78	259	66·75	284	93·23	308	121·20
211	29·41	235	45·58	260	67·73	285	94·35	309	122·37
212	30·00	236	46·39	261	68·72	286	95·48	310	123·53
		237	47·20	262	69·72	287	96·64	311	124·69
213	30·60	238	48·02	263	70·73	288	97·80	312	125·85
214	31·21	239	48·84	264	71·74	289	98·96	313	127·00
215	31·83	240	49·67	265	72·76	290	100·12	314	128·15
216	32·46	241	50·50	266	73·77	291	101·28	315	129·29
217	33·09	242	51·34	267	74·79	292	102·45	316	130·43
218	33·72	243	52·18	268	75·80	293	103·63	317	131·57
219	34·35	244	53·03	269	76·82	294	104·80	318	132·72
220	34·99	245	53.88	270	77·85	295	105·97	319	133·86
221	35·63	246	54·68	271	78·89	296	107·14	320	135·00
222	36·25	247	55·54	272	79·94	297	108·31	321	136·14
223	36·88	248	56·42	273	80·98	298	109·48	322	137·28
224	37·53	249	57·31	274	82·01	299	110·64	323	138·42
225	38·20	250	58·21	275	83·13	300	111·81	324	139·56
226	38·89	251	59·12	276	84·35	301	112·98	325	140·70
227	39·59	252	60·05	277	85·47				

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.

8. The specific gravity of different vapours differs according to

the nature of the liquid from which they proceed. The following table shows the boiling points of various liquids, and the specific gravity of the vapours which they form as far as the subject has been hitherto investigated.

	Specific gravity, air being 1.	Boiling point.
Water	0·6235*	212°
Hydrocyanic vapour	0·9476*	79·7
Alcohol	1·603*	173
Muriatic ether	2·219†	52
Sulphuric ether	2·586*	96
Sulphuret of carbon	2·6447*	116
Oil of turpentine	5·013*	314‡
Hydriodic ether	5·4749*	148

9. 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 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 40½° 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 40½ × 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 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

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* Gay Lussac, Ann. de Chim. xci. p. 95, 150.—Ann. de Chim. et Phys. i. 218.

† Thenard. Mem. D'Arcueil, i. 121.

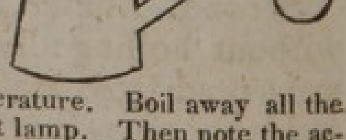
‡ By my experiment.

§ Black's Lectures, i. 157.

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°. According to Rumford it amounts to 1040·8°.* The latent heat of the vapour of boiling alcohol according to the same experimenter is between 477° and 500°.†



* [Place a tin can of the following form on a dry piece of cork as a bad conductor. It is better that the surface of the tin should be very clean and bright. It should hold about a pint and a quarter. It will weigh about 4 oz., or 5 oz. at the utmost. Put into it 16 oz. by measure, or one pound by weight, of pure water, of the common temperature of the room; and into a small retort, 1 oz. measure of the same water. Note the temperature. Boil away all the water in the retort, by means of a small chaffing dish or a patent lamp. Then note the accession of temperature communicated to the water and the tin can, by thus converting 1 oz. of water into steam. Suppose the water weighed 16 oz., and the tin can weighed 4 oz., and the original temperature being 50° of Fahrenheit, it is raised by the steam to the temperature of 100°. Then here is an accession of 50° of heat communicated to each of 20 oz. of water and tin, by the latent heat of 1 oz. of water, which in such case will be 1000, beside the heat communicated to the beak of the retort, through which the steam passes.—C.]

† Gilbert's Annalen, xlv. 312.

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.

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.

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 temperatures. Ammoniacal gas condenses into a liquid at — 45°. None of the other gases have been hitherto condensed.

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.

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 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, 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.

SECTION V.

OF THE QUANTITY OF CALORIC 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 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.

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 $83\frac{1}{3}$°; consequently the water has only lost $16\frac{2}{3}$, while the oil has gained $33\frac{1}{3}$. 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 $66\frac{1}{3}$, so that the oil has given out $33\frac{1}{3}$, and the water has received only $16\frac{2}{3}$. 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 oil 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 (one degree for instance) be made = 1, we can determine, by experiment, how much more, or 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.

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 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 1781.§ The manner in which they

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* Black's Lectures, i. 504.

† Ibid.

‡ The term *specific caloric* has been employed in a different sense by Seguin. He used it for the *whole caloric* which a body contains.

§ Mr. Wilcke quotes Klingenstjerna as the author who first started the doctrine of the difference between the specific heat of bodies. *Kongl. Vetenskaps Academiens nya handlingar*, tom. ii. for 1781, p. 49. I have been informed by the late Professor Robison, that Wilcke's information was first got from a Swedish gentleman, who attended Dr. Black's lectures about 1770. But I do not know on what evidence he founded his statement.

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 tin-plate, filled with boiling water, and kept there till it acquired a certain temperature, which was ascertained by a thermometer. Into another small box of tin-plate 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 an ingenious calculation, the specific caloric of the metal, that of water being considered as unity.

Next, in point of time, and not inferior in ingenious contrivances to ensure accuracy, were the experiments of Dr. Crawford, made by mixing together bodies of different temperatures. These were published in his Treatise on Heat. 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 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 considered as inversely proportional to its specific caloric.*

To the labours of this ingenious experimenter we are indebted for some of the most remarkable 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 the well-known accuracy of these philosophers cannot but be very valuable.

Their method was extremely simple and ingenious; it was first suggested by Mr. Laplace. An instrument was contrived, to which Lavoisier gave the name of *calorimeter*. It consists of three cir-

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* 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 specific 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.

cular 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 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 is covered by a lid, which is composed of the same materials. The middle cavity is filled with ice. This ice is supported by a grate, and under the grate is placed a sieve. The external cavity is also filled with ice. We have remarked already, that no caloric can pass through ice at 32.° It can enter ice, indeed, but it remains in it, and is employed in melting it. The quantity of ice melted, then, is a measure of the caloric which has entered into the ice. The exterior and middle cavities being filled with ice, till 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 and the tube 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 a pipe. 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 of Mr. Wedgewood, one would be apt to conclude that this does not happen. He found that the melted ice, so far from flowing out, actually *froze* again, and choked up the passage.

A table of the specific caloric of various bodies was likewise drawn up by Mr. Kirwan, and published by Magellan in his Treatise on Heat. Mr. Meyer published a set of experiments on the specific caloric of dried woods; and Mr. Leslie, in his Essay on Heat, has given us the result of his experiments on various bodies. The experiments of Meyer were made by ascertaining the rate of cooling of the same bulks of different bodies. From this he deduced their conducting power for heat; and he considered the specific caloric as the reciprocal of the product of the conducting power multiplied into the specific gravity of the body.[*] Mr. Leslie likewise made his observations by ascertaining the time that various bodies of equal bulks took up in cooling in the same circumstances. He then multiplied the proportional numbers thus got into the specific gravity of the various bodies tried.[†]

Mr. Dalton has also turned his attention to this important subject, and has published a table of the specific heats of different bodies. His method was similar to that employed by Leslie; and Mr. Dalton informs us that he found that method susceptible of considerable precision.

Count Rumford, who had attached himself in a particular manner to the science of heat, likewise made some experiments on the specific heat of various bodies. But his results differ very much from those of the other experimenters, that have turned their attention to the subject and are probably not so accurate.[‡]

In the year 1813, a most elaborate set of experiments was published by Delaroche and Berard on the specific heat of gaseous bodies—a subject which had occupied the particular attention of Crawford, and likewise of Lavoisier and Laplace. But the methods employed by these philosophers had not acquired the confidence of chemists. The process of Delaroche and Berard was somewhat difficult of execution; but seems in skilful hands to be susceptible of considerable precision, and as far as appears, the experiments were conducted with the utmost care.[§]

The following table exhibits a view of the specific heats of various bodies as they have been determined by the different experiments hitherto made:

I. GASES REFERRED TO AIR.[‖]

	Same bulk.	Same weight.
Air	1·0000	1·0000
Hydrogen	0·9033	12·3401
Carbonic acid	1·2583	0·8280
Oxygen	0·9765	0·8848
Azote	1·0000	1·0318
Oxide of azote	1·3503	0·8878
Olefient gas	1·5530	1·5763
Carbonic oxide	1·0340	1·0805

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[*] Let L be the conducting power, A the specific caloric, and M the specific gravity. According to Meyer we have $A = \frac{1}{LM}$. See Ann. de Chim. xxx. 46.

[†] See Leslie on Heat, p. 240.

[‡] His mode of making the experiment may be seen in the Philosophical Magazine, xliii. 212, or in Gilbert's Annalen, xlv. 306.

[§] See Ann. de Chim. lxxxv. 72, or annals of Philosophy, ii. 134.

[‖] Delaroche and Berard. Annals of Philosophy, ii. 291.

GASES REFERRED TO WATER.*

	Same weight.
Water	1·0000
Air	0·2669
Hydrogen	3·2936
Carbonic acid	0·2210
Oxygen	0·2361
Azote	0·2754
Oxide of azote	0·2369
Olefiant gas	0·4207
Carbonic oxide	0·2884
Aqueous vapour	0·8470

II. WATER.

	Sp. Caloric.
Ice	0·9000† ·8000(a)
Water	1·0000
Steam	1·5500*

III. SALINE SOLUTIONS.

		Sp. Caloric.
Carbonate of ammonia		0·851† 0·95(D)
Sulphuret of ammonia (0·818)		0·994†
Sulphate of magnesia	1	0·844†
Water	2	
Common Salt	1	0·832†
Water	8	
Ditto (1·197)		0·78(D)
Nitre	1	0·8167‡
Water	8	
Nitre	1	0·646†
Water	3	
Carbonate of potash (1·30)		0·75(D)
Muriate of ammonia	1	0·798†
Water	1·5	
Tartar	1	0·734†
Water	237·3	
Sulphate of iron	1	0·765†
Water	2·5	
Sulphate of soda	1	0·728†
Water	2·9	
Alum	1	0·649†
Water	2·9	
Nitric acid	9⅓	0·6189‡
Lime	1	
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)
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)
Acetic acid	(1·056)	0·66(D)
Potash	(1·346)	0·759†
Amm.	(0·997)	0·708†
	(0·948)	1·03(D)

V. INFLAMMABLE LIQUIDS.

Alcohol	(0·817)	1·086† 0·930(a) 0·70(D) 0·6666* 0·64(L) 0·602*
	(0·853)	0·58978‖
	(0·818)	0·54993‖
	(·848)	·76(D)
Sulph ether.	(0·76)	0·66(D)
	(·729)	0·54329‖

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* Delaroche and Berard. Annals of Philosophy, ii. 432.

	Sp. Caloric.
Oil of olives	0·718† 0·50(L) 0·43 9‖
Linseed oil	0·528† 0·45192‖
Spermaceti oil	0·5000* 0·52(D)
Oil of turpentine	0·472† 0·400(a) 0·33856‖
Naphtha	0·41519‖
Spermaceti	0·399†
Ditto fluid	0·320(a)

VI. ANIMAL FLUIDS.

Arterial blood	1·0300* 0·913(b)
Venous blood	0·8928* 0·903(b)
Cow's milk	0·9999* 0·98(D)

VII. ANIMAL SOLIDS.

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¶
Cotton	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¶
Dyaspyrus 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.

Hydrate of lime	0·40(D)
Chalk	0·27(D) 0·2564*
Quicklime	0·30(D) 0·2229* 0·2168‡
Ashes of pit-coal	0·1855*
Ashes of elm	0·1402*
Agate (2·648)	0·195§
Stoneware	0·195†
Crown glass	0·200(a)
Crystal	0·1929‡
Swedish glass (2·386)	0·187§
Flint glass	0·19(D) 0·174†
X. Sulphur	0·19(D) 0·183†
Muriate of soda	0·23(D)

XI. METALS.

Platinum	0·13(a)
Iron (7·876)	0·143(a) 0·13(D) 0·125† 0·1269* 0·126§
Brass (8·356)	0·1123* 0·116§ 0·11(D)

	Sp. Caloric.
Copper (8·784) -	0·1111* 0·114§ 0·11(D)
Sheet iron - -	0·1099‡
Gun metal - -	0·1100‖
Nickel - -	0·10(D)
Zinc (7·154) -	0·0943* 0·102§ 0·10(D)
Silver (10·001	0·082§ 0·08(D)
Tin - -	0·068† 0·0704* 0·07(D) 0·060§
Antimony - (6·107)	0·086† 0·0645* 0·063§ 0·06(D)
Gold (19·040)	0·050§ 0·05(D)
Lead (11·456)	0·050† 0·0352* 0·042§ 0·04(D)
Bismuth (9·861)	0·043§ 0·04(D)
Mercury -	0.033† 0·0357* 0·0290‡ 0·0496(D)

XII. OXIDES.

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†

* Crawford; † Kirwan; ‡ Lavoisier and Laplace; § Wilke; ¶ Meyer; (L) Leslie; ‖ Count Rumford; (D) Dalton, New System of Chemical Philosophy, p. 62. (a) Irvine, Essays, p. 84 and 88. (b) John Davy, Phil. Trans. 1814, p. 593.

The following are the most important points respecting the specific caloric of bodies hitherto investigated.

1. Dr. Crawford made a great many experiments relative 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

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* Crawford on Heat, p. 33.

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 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 in 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 bodies continues the same at all temperatures, the absolute quantity of caloric in bodies must be proportional to the specific caloric. Thus if the specific caloric of spermaceti oil be only half of that of water, water must contain twice as much caloric as spermaceti oil of the same temperature. Let us suppose both bodies to be totally deprived of caloric, and that we apply to them a thermometer, the zero point of which indicates absolute cold or a total deprivation of heat. To

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[*] [I see no reason whatever for the names *specific heat*, or, *caloric of capacity;* or for supposing that the substance caloric, has not, like all other substances, it own peculiar affinities; combining with one substance in one proportion, with another in another. Sensible heat, or caloric of temperature, seems to be caloric *mixed* with a body—pervading its pores: latent heat, is caloric *chemically combined* with a body; and of course its properties will be merged, until by chemical decomposition of the compound thus formed, the caloric becomes separated, and exhibits again its characteristic properties. Thus muriatic acid in common salt is latent; when set free by sulphuric acid taking its place, it becomes sensible. Such seems to be the case with caloric.—C.]

raise the oil and water one degree, we must throw in a certain quantity of heat, and twice as much heat will be necessary 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 $10\,x = 9\,x + 1260$, fron 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 Fahrenheit's 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 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

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* New System of Chemical Philosophy, p. 97.

† On Heat, p. 478.

‡ [See note to page 107.—C.]

§ Crawford on Heat, p. 455.

compound generates cold; when the specific caloric diminishes, heat is evolved.

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 hyphothesis 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, $C\,Q + c\,q - \overline{K\,Q + k\,q} : \overline{K\,Q + k\,q} :: l : S$. Hence $S = \frac{l\,(K\,Q + k\,q)}{C\,Q + c\,q - K\,Q - k\,q}$. 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 $\frac{1889}{-0{\cdot}01783}$ below 32°, $= + 23837°$.*

The mean result of Gadolin's experiments on mixtures of sulphuric acid and water place it at 2300° below 0.

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* See Seguin, Ann. de Chim. v. 231.

Mr. Dalton's results vary from 4150° to 11000°; 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, 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.

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 $x + 157$. 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 conceives that this is owing to the thermometer not being an accurate measure of the scale of temperature;[‖] for when the

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[*] New System of Chemical Philosophy, p. 97.

[†] Manchester Memoirs, v.

[‡] Manchester Memoirs, v. 601.

[§] 1803, vol. iv. 223.

[‖] Ibid. v. 34.

temperature is corrected by Deluc's experiments, the anomaly in one of the instances disappears.

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 portion 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 should 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.

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*. 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.

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 Muschenbroek 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*.

They were induced to adopt this hypothesis, because they could not otherwise account for the freezing of water. According to them, these frigorific particles insinuate themselves like wedges between the molecules of water, destroy their mobility, and thus convert water into ice. Dr. Black, by discovering the cause of the freezing of water, banished the frigorific particles from the regions of philosophy; because the advocates for them never brought any other proof for their existence than the convenience with which they accounted for certain appearances. Of course, as soon as these appearances were explained without their use, every reason for supposing their existence was destroyed.

The only fact which gives any countenance to the opinion that cold is a body, has been furnished by the following very curious experiment of Mr. Pictet.* Two concave tin mirrors being placed at the distance of 10½ feet from each other, a very delicate air thermometer was put into one of the foci, and a glass matrass full of snow into the other. The thermometer sunk several degrees, and rose again when the matrass was removed. When nitric acid was poured upon the snow (which increases the cold), the thermometer sunk 5° or 6° lower. Here *cold* seems to have been emitted by the snow, and reflected by the mirrors to the thermometer, which could not happen unless cold were a substance.

But this curious experiment is explained in a satisfactory manner, by applying to it Prevost's theory of radiant heat. We see from that theory that the fall of the thermometer is really owing to a smaller proportion than usual of heat being radiated.

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.

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 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 favoured by Mr. Walker.

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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 500lbs. 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 (whatever 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." The experiment of Pictet appears likewise to have been made by Andrew Gaertner, Mechanician to the King of Poland, and published by him in 1785. See Ann. de Chim. lxxi. 159.—[Si quis candelam in loco ubi spectabilis res locari debet, opposuerit, accedat candela per aerem usque ad oculos ut illos calore et lumine offendet; hoc autem mirabilius erit, ut calor, *ita frigus reflectitur, si eo loco, nix objiciatur, si oculum retigerit, quia sensibilis etiam frigus percipiet.* Sed admirabilior est quod idem speculum non solum calorem et frigus, sed vocem refringit. Baptista Porta magia Naturalis: editio septima xvi. 4. 26 Nicholson's Journal, 314.—C.]

† 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.		
Muriate of ammonia Nitrate of potash Water	5 5 16	From + 50° to + 10°.	40
Muriate of ammonia Nitrate of potash Sulphate of soda Water	5 5 8 16	From + 50° to + 4°.	46
Nitrate of ammonia Water	1 1	From + 50° to + 4°.	46
Nitrate of ammonia Carbonate of soda Water	1 1 1	From + 50° to — 7°.	57
Sulphate of soda Diluted nitric acid	3 2	From + 50° to — 3°.	53
Sulphate of soda Muriate of ammonia Nitrate of potash Diluted nitric acid	6 4 2 4	From + 50° to — 10°	60
Sulphate of soda Nitrate of ammonia Diluted nitric acid	6 5 4	From + 50° to — 14°	64
Phosphate of soda Diluted nitric acid	9 4	From + 50° to — 12°.	62
Phosphate of soda Nitrate of ammonia Diluted nitric acid	9 6 4	From + 50° to — 21°	71
Sulphate of soda Muriatic acid	8 5	From + 50° to 0°.	50
Sulphate of soda Diluted sulphuric acid	5 4	From + 50° to + 3°.	47

N. B. If the materials are mixed at a *warmer* temperature than that expressed in the table, the effect will be proportionably *greater*; thus, if the 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.*

SECTION VI.

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 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 six: It *radiates* constantly from the sun; it is evolved during *combustion;* and it is extricated in many cases by percussion, friction, mixture, and electricity. The sources of heat, then, are the *sun*, *combustion*, *percussion*, *friction*, *mixture*, *electricity*. Let us consider each of these sources in the order in which we have enumerated them.

I. 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 observations of Dr. Herschel render it probable that this opinion is erroneous.† From these observations it ap-

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* Walker, Phil. Trans. 1795.

† Phil. Trans. 1801, p. 265.

pears, 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 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.

1. 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 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 70°. 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,

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* Beddoe's Contributions, p. 4.

and both the lumps of marble were again placed on the hot iron: The one that had been blackened gave out just as little light as the other.* In this case, the light which ought to have proceeded from the luminous marble disappeared: it must therefore have been stopped in its passage out, and retained by the black paint. Now black substances are those which absorb the most light, and they are the bodies which are most heated by exposure to light. Cavallo observed, that a thermometer with its bulb blackened stands higher than one which had its bulb clean, when exposed to the light of the sun, the light of day, or the light of a lamp.† Mr. Pictet made the same observation, and took care to 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.‡

2. 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, 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°.‖

3. 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.

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* Phil. Trans. 1792.

† Phil. Trans. 1780.

‡ Sur le Feu, chap. iv.

§ Voyages sur les Alpes, ii. 932.

‖ 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. Robinson concluded, the moist air conducts better than dry; a conclusion fully confirmed by the subsequent experiments of Count Rumford.

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.*

4. 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 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.

But some of the recent experiments related in a preceding part of this chapter seem to render it rather probable that heat and light are modifications of the same matter, and that it is susceptible, by means which at present we are incapable of fully appreciating, of assuming either the modification to which we give the name of light, or that which we call heat.

II. 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 continues to emit light and caloric for a long time. When the emission ceases, the charcoal has all disappeared, except an inconsiderable residuum of ashes; being almost entirely converted into carbonic acid gas, which makes its escape unless the experiment be conducted in proper vessels. If it be collected, it is found to exceed greatly in weight the whole of the charcoal consumed.

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

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* Jour. de Phys. lxi. 32.

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 hypothesis 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.[*][†]

About ten years after the publication of Hooke's *Micrographia*, his theory was adopted by Mayow, without acknowledgment, in a tract which he published at Oxford on saltpetre.[‡] We are indebted to him for a number of very ingenious and important experiments, in which he anticipated several modern chemical philosophers; but his reasoning is for the most part absurd, and the additions which he made to the theory of Hooke are exceedingly extravagant. To the solvent of Hooke he gives the name of *spiritus nitro-aereus*. It consists, he supposes, of very minute particles, which are constantly at variance with the particles of combustibles, and from their quarrels all the changes of things proceed. Fire consists in the rapid motion of these particles, heat in their less rapid motion. The sun is merely nitro-aerial particles moving with great rapidity. They fill all space. Their motion becomes

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[*] Hook's Micrographia, p. 103. See also his Lampas.

[†] [It may be worth while to enumerate the progress of opinion relating to the phenomena of heat and combustion.

1st. Fire devoured the substance. *Albertus Magnus.*

2d. Heat dissolves the substance consumed. *Hooke.*

3d. Violent friction and agitation between the substance acted on, and something contained in the air nitro-aerial particles. *Mayow.* This is not very unlike Mr. Brande's notion, that combustion is owing to intense chemical action, 8 Brande's Journ. 306.

4th. Violent gyratory motions. *Stahl. Scheele. Davy.*

5th. Setting free combined light. *Macquer.*

6th. Setting free ether. *Newton.*

7th. Heat and light evolved from oxygen in which they were latent. *Crawford.*

8th. Ascribed to hydrogen or phlogiston by *Kirwan* and *Priestley.*

9th. The absorption and fixation by chemical affinity of oxygen gas. *Lavoisier.*

10th. I consider it as owing to the latent heat set free, when oxygen combines with carbon, or with hydrogen; this last gas, when liquified, or solidified, gives out more caloric than the oxygen that combines with it. The light is latent in the carbon and in the hydrogen, and on combustion is given out.—C.]

[‡] De Sal-nitro et Spiritu Nitro-aereo.

more languid according to their distance from the sun; and when they approach near the earth, they become pointed, and constitute *cold.*[*]

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. 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.

4. The celebrated Macquer 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

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[*] Though Mayow's theory was not original, and though his additions to it be absurd, his tract 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.

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.

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 whatsoever state we may suppose them.

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.

8. Mr. Kirwan, who had already raised himself to the first rank among chemical philosophers, by many ingenious investigations of some of the most difficult parts of the science, 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 he at-

tempted in a treatise published on purpose, entitled, *An Essay on Phlogiston and the Constitution of Acids.**

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

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* I have omitted, in the historical view given in the text, the hypothesis published in 1777 by Mr. Scheele, one of the most extraordinary men that ever existed. When very young, he was bound apprentice to an apothecary at Gottenburgh, where he first felt the impulse of that genius which afterwards made him so conspicuous. He durst not indeed devote himself openly to chemical experiments; but he contrived to make himself master of that science by devoting those hours to study which were assigned him for sleep. He afterwards went to Sweden, and settled as an apothecary at Koping. Here Bergman first found him, saw his merit, and encouraged it, adopted his opinions, defended him with zeal, and took upon himself the charge of publishing his treatises. Encouraged and excited by this magnanimous conduct, the genius of Scheele, though unassisted by education or wealth, burst forth with astonishing lustre; and at an age when most philosophers are only rising into notice, he had finished a career of discoveries which have no parallel in the annals of chemistry. Whoever wishes to behold ingenuity combined with simplicity, whoever wishes to see the inexhaustible resources of chemical analysis; whoever wishes for a model in chemical researches—has only to peruse and to study the works of Scheele.

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.

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.

According to the theory of Lavoisier, which is now almost generally received, and considered by chemists 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.

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, chlorine, 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.

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[*] [How does this accord with the statement in this vol. that there are four supporters of combustion?

Mr. Brande, 8 Journ. of Sc. and the Arts 306, observes, that heat is given out in the formation of some sulphurets and phosphurets: and that the only cause that in the present state of our knowledge can be assigned for the phenomena of heat and light, is *intense chemical action*. But this explains nothing. It seems to me, that the theory of Lavoisier will ultimately maintain its ground; but the contradictions of Dr. Thomson still remain.—C.]

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.

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, 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 Journ. de Phys. lx. 289.

bine with thermoxygen; those substances, on the contrary, which by combustion are converted into acids, combine with oxygen.* This ingenious theory obviates the objection completely, provided its truth can be established in a satisfactory manner. But as the evidence for it rests almost entirely upon its convenience in explaining several difficult points in the phenomena of combustion, we must consider it rather in the light of an ingenious conjecture than as a theory fully established.†

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.

The simple supporters at present known are three in number;‡ namely,—Oxygen,—Chlorine,—Iodine.

The compounds which these three bodies make with each other and with azote are likewise supporters.

17. The combustibles are of three kinds; namely, *simple*, *compound;* and *oxides*, *chlorides* and *iodides*. The simple are the following,

1. Hydrogen, 2. Carbon, 3. Boron,
4. Silicon, 5. Phosphorus, 6. Sulphur,
7. The metals.

The compounds are the various bodies formed by the union of these simple substances with each other. The combustible oxides consist chiefly of combinations of hydrogen, carbon and azote with oxygen without undergoing combustion, and they constitute the chief bodies found in the vegetable and animal kingdoms.

18. During combustion, the supporter (supposing it simple, or, if compound, the oxygen, chlorine, or iodine, excluding the base) 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. Now every product is either, 1. an acid; 2. an oxide; 3. a chloride; or 4. an iodide.

19. As light and heat are always emitted during combustion, but never when a supporter combines with a combustible without combustion, it is natural to suppose that the supporters contain either the one or the other of these bodies or both of them.

I am disposed to believe that the supporters contain caloric,

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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.

[‡ Reasons will be assigned, to shew, that there is in reality only one supporter of combustion.—C.]

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 supporter 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 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.

20. 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.

That the light exists combined with the combustible, will appear 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.

21. Were we to suppose that the supporters contain caloric as a component part, while combustibles contain light, it would not be difficult to explain what takes place during combustion. The com-

ponent parts of the supporters are two: 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 supporter combines with the base of the combustible, and forms the product; while at the same time the caloric of the supporter combines with the light of the combustible, and the compound flies off in the form of fire. Thus combustion is a double decomposition; the supporter 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.

22. 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 not formed without the assistance of heat. This melts the sulphur and phosphorus. At the instant of their combination with the metallic or earthy 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.

23. Whenever a supporter enters into a more intimate combination with a combustible than before, combustion is the consequence. This phenomenon appears in several of the metallic oxides, and has been lately particularly attended to by Berzelius,* Thus green oxide of chromium when heated to redness takes fire and

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* Annals of Philosophy, vii. 438.

burns for an instant without altering its weight. Before exposure to the heat it was readily soluble in acids; but after this combustion it has become altogether insoluble; indicating a more intimate combination between the oxygen and chromium, or at least an increased aggregation in the particles of the oxide. Oxide of tantalum, oxide of rhodium, and several other bodies exhibit similar phenomena. The combustions which I formerly ascribed to the action of *partial supporters*, may be explained in this way.

24. 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. He filled a bladder capable of holding 30,000 grains of water with the gas: this bladder was fitted with a stop-cock 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.†

A very numerous set of experiments was likewise made by Count Rumford on the heat evolved during the combustion of oils, spirits, and various woods: and from the length of time which he devoted to the subject, and the numerous precautions to which he had recourse, it is probable that his results are near approximations to the truth.‡ 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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* See his experiments on animal heat, p. 254, 320, 333.

† Dalton's New System of Chemical Philosophy, p. 76.

‡ Nicholson's Journal, xxxii. 105; xxxiv. 319, and xxxv. 95.—Gilbert's Annalen, xlv. 1, 306.

Substances burnt, 1 lb.	Oxygen consumed in lbs.	Ice melted in lbs.			
		Lavoisier.	Crawford.	Dalton.	Rumford.
Hydrogen	6	295	480	320	
Carbureted hydrogen	4			85	
Olefiant gas	3·5			88	
Carbonic oxide	0·58			25	
Olive oil	3·5	148	89	104	93·073
Rape oil					124·097
Wax	3·5	133	97	104	126·242
Tallow	3·5			104	111·582
Oil of turpentine				60	
Alcohol				58	67·470
Ether, sulphuric	3			62	107·027
Naphtha					97·834
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.

The result of Count Rumford's experiments on the combustion of woods will be seen in the following table.

Species of wood.	Quality.	Ice in lbs. melted by the heat developed during the burning of 1 lb. of the combustible.
Lime	Joiner's dry wood, 4 years old	46·145
Ditto	Ditto	46·406
Ditto	Ditto, highly dried over a chafing dish	52·806
Ditto	Ditto	54·210
Ditto	Ditto, rather less dried	51·777
Beech	Joiner's dry wood, four or five years old	45·089
Ditto	Ditto	45·002
Ditto	Ditto, highly dried over a chafing dish	48·445
Ditto	Ditto	48·245
Elm	Joiner's wood, rather moist	36·196
Ditto	Joiner's dry wood, four or five years old	40·478
Ditto	Ditto	40·068
Ditto	Ditto, highly dried over a chafing dish	46·020
Ditto	Ditto	44·868
Ditto	Ditto, dried and scorched in the stove	41·200
Oak	Common fire wood in moderate shavings	34·120

Species of wood.	Quality.	Ice in lbs. melted by the heat developed during the burning of 1 lb. of the combustible.
Oak	Ditto, in thicker shavings, leaving a residuum of charcoal - - - - -	32·997
Ditto	Ditto, in thin shavings - - - -	35·062
Ditto	Ditto, in thin shavings, well dried in the air	38·946
Ditto	Joiner's wood, very dry, in thin shavings -	39·840
Ditto	Ditto - - - - - -	39·728
Ditto	Thick shavings, leaving 0·92 grains of charcoal	34·969
Ash	Joiner's common dry wood - -	40·888
Ditto	Same kind, shavings dried in the air -	44·960
Ditto	Ditto, highly dried over a chafing dish -	47·265
Maple	Seasoned wood, highly dried over a chafing dish	48·156
Service	Ditto, ditto - - -	48·173
Ditto	Same kind, scorched in a stove - -	43·116
Cherry	Joiner's dry wood - - -	44·452
Ditto	Same kind, highly dried over a chafing dish	49·205
Ditto	Same kind, scorched in a stove - -	46·350
Fir	Joiner's common dry wood - -	40·429
Ditto	Shavings well dried in air - -	45·333
Ditto	Highly dried over a chafing dish - -	49·838
Ditto	Dried and scorched in a stove - -	44·477
Ditto	Thick shavings leaving much charcoal -	38·260
Poplar	Joiner's common dry wood - -	46·134
Ditto	Same kind, highly dried over a chafing dish	49·548
Hornbeam	Joiner's dry wood - - -	42·400
Ditto	Ditto - - - - - -	42·145
Oak	With 19·6 per cent. of water imperfectly burnt, leaving in the combustion a charcoal residuum amounting to - - - } 0·81 gramme	35·228
	0·73	34·121
	0·94	34·556

If any confidence can be put in the accuracy of the preceding tables it is pretty obvious that the quantity of heat evolved during combustion is not proportional to the quantity of oxygen which unites with the burning body. When we compare the combustion of the oils, wax, and alcohol made by Count Rumford, with the quantity of heat evolved during the combustion of hydrogen and charcoal as determined by Crawford, reckoning the composition of the compound inflammables, as it has been determined by the experiments of Saussur and Gay Lussac, it would appear that there is a specific quantity of heat evolved during the buring of hydrogen and charcoal, and that the same quantity appears when these bodies are burnt in whatever state of composition they may exist.*

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* [It appears from the table in page 104 ante, that the caloric chemically combined with common air being one, the caloric chemically combined with an equal weight of oxygen, is only ·8848, while the caloric thus combined with an equal weight of hydrogen, is 12·34. Hence when these gasses are liquified, or solidified during that kind of decomposition which constitutes combustion, the greater part of the caloric set free must be ascribed to the hydrogen.—C.]

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 collision of flint and steel is too familiar a fact to require being mentioned. No heat, however, has ever been observed to follow the percussion of liquids, nor of soft bodies which easily yield to the stroke.

1. This evolution of caloric by percussion seems to be the consequence of a permanent or temporary condensation of the body struck. The specific gavity of iron before hammering is 7·788; after being hammered, 7·840: that of platinum before hammering is 19·50; after it, 21·65.

2. Now condensation seems always to evolve caloric; at least this is the case in those bodies in which we can produce a remarkble 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 thermometer 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 cannot be doubted that a much greater rise of temperature than 50 degrees is occasioned by the condensation of air. The experiment first made by Mollet, but which has long been familiar to chemists, shows this in a convincing manner. If a piece of tinder be put into the extremity of a syringe, and the air be suddenly condensed upon it, the tinder catches fire.‡

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°.§

Berthollet, Pictet, and Biot, have made a set of experiments, to ascertain the quantity of heat evolved when ductile metals are suddenly struck forcibly, as when they are stamped in the process of coining. The experiments were made upon pieces of gold, silver,

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* Darwin, Phil. Trans. 1788.

† Manchester Memoirs, v. 515.

‡ Pictet, Phil. Mag. xiv. 364.

§ Ibid. v. 515.

and copper, of the same size and shape, and care was taken that all the parts of the apparatus had acquired the same temperature before the experiments began. Copper evolved most heat, silver was next in order, and gold evolved the least. The first blow evolved the most heat, and it diminished gradually, and after the third blow was hardly perceptible. The heat acquired was estimated by throwing the piece of metal struck into a quantity of water, and ascertaining the change of temperature which the water underwent. The following table exhibits the increase of temperature, experienced by two pieces of copper by three successive blows;

1st Blow	1st Piece - - - -	17·44°
	2d Piece - - - -	20·80
2d Blow	1st Piece - - - -	7·30
	2d Piece - - - -	3·69
3d Blow	1st Piece - - - -	1·90
	2d Piece - - - -	1·46

The whole quantity of heat evolved by each of these pieces of copper is nearly the same; that from the first piece being 26·64°, and that from the second 25·95°.

The following table exhibits the heat evolved from two pieces of silver treated in the same way.

1st Blow	1st Piece - - - -	6·19°
	2d Piece - - - -	7·30
2d Blow	1st Piece - - - -	5·85
	2d Piece - - - -	2·14
3d Blow	1st Piece - - - -	2·76
	2d Piece - - - -	2·02
Total evolved form the 1st piece - -		14·74
Ditto from the 2d - - - -		11·46

The change in the specific gravity which the metals underwent, was found to be proportional to the heat thus evolved, as appears from the following table, deduced from their experiments. The specific gravities were taken at the temperature of 46·5°.

Specific gravity of gold	19·2357
Ditto annealed -	19·2240
Ditto struck - -	19.2487
Specific gravity of silver	10·4667
Ditto annealed -	10·4465
Ditto struck - -	10·4838
Specific gravity of copper	8·8529
Ditto struck - -	8·8898
Ditto struck a 2d time	8·9081

From these experiments it is obvious, that the heat evolved when metals are struck is owing to the condensation, and proportional to the condensation. Hence, when they can no longer be condensed, they cease to evolve heat. These philosophers observed, during their experiments, that heat or cold is propagated much more rapidly, from one piece of metal to another, when they are struck, than when they are simply placed in contact.*

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* Mem. d'Arcueil, ii. p. 441.

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 iron has been heated by the hammer, it is much harder and brittler than before. It must then have become denser, and consequently must have parted with caloric. It is an additional confirmation of this, that the same bar cannot be heated a second time by percussion until it has been exposed for some time to a red heat. It is too brittle, and flies to pieces under the hammer. Now brittleness seems in most cases owing to the absence of the usual quantity of caloric. Glass *unannealed*, or, which is the same thing, that has been cooled very quickly, is always extremely brittle. When glass is in a state of fusion, there is a vast quantity of caloric accumulated in it, the repulsion between the particles of which must of course be very great; so great indeed, that they would be disposed to fly off in every direction with inconceivable velocity, were they not confined by an unusually great quantity of caloric in the surrounding bodies: consequently if this surrounding caloric be removed, the caloric of the glass flies off at once, and more caloric will leave the glass than otherwise would leave it, because the velocity of the particles must be greatly increased. Probably then the brittleness of glass 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.

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 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.

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 exa-

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* T. Wedgewood, Phil. Trans. 1792.

mining 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 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, that 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 a supporter 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 all such bodies are electrics. They are frequently also phosphorescent; which property may likewise contribute to the effect.[‡]

IV. FRICTION.

Caloric is not only evolved by percussion, but also by friction. Fires are often kindled by rubbing pieces of dry wood smartly against one another. It is well known that heavy-loaded carts sometimes take fire by the friction between the axle-tree and the wheel. Now in what manner is the caloric evolved or accumulated by friction? Not by increasing the density of the bodies rubbed against each other, as happens in cases of percussion; for heat is produced by rubbing soft bodies against each other; the density of which therefore cannot be increased by that means, as any one may convince himself by rubbing his hand smartly against his coat. It is true, indeed, that heat is not produced by the friction of liquids; but then they are too yielding to be subjected to strong friction. It is not owing to the specific caloric of the rubbed bodies decreasing; for Count Rumford found that there was no sensible decrease,[§] nor, if there were a decrease, would it be sufficient to account for the vast quantity of heat which is sometimes produced by friction.

Count Rumford took a cannon cast solid and rough as it came from the 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

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[*] T. Wedgewood, Phil. Trans. xxiv. 2165.

[†] Phil. Trans. 1792, p. 45.

[‡] Jour. of the Royal Instit. i. 264.

[§] Nicholson's Journal, ii. 106.

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 10,000lbs. avoirdupois, and the cylinder was turned round at the rate of 32 times in a minute. At the beginning of the experiment the temperature of the cylinder was 60°; at the end of 30 minutes, when it had made 960 revolutions, its temperature was 130°. The quantity of metallic dust or scales produced by this friction amounted to 837 grains. Now, if we were to suppose that all the caloric was evolved from these scales, as they amounted to just $\frac{1}{948}$ part of the cylinder, they must have given out 948° to raise the cylinder 1°, and consequently 66,360° to raise it 70° or to 130°, which is certainly incredible.*

Neither is the caloric evolved during friction owing to the combination of oxygen with the bodies themselves, or any part of them. By means of a piece of clock-work, Mr. Pictet made small cups (fixed on the axis of one of the wheels,) to move round with considerable rapidity, and he made various substances rub against the outsides of these cups, while the bulb of a very delicate thermometer placed within them marked the heat produced. The whole machine was of a size sufficiently small to be introduced into the receiver of an air-pump. By means of this machine a piece of adamantine spar was made to rub against a steel cup in air: sparks were produced in great abundance during the whole time, but the thermometer did not rise. The same experiment was repeated in the exhausted receiver of an air-pump (the manometer standing at four lines;) no sparks were produced, but a kind of phosphoric light was visible in the dark. The thermometer did not rise. A piece of brass being made to rub in the same manner against a much smaller brass cup in air, the thermometer (which almost filled the cup) rose 0·3°, but did not begin to rise till the friction was over. This 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 1¼ 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

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* Nicholson's Journal, ii. 106.

† Pictet, sur le Feu, ch. ix.

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 26·58 lbs. 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 lasted, 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.*

The experiments of Rumford were repeated and diversified by M. Haldot. He contrived an apparatus by which two bodies could be pressed against each other by means of a spring, while one of them turned round with the velocity of 32·8 inches per second. The friction took place in a strong box containing 216 cubic inches of water. The results obtained so nearly resemble those of Count Rumford that it is unnecessary to enter into particular details. The rubber was brass. When the metal rubbed was zinc the heat evolved was greatest; brass and lead afforded equal heat, but less than zinc; tin produced only $\frac{7}{9}$ths of the heat evolved during the friction of lead. When the pressure was quadrupled the heat evolved became seven times greater than before. When the rubber was rough it produced but half as much heat as when smooth. When the apparatus was surrounded by bad conductors of heat, or by non-conductors of electricity, the quantity of heat evolved was diminished.†

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 cannot be easily reconciled to such a supposition. 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

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* Nicholson's Journal, ii. 106.

† Ibid. xxvi. 30.

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 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°.†

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.

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.

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 remarkable exceptions to this rule are some of the gaseous bodies, which when united together constitute a solid body, as ammoniacal and muriatic acid gases. At the instant of union a very considerable heat is evolved. But even these gaseous bodies contain a considerable proportion of water, which in all probability contributes not a little to the effect.

2. In many cases the particular change of temperature which is produced by mixture depends upon the proportion of water pre-

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* Pictet sur le Feu, chap. vi.

† Ibid. chap. ix.

viously combined with one of the ingredients; for the same ingredients are capable either 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, (because the water they combine with, gives out its latent heat on being thus combined).

3. It may be laid down as a rule to which there are few exceptions, 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 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.

From the experiments of Gay Lussac it appears still more clearly that the evolution of heat or cold in such cases depends upon the change of the water from a state of solidity to a state of liquidity, or *vice versa*. He mixed together a solution of nitrate of ammonia of the specific gravity 1·302 at the temperature of 61·3° with water in the proportion of 44·05 of the former and 33·76 of the latter. The temperature of the mixture sunk 8·9°, yet the density increased. For the mean density would have been 1·151, while the density of the mixture was 1·159. This acute experimenter mentions several similar examples; though in none of them was the absorption of heat so great as in the instance which I have selected.*

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* Ann. de Chim. et Phys. i. 214.

5. Whenever water is solidified, a considerable proportion of the 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 the same reason heat is produced when quicklime is thrown into sulphuric acid.

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 solid, heat must be evolved; because a fluid can only become solid by parting with its caloric of fluidity. But the application of the theory to all cases of changes in temperature by mixture is so obvious, that it is quite unnecessary to give any farther illustration.

7. In most combinations which evolve heat or cold, a change takes place in the specific caloric of the bodies combined. To this change Dr. Irvine ascribed the whole of the heat or cold evolved. Though he appears to me to have carried this doctrine too far, the change must doubtless be allowed to have considerable effect.

VI. ELECTRICITY.

1. It is well known that when an excited body is discharged through air, there always appears a very bright flash of light, familiarly known by the name of the *spark*. This spark when sufficiently strong, produces all the effects of heat. It fuses the most refractory metals, and sets fire to gunpowder, to alcohol, and other combustible bodies. Hence, it is obvious, that electricity evolves both heat and light. Indeed the quantity of heat produced by the action of a large galvanic battery is nearly as intense as that produced by the most powerful burning glasses, or by the combustion of a mixture of oxygen and hydrogen gases. This is clearly shown by the experiments of Mr. Children with his magnificent galvanic apparatus.*

2. The effects which electricity produces upon metallic bodies seem to be inversely as their powers of conducting electricity. The best conductors are least injured by its action, and the worst conductors are most injured. Van Marum† made the full charge of a battery, charged by the Teylerian machine, to pass through wires $\frac{1}{32}$ of an inch in diameter, and consisting of different metals in succession. The following table exhibits the length of each wire melted by the discharge.

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* Phil. Trans. 1815, p. 363.

† *Premiere continuation des experiences faites par le moyen de la machine electrique Teylerienne.*

	Inches.		Inches.
Lead wire	120	Silver	0·25
Tin	120	Copper	
Iron	5	Brass	
Gold	$3\frac{1}{2}$		

By equal discharges of the battery.

A wire of iron, $\frac{1}{33}$ inch in diameter, was melted the length of 16
———— silver, $\frac{1}{33}$ inch in diameter, (partly melted, partly reduced to small bits) - - - 8·5
———— copper, $\frac{1}{33}$ inch in diameter, (not melted) - 0·25
———— brass, $\frac{1}{33}$ inch in diameter, (partly melted, partly reduced to small bits) - - - 12

Now it appears from the experiments of Van Marum, that copper is a much better conductor of electricity than brass or iron.

When electrical shocks are made to pass through a good conductor, a thermometer placed in the conductor does not rise. Van Marum made a stream of electric matter pass to the bulb of a thermometer; it rose from 80° to 100°. In the vacuum of an air pump, a thermometer in the same circumstances rose to 120°. Being placed in oxygen gas and in azotic gas, both rarefied to the same degree, the rise of the thermometer was the same.*

Mr. Children's experiments, with his powerful galvanic battery, were more susceptible of accuracy than those of Van Marum, owing to the uninterrupted flow of the electrical current. Hence, in all probability, they are more to be depended on. From the length of metallic wires brought into fusion by this battery, it would appear that the order of the metals as conductors of electricity is as follows.†—1. Silver—2. Zinc—3. Gold—4. Copper—5. Iron—6. Platinum.

It is very remarkable, that when metals are ignited by electricity, they remain longer red hot than when the same effect is induced by a common fire. It would be difficult by a common fire to ignite a wire of zinc. But this may be readily done by means of a galvanic battery.

3. Whenever two bodies in different electrical states, the one plus, the other minus, are brought near each other, so as to produce a discharge and destroy the excitement, heat is always evolved. What is the cause of this heat? By those who consider the two states of electricity as two distinct fluids, this question is considered as capable of a ready answer. Heat, say they, is formed by the union of the two electricities. While separate, they produce the phenomena of electricity; but when united, they lose their electrical properties, and constitute heat. The British philosophers, however, who do not admit of the existence of negative electricity as a distinct substance, but consider it as the consequence of a body being deprived of the usual dose of electricity which it possesses

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* Phil. Mag. viii. 193.

† Phil. Trans. 1815, p. 367.

when in a neutral state, have not been able to answer the question in a satisfactory manner.

4. Berzelius has contrived a theory of combustion and of chemical affinity, which has a very plausible appearance, and which has been embraced, either entirely or with some modifications, by several of the most eminent chemists of the present day. According to him, all bodies which have an affinity for each other are in two opposite states of electricity, and the more intensely each is excited, the stronger is their affinity for each other. When they unite, these opposite electricities are neutralized either in part or entirely, and the neutralization produces the phenomena of combustion, namely, the extrication of heat and light. If we were to modify this theory by adopting the French hypothesis, that resinous electricity is a distinct fluid as well as vitreous electricity; and if we were to suppose farther, that the union of these two electricities constitutes the body, which is capable, according to circumstances, of assuming the form of heat or of light; in that case the phenomena of combustion would admit of a simple and complete explanation.* The hypothesis is plausible; but it cannot be adopted with safety till Berzelius's theory of chemical affinity be better demonstrated than has hitherto been possible. That every body in nature has a peculiar permanent electrical state which it never loses, except by combining with another body, and that bodies which combine are always in opposite states of electricity, may rather, in most cases, be considered as an assertion than a deduction from the phenomena. Oxygen and chlorine, for example, are two bodies which are conceived to be always negatively electric. Phosphorus and sulphur, with which they unite, are positive. Let it be admitted that these consequences are legitimately deduced from the galvanic experiments of Berzelius, confirmed by Davy. Oxygen and chlorine are capable of uniting and of forming permanent compounds. This I consider as inconsistent with Berzelius's doctrine of chemical affinity, taken in its broadest extent. The reason of the union, he says, is, that the oxygen is much more intensely negative than the chlorine. But if negative electricity be a peculiar fluid, the particles of which repel each other, I do not see how bodies charged with it can unite; or at any rate, the union destroys the hypothesis that chemical affinity depends upon the different electrical states of bodies. The subject will require a much closer examination than it has hitherto met with, before the theory of Berzelius can be either adopted or rejected.

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* [The phenomena of electricity can be so well explained by the presence or absence of one fluid—its accumulation or defect—that to introduce two fluids, is to admit of more causes than are necessary to explain the phenomena.—C.]

CHAPTER III.

Of Electricity.

If we rub a piece of sealing wax or a glass tube with a woollen cloth, or the fur from the back of a cat, and then bring into its neighbourhood very small fragments of paper, or the down of feathers, we shall find that these minute bodies will be attracted by it, will adhere for some time to its surface, and then be again repelled. This property, which certain bodies acquire by friction, was observed by the ancients. Amber was the substance in which it was principally distinguished. Now the Greek name for amber is ηλεκτρον. On that account the property received the name of *electricity*. Several other bodies were observed to possess electrical properties by Gilbert and Boyle. But Mr. Stephen Grey, of the Royal Society of London, was probably the first person who made the subject a serious and continued study. He began his electrical experiments in the year 1720, and continued them till the period of his death in 1736. He found that certain bodies could be rendered electric by friction while others could not. Glass, resin, sulphur, silk, wool, hair, paper, &c. belong to the first class of bodies; metals, and most liquids, to the second. When a glass tube is *excited* (the name by which the electric state is denoted by electricians) by friction, if it be brought within a certain distance of a metallic rod, however long, the rod acquires the property of attracting light bodies, provided it be suspended by silk threads or hair; but not if it be suspended by linen or metal. He found that the same was the case with liquids. But glass, resin, and the other bodies capable of being excited by friction, do not acquire this property when placed near a body in an electric state. Those bodies capable of being excited by friction, Mr. Gray called *electrics*, the others were *non-electrics*. Those bodies which become electric by being placed in the neighbourhood of an excited body, he called *conductors;* those which do not, he called *non-conductors*. The *electrics* he found were all *non-conductors;* while the *non-electrics* were all *conductors*. The electrics or non-conductors must be employed to suspend or *insulate* metals when they are to receive and retain electricity: the conductors or non-electrics will not answer that purpose.

M. Dufay, a French philosopher of considerable celebrity, turned his attention to electricity, seemingly in consequence of the experiments of Gray; and in the year 1734 published a paper in the Philosophical Transactions* containing two capital discoveries; the second of which may be considered as constituting the foundation stone of the science of electricity. 1. When an excited body is placed in the neighbourhood of a light body in its natural state, it attracts the body, and continues to attract it till it has acquired a

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* Phil. Trans. vol. xxxviii. p. 258. He published eight dissertations on electricity, in the Memoirs of the French Academy of Sciences.

state of excitement. It then repels it. As soon as the light body has lost its electricity by coming in contract with some body in its natural state, it is again attracted, and becoming a second time electric, is repelled as before. So that excited bodies attract bodies in their natural state, but repel them when excited. 2. There are two kinds of electricity; the first belonging to glass, rock crystal, precious stones, hair, and wool; the second to amber, copal, lac, silk, thread, paper, resins, &c. The first kind he called *vitreous* electricity, the second *resinous* electricity. When bodies possess the *same* kind of electricity, they *repel* each other; when they possess *different* kinds of electricity, they *attract* each other.

These discoveries excited the universal attention of philosophers. The science was cultivated with assiduity in every part of Europe, and likewise in America, and has been gradually brought to its present state. The two most distinguished electricians after the two that have been mentioned, are, perhaps, Franklin and Volta. The first discovered the identity of thunder and electricity, and contrived an ingenious theory, which united all the facts, and afforded a plausible explanation of the phenomena. The second discovered that conductors when brought in contact acquire *different* electric states, and was led by this discovery to contrive the Voltaic pile, which has been so important an instrument of investigation in the hands of chemists. Electricity contains so vast a collection of facts, that it would be impossible to detail them in the present work; and even if it were possible it would be improper, because the greater part of them have no connxtion with the science of chemistry. I propose, hereafter, to treat of the science of electricity in a separate work. At present I shall merely give such a sketch of the theory as will enable the reader to appreciate the electrical experiments which now constitute an indispensable part of every system of chemistry.

1. Electricity may be conceived to be produced by the agency of a subtile fluid, of such a nature that no quantity of it which we can accumulate in bodies is capable of producing any perceptible effect upon the most delicate balance. The electric fluid then, supposing it to exist, is imponderable. Dufay's original opinion that there exist two kinds of electric fluids, the vitreous and resinous, seems to me to correspond better with all the phenomena, and to lead to fewer perplexing consequences than the theory afterwards substituted for it by Dr. Franklin. According to him bodies may be *excited* two ways, either by adding to them a superabundant quantity of electricity, or by depriving them of a portion of what they naturally contain. When in the first state, he said that they were electrified *positively* or *plus;* when in the second state, he said that they were electrified *negatively* or *minus.* When they contain their usual quantity of the fluid they exhibit no signs of electricity, in that case they are said to be neutral. Franklin's *positive* electricity is the same with the *vitreous* electricity of Dufay; while his *negative* electricity is the *resinous* electricity of Dufay. This

theory of Franklin was put into a mathematical dress by Epinus and Cavendish, and has been almost universally adopted both in Great Britain and on the continent. But the recent discoveries made in the science, by the invention of the Voltaic pile, seem to me to agree much better with the theory of Dufay than with that of Franklin; I shall therefore adopt it in preference in the present sketch.*

2. From the experiments of Coulomb we are entitled to infer that the vitreous electricity attracts the resinous with a force inversely as the square of the distance. But the particles of the vitreous electricity repel each other with a force inversely as the square of the distance, and the same law holds with the particles of the resinous electricity.

3. When the two electricities are combined together they neutralise each other, and in that case the body containing them exhibits no sign of electricity. But when the two electricities are separated from each other, and accumulated either in different bodies or in different parts of the same body, in such cases, the bodies so circumstanced exhibit signs of electricity, by attracting or repelling light bodies, and are then said to be in a state of excitement.

4. Through some substances the electric fluids are capable of passing with great facility; while through other bodies they pass with considerable difficulty or not at all. The first set of bodies are called *conductors*, the second *non-conductors*.

All metals are conductors; so is charcoal, and plumbago, and most liquids. Glass, resins, sulphur, diamond, phosphorus, precious stones, silk, hair, wool, are non-conductors.

5. When two bodies are rubbed against each other, the two electricities are separated from each other by the friction; one of them is accumulated in one of the bodies, and the other in the other. Hence both bodies become excited, the one possessing vitreous and the other resinous electricity. If the bodies be conductors, this state cannot continue for an instant, unless they be insulated; but if the bodies be non-conductors the state possesses some permanence. Hence non-conductors alone in ordinary cases can be excited. It is on this account that they have received the name of *electrics*. When the substances contained in the following table are rubbed against each other, the one that stands first in the list acquires the vitreous electricity, and the one that follows it acquires the resinous electricity. Thus the fur of a cat becomes vitreously electric against whatever substance it is rubbed, while rough glass becomes resinously electric when rubbed against any body in the table, except sulphur. Feathers when rubbed against wool become resinously electric; but they become vitreously electric when rubbed against wood.

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* [There seems to be no more reason for introducing two different electric fluids, than for introducing one fluid to account for heat, and another to account for cold. Again, both the vitreous and the resinous electricities may be made apparent in the same piece of glass. —C.]

The fur of a cat.
Polished glass.
Woollen cloth.
Feathers.
Wood.
Paper.
Silk.
Lac.
Rough glass.
Sulphur.

6. The electricities when separated from each other are capable of moving through conductors with inconceivable velocity. It appears from the experiments of Sir William Watson, and the other members of the Royal Society, who accompanied him, that the charge of a leyden phial passed through a metallic wire several miles in length, (12276 feet) with a degree of velocity so great, that no perceptible time was seen to elapse between completing the circuit and receiving the shock.* Mr. Cavendish however ascertained that iron wire conducts 400 millions of times better than pure water; that sea water containing one-thirtieth of salt conducts 100 times better than pure water, and that a saturated solution of salt conducts 720 times better than pure water.† The following table exhibits a list of the different conductors, arranged according to their goodness, as far as that has been ascertained. The higher in the table the substance occurs, the better a conductor it is.

Gold.
Silver.
Copper.
Brass.
Platinum.
Iron.
Tin.
Mercury.
Lead.
Other metals.
Metallic ores.
Charcoal.
Hot water.
Cold water.
Liquids, excepting oils.
Red-hot glass.
Melted resin.
Flame.
Ice, not too cold.
Metalline salts.
Salts in general.
Animal fluids.
Acids.
Saline solutions.
Earths and soft stones.
Glass filled with boiling water.
Smoke.
Steam or vapour.
An imperfect vacuum.
Hot air.

7. In what way the electric fluids are retained in bodies has not been yet made out in a satisfactory manner. But the air, which is itself a non-conductor, seems to be a principal agent. At least it is known that bodies cannot be excited in vacuo, the electricity making its escape as soon as evolved.

8. The electric fluid appears to spread itself over the surface of bodies. For the quantity which can be accumulated in a body is always proportional to its surface. If a hollow metallic sphere and a solid metallic sphere of the same diameter be both equally charged with electricity, the quantity accumulated in the hollow sphere will be just as great as that accumulated in the solid sphere. M. Poisson has lately reduced to calculation the manner in which electricity is distributed on the surface of bodies. If the body electrified be a sphere, the fluid will be of an equal thickness over every part of the surface. If the body be an ellipsoid, the electricity will be thickest at the extremities of the larger axis, and thinnest at the extremities of the smaller axis. The whole fluid will

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* Phil. Trans. 1748, p. 49, and 491.

† Ibid. 1776, p. 196.

assume the form of an ellipsoidal shell, regulated by these laws. In every case the exterior surface of the electric fluid is the same with that of the body; the problem is always reduced to finding the form of the interior surface. If two excited spheres be in contact, the point of contact is neutral, and the greatest quantity of electricity is accumulated in each sphere at the point which is farthest remote from the point of contact. The quantity of electricity in each increases from the point of contact to the maximum point, according to laws which depend upon the relative diameters of the two spheres, and which have been determined by M. Poisson in a variety of cases. Thus in the case of two spheres, the diameter of the first of which was to that of the second as 1 to 2, the relative thickness of the electricities at the following points from the place of contact was as follows:

30°	Insensible.	90	1·0000
60	0·5563	180	1·3535

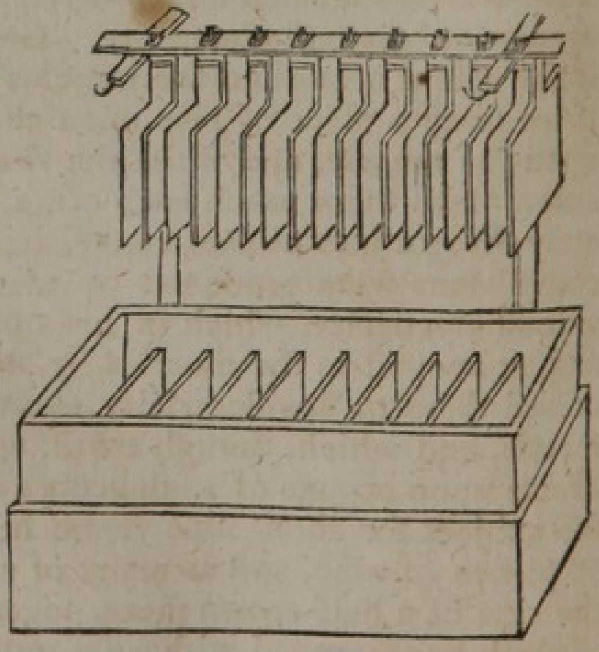
When the conducting body, in which electricity is accumulated, terminates in a sharp point, the accumulation of electricity at the point is much greater than if the extremity were hemispherical. Hence the reason why a pointed body discharges electricity more readily than a rounded body. Hence the superior advantage of points at the extremity of thunder rods.

8. If an insulated plate of zinc be placed upon an insulated plate of copper, and then withdrawn, if we examine the state of the electricity of each by means of Volta's condenser, we shall find that both are in a state of excitement, and that the electricity of the zinc is vitreous, and that of the copper resinous. This fact was discovered by Volta when he repeated the experiments of Galvani on frogs, about the year 1791, and it induced him to conclude, that what Galvani termed *animal electricity*, was brought about by the agency of common electricity. Galvani found out by accident that if the crural nerve and the muscles of the leg of a frog be laid bare, if we place a piece of zinc upon the nerve, and a piece of copper upon the muscle, and while the two pieces of metal are in this position make them touch each other, the leg of the frog is immediately thrown into violent convulsions. Galvani conceived that the convulsions were produced by means of a fluid, which he called animal electricity, which in his opinion was lodged in the nerve and conveyed to the muscles by means of the metals. Volta ascribed them to the electricity evolved by the contact of the two metals, and which, though small, was sufficient to produce sensible effects upon organs of so delicate a nature. After meditating upon the subject for about nine years, he discovered that if about 40 or 50 pieces of zinc, and as many of copper be procured, each about the size of a half-crown piece, together with as many round pieces of cloth impregnated with a saturated solution of common salt, and if these be piled up upon each other in the following order,

1. A zinc plate.
2. A copper plate.
3. A piece of cloth.
4. A zinc plate.
5. A copper plate.
6. A piece of cloth.
7. A zinc plate.
8. A copper plate.
9. A piece of cloth.

In this way you proceed till all the plates have been piled up in order with a piece of cloth between each pair. The cloth should be of a somewhat smaller diameter than the metallic plates, and care should be taken not to soak it with so much of the liquid that any of it will be squeezed out by the weight of the plates placed above it. If each pair of zinc and copper plates be soldered together so much the better. Care must be taken (supposing them soldered) that the plates be so placed in the pile, that the same metal is always undermost in each pair. Volta discovered that a pile, constructed in this way, furnishes a continued stream of electricity for a considerable time. He published a description of this new apparatus in the Philosophical Transactions for 1800. It became immediately celebrated in every part of Europe under the name of the *Galvanic* or *Voltaic* pile. Mr. Cruickshanks, of Woolwich, soon after substituted a trough of wood for the pile. It was made water tight, and covered within with pitch; and the pairs of plates, previously soldered together, were cemented at small distances from each other, so as to leave a cell between each. These cells were filled with water holding some salt in solution, or impregnated with about a thirtieth part of its weight of sulphuric, nitric, or muriatic acids.

More lately an improvement has been introduced into these troughs, which adds considerably to the convenience of the experimenter, and at the same time increases the energy of the apparatus. The troughs are made of stoneware, with a sufficient number of stoneware diaphragms, dividing them into the requisite number of cells. The metallic plates are square, and a slip of metal of the shape of the letter U is made to join each pair, by one end being soldered to the extremity of a zinc plate, and the other end to the extremity of a copper plate. One of these plates is dipped into one cell, and the other into the contiguous cell, while the metallic slip that unites them passes over the diaphragm that divides the two cells. All the plates thus united together are fixed to a metallic rod above, so that they may be lifted out of the trough altogether, either by the hand, or, if too heavy for the hand, by means of a pully properly placed for the purpose. This structure will be understood by inspecting the annexed figure.



Volta at first constructed his piles of pieces of metal about the size of half crowns; but it was afterwards ascertained, that the energy of the pile, at least as far as chemical phenomena are concerned, increases in proportion to the size of the pieces. At present they are usually made of a diameter amounting to 4, 6, or 8 inches. Indeed, Mr. Children constructed one, each plate of which was 6 feet long and about 4 broad. Several of these troughs are often joined together in experiment. The apparatus is then called a *Galvanic* or *Voltaic battery*.

Suppose a pile constructed according to Volta's method. If a condenser be applied to that end of it in which the zinc plate is, we shall find that it is charged with vitreous electricity. By the same method we shall find that the electricity of the copper end is resinous. If we moisten our fingers, and apply those of one hand to the zinc end of the pile, upon touching the copper end with the other hand, we receive a shock, the violence of which is always proportional to the number of pairs of plates in the pile. When they amount to several hundreds, the shock is so violent as to be painful. Even in that case, if three or four people take hold of each other's hands, and form a chain, and if the two persons at the extremities touch each an end of the pile, they alone feel the shock, while the intermediate persons are sensible of nothing. When one person touches the two ends of the pile with his two hands, he feels the shock much more violently in his arms than in any other part of his body.

If a wire of gold or platinum be fixed to each extremity of the pile, and the other extremity be introduced into a glass containing water, and so placed that the ends of the wires approach near each other, but do not touch, a stream of gas will be perceived to flow from each wire, and the gas from the wire, proceeding from the negative or resinous end of the pile, is twice as great as that proceeding from the other wire. If these gases be collected in separate vessels, it will be found that the gas proceeding from the negative wire is hydrogen, and the gas from the positive wire oxygen, exactly in the proportion that they exist in water. Hence it is inferred that they are produced by the decomposition of the water. This important fact was first observed by Messrs. Nicholson and Carlise.

It was soon after observed, that the galvanic pile is capable of decomposing many other substances besides water. Ammonia, sulphuric acid, nitric acid, and different metalline salts were subjected to its action, and decomposed in a similar way. When the wires proceeding from the two poles of the pile are of iron, copper, or any other metal except platinum or gold, hydrogen gas proceeds as usual from the negative wire, but no gas is extricated from the positive wire, the wire however is speedily encrusted with a coat of oxide. It is easy to see what happens in this case, the oxygen instead of being extricated, combines with the wire, and converts it into an oxide.

About the year 1803, a capital discovery, respecting the action of the galvanic battery in decomposing bodies, was made by Berzelius and Hisinger.* They tried its effect upon a great variety of salts and other compound bodies, and found that when they were decomposed, they observed the following law: *Oxygen and acids are accumulated round the positive pole; while hydrogen alkalies, earths, and metals, are accumulated round the negative pole.* Acids and bases may be made to pass through a considerable column of water, and even to cross each other, in order to accumulate round the poles to which they are respectively attracted. From this general law, Berzelius deduced as a consequence, that the decompositions were owing to the attractions existing between the bodies and the respective electricities. He afterwards generalized the subject still farther, or rather he adopted the opinion advanced by Sir Humphry Davy, that chemical affinity is identical with electrical attractions; that bodies which unite chemically possess different kinds of electricity; that oxygen and acids are always resinously electric, while hydrogen, alkalies, earths, and metals, are always vitreously electric. Hence the reason, why the one set is attracted by the negative pole and the other by the positive.

Sir Humphry Davy took up the subject where Berzelius and Hisinger laid it down. His celebrated dissertation for which Bonaparte's galvanic prize was awarded to him, contains merely a verification of the law discovered by Berzelius and Hisinger. He afterwards went a step farther. According to him bodies continue united, because they are in different electrical states. If we can bring them into a similar state by making them both positive, or both negative, they will repel each other, and of course be decomposed. The galvanic battery produces this effect, if it be sufficiently powerful. Hence in his opinion, we have only to expose any compound whatever to the action of a sufficiently powerful galvanic battery, and it will be decomposed. He applied this theory to the decomposition of the fixed alkalies, and succeeded, showing them to be compounds of oxygen and a metallic basis. He tried the earths by the same means. Some gave traces of decomposition, while others resisted the most powerful battery which it was in his power to apply.

The preceding short sketch will enable the reader to understand the galvanic experiments, when I have occasion to introduce them in the subsequent parts of this work. I shall not enter here into any theory of the pile, nor discuss the respective opinions on the subject advanced by Volta and Berzelius, neither shall I describe the electric column of Deluc and Zamboni, nor the secondary piles of Ritter. These and many other topics will find their place in another work, which I intend to publish hereafter on Electricity and Galvanism. In the present work, I think, they would be improperly introduced, as they would divert our attention too long from the proper phenomena of chemistry.

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* The paper containing these experiments was first published by Gehlen in 1803, under the following title; Versuche, betreffend die wirkung der electrischen Säule auf Salze und auf einige von ihren Basen. Gehlen's Neues Allgemeines Journal der Chemie, i. 115. It was afterwards published in Swedish by Berzelius himself, in the first volume of the Afhandlingar, printed at Stockholm in

DIVISION II.

OF PONDERABLE BODIES.

The ponderable bodies at present known amount to 49. They may be arranged under the three following heads.

1. Supporters of combustion—2. Incombustibles—3. Combustibles.

These classes of bodies will be treated of in their order in the three following chapters.

CHAPTER I.

OF SIMPLE SUPPORTERS OF COMBUSTION.

The term *supporter of combustion* I apply to those substances which must be present before combustible bodies will burn. Thus a candle will not burn unless it be supplied with a sufficient quantity of *common air*. *Common air*, then, is a *supporter* of combustion. But we are acquainted with several other substances besides common air which answer the same purpose, and the term *supporter* is applied to them all. By *simple supporters* we understand such of those bodies as have not hitherto been decompounded.

We are at present acquainted with three supporters of combustion that have not hitherto been decomposed. The existence of a fourth has been suspected by M. Ampere, and its existence rendered probable by the ingenuity of Sir Humphry Davy. These four bodies have been distinguished by the following names.

1. Oxygen—2. Chlorine—3. Iodine—4. Fluorine.

[As this is a very important part of Dr. Thomson's System of Chemistry, wherein I think he has adopted Sir Humphrey Davy's opinions far too implicitly, and with a strange neglect of the very serious objections that lay against it, I think it necessary to present to the reader, the present state of the controversy; which I apprehend is far from being favourable to the opinions adopted in this system of chemistry.

When Scheele first discovered the gas now called chlorine (a very appropriate name, from the green tinge it assumes) he suspected it was not a compound, but a simple substance. When this gas was afterwards examined, and its properties investigated by Berthollet, he considered it as a compound of oxygen with muriatic acid gas; and the proportions usually assigned to it, (though in this, as in other cases, chemists differed in opinion as to the details) were 77·65 mur. ac. gas, and 22·35 per cent. oxygen. Hen.

Che. 465. 6th edit. The arguments in support of its being a compound of these two gases, are in brief, as follows:

1. Chlorine is never produced, but by treating muriatic acid with substances containing oxygen; as red lead, manganese, &c.; which part with their oxygen, during the process. 2. This gas is possessed of all the properties which may be expected from an union of oxygen with muriatic acid gas. 3. When water saturated with chlorine, is exposed to the sun's light, oxygen is separated, and common muriatic acid gas and water are formed in the vessel. 4. It has the same effect as oxygen in destroying (not changing) vegetable colours; hence the bleachers substitute it in all cases for exposure to air. 5. When used to destroy vegetable colours, the oxygen alone is separated in the process; for after the process, common muriatic acid remains. 6. The mode of forming it is analogous to other combinations of oxygen: when nitrogen, or sulphur, or phosphorus, or sugar, or arsenic, or molybdena, are treated with substances that give out oxygen, the substances are deoxyded, and (as every chemist agrees) the oxygen combines with the substances so treated. These, and other numerous analogies, would lead us to apply the same reasoning to the formation of chlorine (and indeed to iodine and fluorine).

On the other hand, it is urged by Sir H. Davy, and those who coincide in opinion with him, that this gas, chlorine, is a simple substance: because,

1. Common muriatic acid gas is formed by detonating together equal volumes of chlorine and hydrogen: after which the bulk of the gases remain the same; whereas, if chlorine contained oxygen, water would have been formed, and the bulk of the gases would have been diminished in proportion to the quantity of water thus formed. Hence, muriatic acid gas, and not chlorine, is the compound; and consists of equal volumes of chlorine and of hydrogen. 2. Metals form compounds with chlorine, many of which are decomposed by water, and afford muriatic acid gas and metallic oxide: the decomposed water furnishing hydrogen to the chlorine to form common muriatic acid gas, and oxygen to the metal, to form the oxide. 3. When the alkaline and earthy metals (or metalloids rather) of potash, soda, calcia, &c.—or when mercury, tin, zinc, or iron, are heated in common muriatic acid gas, hydrogen in quantity equal to half the volume of the muriatic acid gas, appears free; and the compounds are such as would have been produced by uniting these metals at once to chlorine. The hydrogen produced is the same in quantity whether the muriatic acid gas had been previously exposed to deliquescent salts, or whether made from liquid muriatic acid. Hence it does not proceed from the decomposition of any water hygrometrically mixed with the muriatic acid gas employed; nor can it proceed from the decomposition of any water chemically combined with the muriatic acid gas; because there is no proof that this gas contains any such. 4. When metallic oxides are acted upon by chlorine, oxygen is evolved—and

when acted upon by muriatic acid, water is produced: the oxygen produced, when acted upon by chlorine, is exactly the quantity previously contained in the metallic oxide; and the water produced contains the same quantity of oxygen that the metallic oxide contained. 5. Chlorine is not decomposed by red hot charcoal, which usually separates oxygen from every other substance containing it. 6. When tin is combined with chlorine, no oxide of tin is produced by saturating the chlorine with ammonia. 7. When phosphorus is treated with chlorine, a peculiar substance is formed: not the same as when muriatic acid gas is added to phosphoric acid. 8. When this compound is neutralized with ammonia, the product is not muriate of ammonia and phosphoric acid, but an indecomposable, ternary substance. 9. When chlorine and hydrogen are detonated, no water is produced. 10. When chlorine and steam are transmitted through a red hot tube, the water is decomposed, its oxygen is evolved, and common muriatic acid is formed by the hydrogen of the water combining with the chlorine. 11. The specific gravity of muriatic acid gas is intermediate between the specific gravities of hydrogen and chlorine. 12. Finally, if chlorine cannot by analysis be decomposed into muriatic acid gas and oxygen, there is no sufficient evidence to a chemist that it is a compound formed out of these gases.

To these arguments, several theoretical objections are stated in two papers signed T. D. in 28 Nicholson's Journ.

In 29 Nich. Journ. 190, Mr. Murray of Edinburgh, takes up the subject in opposition to Davy. He states, that the circumstance of charcoal not acting upon chlorine, is as much a difficulty on Mr. Davy's hypothesis, as on M. Berthollet's; for as chlorine is a supporter of combustion, it ought to act on so combustible a substance as red hot charcoal: but he shews by direct experiment, that carbonic *acid* gas is actually produced from carbonic *oxide* and chlorine; which he says could not be the case, unless chlorine had furnished the acidifying dose of oxygen to carbonic oxide. Mr. Murray afterward, in contradiction to the Messrs. Davy's, insists that the explosion produced between chlorine and hydrogen, forms water by the union of the hydrogen to the oxygen of the chlorine, and that this water combines chemically with the original muriatic gas remaining: and as the Messrs. Davy's had strenuously denied that muriatic acid gas contained any water whatever in chemical union, he undertakes to shew that it does, as an *experimentum crucis*. He proceeds thus. There can be no suspicion of water existing in ammoniacal gas when well dried by passing it through hot muriate of lime: for as ammoniacal gas consists only of nitrogen and hydrogen, it contains nothing out of which water can be formed; to the presence whereof, oxygen is indispensible. He then forms muriate of ammonia by combining muriatic acid gas with ammoniacal gas, both previously made as dry as possible by means of hot muriate of lime, which is known to imbibe moisture with more avidity than almost any other substance. He then distilled the muriate of ammonia so produced, and obtained from it manifest signs of water. This water could not have proceeded from the ammoniacal gas; it must therefore have proceeded from the muriatic acid gas; this gas, then, contains water, not hygrometrically —mechanically mixed like moist vapour in the atmosphere—but chemically combined.

To these experiments Mr. J. Davy replied in 31 Nichols. Journ. 314, stating that the water thus produced was owing to an inaccuracy in conducting the process; for that the materials being transferred and exposed to the atmosphere during the experiment, the water that appeared was probably no other than what had been imbibed from the atmosphere; inasmuch as no water could be procured from the sal ammoniac thus formed, when the combination was made, the salt transferred, and the distillation conducted without access to the atmosphere. This experiment was not only made by Mr. J. Davy, but was also shewn publicly by Sir H. Davy, in his Lectures at the Royal Institute. Dr. Bostock, and Dr. Trail of Liverpool, however, (supplement to 31 Nich. Jour.) repeated Mr. Murray's experiment, with the required precaution of excluding the atmosphere, and they found, contrary to Messrs. Davy's experience, that the muriate of ammonia, formed as above mentioned, did afford water. In 32 Nich. Jour. 185, Mr. Murray again repeats his experiment excluding the atmosphere, and procures water: he also exposed dry muriate of ammonia for some time to the atmosphere, and found that it had gained no accession of weight by imbibing any atmospheric moisture.

So rested this controversy until August or September 1817: for in the Phil. Mag. for Sept. 1817, page 231, Dr. Ure, of Glasgow, is said "to have lately finished a very elaborate series of experi-"ments on the controversial subject of chlorine. Their principal "object was, to ascertain whether water, or its elements, existed in "or could be obtained from muriate of ammonia. He has perfectly "succeeded in obtaining water from the dry, recently sublimed "salt, by methods quite unobjectionable. The vapour of such "muriate of ammonia being transmitted through laminæ of pure "silver, copper, and iron, ignited in glass tubes, water and hydro-"gen were copiously evolved, while the pure metals were convert-"ed into metallic muriates. This fact is decisive in the Doctor's "opinion of the great chemical controversy relative to chlorine and "muriatic acid, and seems clearly to establish the former theory of "Berthollet and Lavoisier, in opposition to that more lately ad-"vanced by Sir H. Davy, with such apparent cogency of argument "as to have led almost all the chemists of Europe to embrace his "opinion. The details of the experiments have been for some time "communicated to a distinguished member of the Royal Society, "and will speedily be laid before the public. This decomposition "of the salt by the metals at an elevated temperature, is analagous "to the decomposition of potash in ignited gun barrels by Gay "Lussac and Thenard." Of these experiments (not being then fully detailed) Dr. Thomson seems to have taken no notice; for his preface to this System of Chemistry is dated October 1817.

On Monday the 15th of last December, a paper was read before the Royal Society of Edinburgh, by Dr. Murray, containing a series of experiments made with all possible precautions in addition to, and confirmation of, those of Dr. Ure, the professor of chemistry at Glasgow. Water was in these cases indisputably procured from the decomposition of dry muriate of ammonia made with every precaution that could be taken to exclude extraneous moisture. This is the last account of the controversy that has reached this country, Dr. Murray's experiments being noticed only in the Phil. Mag. for Dec. 1817, page 457, and this note being written the 1st of March 1818. I consider these experiments fatal to the whole theory of Sir H. Davy, herein adopted by Dr. Thomson; for they enable us to account for the water formed by the hydrogen exploded with the oxygen of the chlorine. To me, they seem also fatal to the theory that constitutes iodine and fluorine supporters of combustion; for iodine is always procured by means of some substance that gives out its oxygen in the process: and fluorine is so indecisively ranked in this class, as to form but a slight difficulty (vide sect. 4, chap. i. of this division). Oxygen alone then, seems likely to be reinstated as the exclusive supporter of combustion.—C.]

[Since writing the above the following notice of Dr. Murray's Paper relative to this subject has been received. See Tilloch's Phil. Mag. for Jan. 1818, vol. li. p. 60.

"Jan. 12, 1818. The continuation of Dr. Murray's Paper on Muriatic Acid was read. In the preceding part of it the results of experiments had been stated, whence it appeared that from the action of metals on muriatic acid gas water is deposited. This is a result obviously incompatible with the doctrine in which chlorine is considered as a simple substance, since, according to that doctrine, muriatic acid gas is the real acid, altogether free from water. As the opposite doctrine holds the existence of combined water in the gas to the amount of a fourth of its weight, a portion of this may be supposed to be liberated by the action of the metal. A difficulty however presents itself even on this view of the subject. The action consists in the acid enabling the metal to decompose the water and combine with its oxygen; with the oxide thus formed the acid unites, and no water remains to be deposited, since none is liberated from its combination with the acid, but what is spent in the oxidation of the metal. The products therefore ought to be the same on this hypothesis as on the other, namely, a dry muriate or chloride, and hydrogen gas.

"It was shown that the water obtained in the experiments could not be derived from hygrometric vapour; that it could not be accounted for from the supposition of a portion of water being combined with the acid in the gas beyond that which is strictly essential to its constitution;—and that it could not be ascribed to any lower degree of oxidation of the metal being established. One explanation remained, that it might arise from the formation of a supermuriate, the quantity of water combined with the quantity of acid, which forms a neutral muriate, being sufficient for the oxidation of the metal; so that if an additional portion of acid entered into the combination, the water of this might be liberated. It was accordingly found that the products in all these cases were sensibly acid, and this even when any source of fallacy, from a subversion of the combination by the agency of water, was obviated. In the sequel another explanation was suggested on a different view of the subject, if this should not be considered as sufficient.

"Dr. Murray considered the results of these experiments as confirming, in addition to what he had before done, the fallacy of the opinion in which chlorine is regarded as a simple substance, which, with hydrogen, forms muriatic acid. The opposite opinion, that it is a compound of muriatic acid with oxygen, and that muriatic gas is a compound of muriatic acid and water, might be held to be established; and it undoubtedly may be maintained. But he has presented a different view of the subject, as being more conformable to the present state of chemical theory.

"The progress of chemical discovery has shown that oxygen cannot be regarded as exclusively the principle which communicates acidity. The same property is in different cases communicated by hydrogen; and this fact he regards as affording the only argument of any weight in support of the new theory of chlorine.

"When water is obtained from muriatic acid gas, it does not necessarily follow that it has pre-existed in the state of water. It is equally possible, *à priori*, that the elements of water may have existed in the gas. On this view oxymuriatic acid will be a binary compound of a radical at present unknown with oxygen, and muriatic acid a ternary compound of the same radical with oxygen and hydrogen. And when muriatic acid gas is formed from the mutual action of oxymuriatic gas and hydrogen, it is simply from the hydrogen entering into the combination. In the processes by which water is obtained from it, the water is formed by its hydrogen and part of its oxygen entering into union. The same view he extends to the other acids which have been supposed to contain combined water. Sulphurous acid is the proper binary compound of sulphur and oxygen; sulphuric acid is a ternary compound of sulphur, oxygen, and hydrogen; and nitric acid is a ternary compound of nitrogen, oxygen, and hydrogen.

"While each of these elements, oxygen and hydrogen, communicates acidity, their combined action seems to do so in a still higher degree. Sulphur with hydrogen forms a weak acid;—with oxygen another acid somewhat stronger;—with oxygen and hydrogen one of still greater power. Nitrogen with hydrogen forms a compound having no acidity; with oxygen in two proportions it forms oxides; with oxygen and hydrogen a powerful acid. Carbon with hydrogen forms compounds which are not acid; with oxygen in one proportion it forms an oxide, in another a weak acid; with oxygen and hydrogen the different vegetable acids which are of much superior strength.

"This explains the apparent anomaly which appeared in the old doctrine with regard to oxymuriatic acid, that it is a weaker acid than the muriatic, though it has received an additional portion of oxygen. It is so precisely as sulphurous acid is weaker than sulphuric. The proper points of resemblance are the sulphurous acid with the oxymuriatic, and the sulphuric with the muriatic. It was shown that oxymuriatic acid has a stricter analogy to sulphurous acid than to any other body; and that any deviation from this analogy arises from the large proportion of oxygen which the former contains.

"The relations of iodine, the analogy of which in some respects to those of chlorine has chiefly given predominance to the new doctrine, with regard to the latter accords perfectly with these views. The nature of the compounds of inflammable bodies with chlorine accords also better with them than with either of the other doctrines. And they serve to explain a number of other facts connected with the action of acids and their combinations. They afford for example a solution of the difficulty which gave rise to the investigation—that of the production of water in the action of metals on muriatic acid gas.

"Dr. M. extended the same view to the constitution of the alkalies. Alkalinity is as well as acidity a result of the agency of oxygen,—the fixed alkalies, the earths, and metallic oxides, all of which contain oxygen as a common element, forming a series in which there is no well defined line of separation. Ammonia stands insulated; it contains no oxygen, yet its alkaline properties are energetic, an anomaly which has led generally to the belief that oxygen must exist in one or other of its constituent principles. It may be explained, however, on a very different principle. As hydrogen like oxygen communicates acidity, so it may like oxygen give rise to alkalinity. Ammonia therefore will be a compound, of which nitrogen is the base, deriving its alkaline quality from hydrogen; and hence stands in the same relation to the other alkalis that sulphuretted hydrogen does to the acids. If the claim of the newly-discovered principle in opium to the rank of an alkali be established, it may stand in the same relation to the others that prussic acid or some of the vegetable acids do to the acids.

"The fixed alkalies, barytes, strontites, and lime have been supposed to contain combined water essential to them in their insulated form. It is probable that the elements of water rather exist in direct combination with their metallic base: that potash, for example, is a ternary compound of potassium, oxygen, and hydrogen; and thus the entire class will exhibit the same relations as the class of acids, some being compounds of a base with oxygen, ammonia a compound of a base with hydrogen, and potash, soda, &c. compounds of a base with oxygen and hydrogen; and these last, like the analogous order among the acids, exceed the others in power. When an acid and alkali unite, the hydrogen of both is expended in forming water. The neutral salts, according to these views, will therefore be either sur-compounds of two binary compounds, one of the radical of the acid, the other of the radical of the base with oxygen, or they are ternary compounds of the two radicals with oxygen. The latter is the more probable opinion."

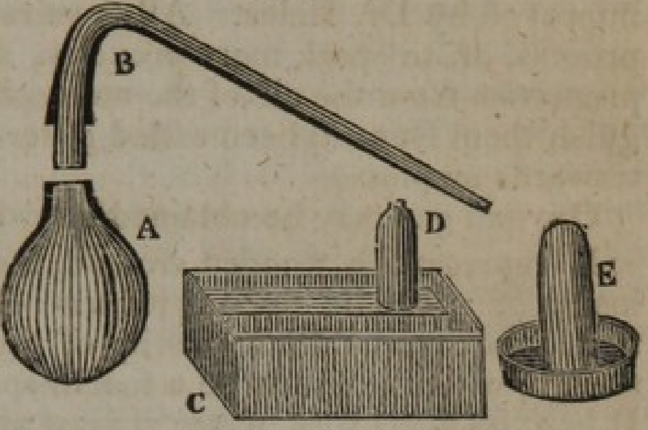
Dr. Thomson, in the Annals of Philosophy for January and February, 1818, has noticed these papers of Dr. Ure and Dr. Murray, and given a similar abridgment of the latter. Whether any attempt will be made to contradict the facts, or to reconcile the reasonings with the modern doctrine of chlorine being a simple substance, the editor cannot know; the periodical numbers of Dr. Tilloch and Dr. Thomson having arrived just before the former part of this note was struck off.—C.]

They act so important a part in chemistry, that it is proper to become acquainted with them as early as possible. I shall treat of them in order in the four following sections.

SECTION I.

OF OXYGEN.

Oxygen may be obtained by the following process:



Procure an iron bottle of the shape A, and capable of holding rather more than an English pint. To the mouth of this bottle an iron tube bent like B, 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 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 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

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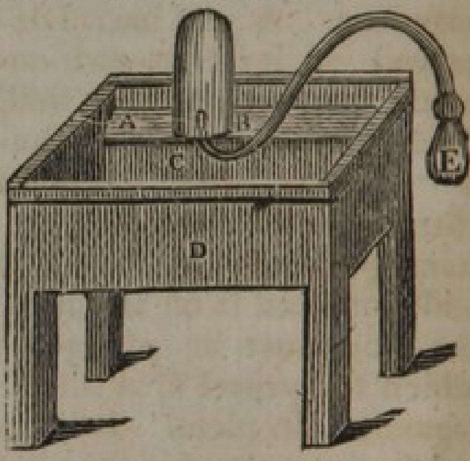
* This substance shall be afterwards described. It is now very well known in Britain, as it is in common use with bleachers and several other manufacturers, from whom it may be easily procured. [In America, the most convenient material, is nitre; such as it exists when purified for the use of the gunpowder makers; that is, freed from common salt and mechanical impurities. The heat should be *gradually* raised, till the oxygen comes over, and then rather diminished than increased. Small portions should be collected during the first part of the process, and tried with a taper, before the receiver be adapted. Manganese often furnishes much carbonic acid.—C.]

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

Oxygen gas may be obtained likewise by the following process:



D 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 about 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 the glass tube F, so closely that no air can escape except through the tube. This may

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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. [A better reference would be to Henry's or Accum's Chemistry, which are common in America.—C.]

† 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.

be done either by grinding, or by covering the joining with a little glazier's putty, and then laying over it slips of bladder or linen dipped in glue or in a mixture of the white of eggs and quicklime. The whole must be made fast with cord.[*] The end of the tube F is then to be plunged into the pneumatic apparatus D, and the jar G, previously filled with water, to be placed over it on the shelf. The whole apparatus being fixed in that situation, the glass vessel E is to be heated by means of a lamp or a candle. A quantity of oxygen gas rushes along the tube F, and fills the jar G. As soon as the jar is filled, it may be slid to another part of the shelf, and other jars substituted in its place, till as much gas has been obtained as is wanted. The last of the these methods of obtaining oxygen gas was discovered by Scheele,[†] the first by Dr. Priestley.[‡]

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.

1. Oxygen gas is colourless, and invisible like common air. Like it, too, it is elastic, and capable of indefinite expansion and compression. It has no perceptible taste, and when pure is destitute of smell.

2. Oxygen gas is somewhat heavier than common air. If we reckon the specific gravity of common air 1·000, then the specific gravity of oxygen gas, according to different experimenters, is as follows:—1·103 Kirwan[‖].—1·114 Saussure.[¶]—1·1088 Allen and Pepys.[**] The mean of these experiments gives us 1·1088, which is certainly very near the truth. I am disposed to consider the specific gravity deduced by Dr. Prout, from considerations which I cannot explain here, as in all probability still more correct, name-

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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.

[LUTES.—Paste of linseed meal. Slacked lime sifted through muslin into common paste. It is convenient to smear linen or strips of paper with these pastes, and tie them on with thread. Loam beat up with molasses forms a lute that bears great heat.—C.]

[†] On Air and Fire, p. 43. Engl. Trans.

[‡] Priestley on Air, ii. 154.

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

[‖] On phlogiston, p. 25. Lavoisier, Biot, and Arago, give the same specific gravity.

[¶] Ann. de Chim. lxxi. 260.

[**] On the quantity of carbon in carbonic acid. Phil. Trans. 1807.

ly, 1·1111.[*] On that supposition 100 cubic inches of this gas at the temperature of 60°, and when the barometer stands at 30 inches, will weigh 33·888 grains. At the same temperature, and under the same pressure, 100 cubic inches of common air will weigh 30·5 grains.[†]

3. 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.

4. 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.

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

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

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

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

5. It has been ascertained by experiments, which shall be afterwards related, that the atmospherical air contains 21 parts in the hundred (in bulk) of oxygen gas; and that no substance will burn in common air previously deprived of all the oxygen gas which it contains. But combustibles burn with great splendour in oxygen gas, or in other gases to which oxygen has been added.

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

7. When substances are burnt in oxygen gas, or in any other gas

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[*] Annals of Philosophy, vi. 322.

[†] This determination results from the experiments of Sir George Stuckburgh, which appear to have been made with great precision.

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. The oxygen in this case combines with the combustible body. The new compound formed is called an *oxide*, or sometimes an *acid*. 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.

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.* Saussure found that water, in the same circumstances, absorbs 6·5 cubic inches of this gas.† But Mr. Dalton has rendered it probable that Saussure's estimate is considerably above the truth.‡

SECTION II.

OF CHLORINE.

CHLORINE may be obtained by the following method:

Put into a small glass retort a quantity of the black oxide of manganese in powder, and pour over it as much of the common muriatic acid of the shops as will make the whole into a very thin paste. Then plunge the beak of the retort into the water trough, and place over it a stout glass phial capable of holding about a quart, previously filled with water. Apply the heat of a lamp to the bottom of the retort. A gas is extricated which enters into the mouth of the inverted phial, displaces the water and fills it. As soon as the phial is full it is to be withdrawn and its mouth carefully stopped with a glass stopper, accurately ground so as to fit, and which must be previously provided. Other phials may be then substituted and filled in succession till the requisite quantity of gas is obtained. This gas is *chlorine*.

This substance was discovered by Mr. Scheele, and an account of it published by him in the Memoirs of the Swedish Academy of Sciences, for 1774, in his celebrated paper on manganese, which

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* Phil. Trans. 1803, p. 174.

† Annals of Pilosophy, vi. 340.

‡ Annals of Philosophy, vii. 218.

had occupied him for three years.[*] He gave it the name of *dephlogisticated muriatic acid*, considering it as muriatic acid deprived of phlogiston. Berthollet made a set of experiments on it, about the year 1785, which were published in the Memoirs of the French Academy of Sciences. He considered himself to have proved that it is a compound of muriatic acid and oxygen; an opinion which was soon after adopted by the chemical world in general. On that account it received the name of *oxygenized muriatic acid*, which was afterwards contracted by Mr. Kirwan to *oxymuriatic acid.* The experiments of Scheele and Berthollet were repeated and varied by all the eminent chemists of the time. But the first great addition to the discoveries of these philosophers was made by Gay-Lussac and Thenard, and published by them, in 1811, in the second volume of their *Recherches Physico-chemique*, p. 94. They showed that the opinion that oxymuriatic acid contains no oxygen might be supported. But at the same time assigned their reasons for considering the old opinion as well founded. An abstract of these important experiments had been published however in 1809.[†] These experiments drew the attention of Sir Humphry Davy to the subject, and he soon after communicated a paper to the Royal Society to show that no oxygen gas could be separated from oxymuriatic acid, nor any proof produced that it contained oxygen. This paper was published in the Philosophical Transactions for 1810.[‡] This was speedily followed by another paper upon the same subject.[§] He drew as a conclusion that oxymuriatic acid is an undecompounded substance; on that account he applied to it the new name *chlorine*, from the yellow colour which it possesses. At present, this name is almost generally adopted by chemists. Few chemists were disposed at first to accede to the opinion of Davy. But subsequent discoveries have greatly augmented the weight of his reasoning, and, at present, his view of the subject is almost universally adopted.[‖] Chlorine possesses the following properties.

1. It is a gaseous body and possesses the mechanical properties of common air. Its colour is greenish yellow. Its odour is exceedingly strong and suffocating, exactly similar to that of *aqua regia*, or the well known mixture of nitric and muriatic acid. When a person is obliged to inspire the fumes of chlorine, it produces a most insufferable sensation of suffocation, occasions a violent cough with much expectoration, which continues for some time, and brings on a very great degree of debility. Its taste is astringent.

2. The specific gravity of chlorine gas, according to the experiments of Gay-Lussac and Thenard, is 2·4700;[¶] according to Davy it is 2·395. Dr. Prout, guided by theoretic reasons, which

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[*] Memoires de Chymie de M. C. W. Scheele, i. 67.

[†] Memoires d'Arcueil, ii. 295.

[‡] P. 231.

[§] Phil. Trans. 1811, p. 1.

[‖] [See note p. 155.—C.]

[¶] Recherches physico-chemique, ii. 125.

cannot be stated here, considers 2·500 as probably the true specific gravity, and with this opinion I am disposed to agree. In all these cases the specific gravity of air is reckoned 1·000. Supposing the true specific gravity to be 2·5, then 100 cubic inches of it will weigh 76·25 grains at the temperature of 60° and when the barometer stands at 30 inches.

3. When any vegetable, blue colour, is exposed to the action of chlorine, it is immediately destroyed and cannot afterwards be restored by any method whatever. Indeed chlorine possesses the property of destroying all vegetable colours, and of rendering coloured bodies white. This property was first observed by Scheele. The knowledge of it induced Berthollet to propose the introduction of chlorine into the practice of bleaching. This suggestion has been successfully adopted in Great Britain and Ireland. At present all the great bleaching works, in this country, employ chlorine as the grand whitening agent. For the first introduction of it we are indebted to Mr. Watt.*

4. If a lighted taper be plunged into a phial filled with chlorine gas, it continues to burn with a low red flame, emitting much smoke but giving out but little light. If a piece of phosphorus be put into this gas it takes fire of its own accord, burning with a pale yellowish green light. Antimony, likewise arsenic, zinc, iron, and several other metals, take fire of their own accord when plunged into chlorine, and burn with considerable splendour. During all these cases of combustion the quantity of chlorine diminishes, and if the portion of combustible be sufficient the gas disappears altogether. The combustible is totally altered in its appearance and converted into a new substance, which has received the name of *chloride*. This chloride is a compound of the combustible substance and the chlorine.

5. If an animal be plunged in an atmosphere of chlorine, so as to be obliged to breathe it in a pure state, it dies almost instantly. This gas then is incapable of supporting animal life. In this respect it differs entirely from oxygen gas.

6. Water absorbs this gas with considerable rapidity, provided the gas be pure; but much more slowly when it is mixed with air or any other foreign gas. According to the experiments of Dalton, one volume of water at the ordinary temperature, and under the common pressure, absorbs two volumes of chlorine gas.† The water acquires the greenish yellow colour, the disagreeable smell, the astringent taste, and the whitening qualities of the gas itself.

7. When chlorine in combination with any other body is exposed to the action of the galvanic battery, the compound is decomposed and the chlorine is deposited at the positive pole, while the other substance is deposited at the negative pole. The only probable ex-

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* See Annals of Philosophy, viii. 1. [See a far better account in all respects in 4 Parke's Essays, page 47, 48.—C.]

† Dalton's New System of Chemistry, ii. 298.

ception to this rule is when chlorine and oxygen are in combination; in such a case it is reasonable to believe that the oxygen would be given off at the positive pole, and the chlorine at the negative pole, but I am not certain whether the experiment has been tried. At high temperatures chlorine displaces oxygen from its combination with many of the metals and unites with them itself.

8. Chlorine gas may be exposed to a very high temperature by passing it through a white hot porcelain tube, without experiencing any change.

9. Chlorine has the property of combining with oxygen, and of forming four distinct substances, which have been particularly examined. We cannot form the combination directly. All these compounds are obtained by means of a salt first prepared and described by Berthollet. It was long distinguished by the name of *hyperoxymuriate of potash*, a name which has been recently changed into *chlorate of potash*. It is obtained by dissolving a quantity of the common potash of the shops in water, and causing a current of chlorine gas to pass through the solution as long as it continues to be absorbed. After some time flat rhomboidal crystals possessing considerable lustre are deposited; these crystals constitute the salt in question. Let us explain the way in which the different compounds of oxygen and chlorine may be obtained from it.

1. When this salt is put into a small glass flask and muriatic acid poured over it, an effervescence takes place and a greenish yellow gas is extricated in abundance. If the muriatic acid be diluted with water, and the quantity of salt with which it is mixed be considerable in proportion to that of the acid, and if a very gentle heat only be employed, a gas is extricated very slowly, which may be recived in small glass jars standing over mercury. After the gas has been prepared in this manner, it is better to allow it to remain for 24 hours in contact with the mercury. For, as originally prepared, it always contains a good deal of chlorine gas mixed with it, which disguises and greatly injures its properties. Mercury has the property of absorbing and uniting with chlorine, while it does not act upon the new gas. It therefore gradually removes the chlorine and leaves the new gas in a state of purity.

The new gas prepared in the way just described was discovered, in 1811, by Sir Humphry Davy, who gave it the name of *euchlorine*.* But it will be better to distinguish it by the appellation of *protoxide of chlorine*, indicating by that name, that it is a compound of chlorine with the smallest quantity of oxygen with which it is capable of combining. It possesses the following properties.

Its colour is much more intense and more yellow than that of chlorine. When contained in a small glass tube it still appears of a very lively yellow, whereas chlorine, in the same circumstances, would scarcely be visible.

Its smell resembles that of burnt sugar, mixed, however, with

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* Phil. Trans. 1811, p. 155.

the odour of chlorine. In all probability this last odour is owing to the presence of a small portion of this gas. For it is extremely difficult to free it completely from chlorine.

When a moderate heat is applied to a vessel filled with protoxide of chlorine an explosion takes place, and the gas is decomposed into a mixture of chlorine and oxygen gas. A very gentle heat is sufficient to produce this decomposition, sometimes even the heat of the hand will do it. The explosion is but feeble. According to the experiments of Davy, five volumes of protoxide of chlorine become six when decomposed, and the decomposed gas is a mixture of two volumes of chlorine and one volume of oxygen.[*] Hence it is composed by weight of

[†]Chlorine	5·000	81·82	100	4·50
Oxygen	1·111	18·18	22·22	1·00
		100·00		

Now if we make 1·00 represent the weight of the smallest particle of oxygen which can unite with a body, we shall find afterwards that the smallest quantity of chlorine that can combine with a body will be represented by 4·5. Hence we may conclude that protoxide of chlorine is a compound of one atom of chlorine and one atom of oxygen.

From the preceding data it follows that the specific gravity of protoxide of chlorine is 2·407, supposing the specific gravity of air to be 1.[‡]

This gas destroys vegetable colours, as well as chlorine; but it first gives blue colours a tint of red.

Several substances, as phosphorus, take fire when they come in contact with protoxide of chlorine, and occasion an explosion.

Water absorbs eight times its volume of this gas, and acquires an orange colour, and the peculiar smell of the gas.

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[*] Phil. Trans. 1811, p. 157.

[†] [These numbers will be found proportionate to one another in the same line. But as Dr. Thomson relies on Dr. Prout's calculations in the 6th volume of the Annals of Philosophy, I find it absolutely necessary to insert those calculations at the end of this volume; which will furnish the required formulæ.—C.]

[‡] [That is, the specific gravity of chlorine when compared with common air being 2·5 and of oxygen 1·1111, as stated in page 167 from Dr. Prout—and as the protoxide of chlorine, according to Dr. Thomson, consists of two volumes of chlorine and one of oxygen, as stated in page 168, then

Specific gravity of chlorine - - - -	2·5
——— ——— oxygen - - - -	1·1111
	3·6111

The half of this would be the mean specific gravity, if the compound consisted only of one part chlorine and one part oxygen: but it consists of two parts chlorine and one part oxygen: therefore divide 3·6111 by three and multiply the quotient by two, and you will arrive at the specific gravity of chlorine alone: thus $\frac{3\cdot6111}{3} = 1\cdot2037 \times 2 = 2\cdot4074$. But in producing this result, no notice is taken of the condensation of six volumes into 5, which in my opinion should enter into the calculation. Throughout this book, the number assigned as the weight of an atom of oxygen, the standard of comparison, is, 1.—C.]

2. The deutoxide of chlorine[*] was discovered about the same time by Sir Humphry Davy and Count Von Stadion, of Vienna; but Davy's account of it was published sooner than that of Count Von Stadion.[†] The method of obtaining it is as follows: mix together a small quantity (not more than 50 grains) of chlorate of potash in powder with sulphuric acid, till the whole forms a dry paste, which will have an orange colour. Put this paste into a small glass retort, and plunge the belly of the retort into hot water, and keep it in that position for some time, taking care that the temperature of the water never becomes so high as 212°. A bright yellowish green gas separates from the paste, which must be received in small glass jars standing over mercury. This gas constitutes the deutoxide of chlorine. It possesses the following properties.

Its colour is a still brighter yellowish green than that of protoxide of chlorine. Its smell is peculiar and aromatic, without any mixture of the smell of chlorine. Water absorbs, at least, seven times its volume of this gas. The solution is deep yellow, and has an astringent and corrosive taste, leaving a disagreeable and lasting impression on the tongue. It destroys moist vegetable blues without previously reddening them. It does not act upon mercury, nor upon any of the combustible substances, tried by Davy, except phosphorus; which, when introduced into the gas occasions an explosion, and burns with great brilliancy.

When heated to the temperature of 212° it explodes with more violence than protoxide of chlorine, giving out much light. Two volumes of deutoxide of chlorine when thus exploded are converted into three volumes, consisting of a mixture of two volumes of oxygen and one volume of chlorine.[‡] Hence it is composed by weight of

Chlorine	2·5	52·94	100	4·50
Oxygen	2·222	47·06	88·88	4·00
		100·00		

Now as the weight of an atom of chlorine was represented by 4·5, and that of an atom of oxygen by one, we see from the last column of the preceding table that the deutoxide of chlorine is composed of one atom of chlorine combined with four atoms of oxygen.[§]

From the preceding data it is obvious that the specific gravity of

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[*] [If Dr. Ure and Dr. Murray be well founded in their late experiments, chlorine will be the protoxide of muriatic acid gas; and the gas here mentioned will be the tritoxide.—C.]

[†] Davy's account is published in the Philosophical Transactions for 1815, p. 214. Count Von Stadion's in Gilbert's Annalen der Physik, lii. 179, published in February, 1816.

[‡] Davy, Phil. Trans. 1815, p. 216, and Gay Lussac, Ann. de Chim. et Phys. i. 220.

[§] According to Count Von Stadion its constituents are two volumes chlorine and three volumes oxygen. This would make it a compound of one atom chlorine and three atoms oxygen. But the properties of the substance described by the Count differ so much from those of the gas examined by Davy that it is probable they are distinct substances. The reader will find an account of the properties of the deutoxide of chlorine of Count Von Stadion in the Annals of Philosophy, vol. ix. p. 22.

deutoxide of chlorine must be 2·361, supposing that of common air to be 1·00.[*]

3. The third compound of chlorine and oxygen is called *chloric* acid. It was first obtained in a separate state by M. Gay Lussac. It is the acid which exists in chlorate of potash. His method of obtaining it in a separate state was as follows: he prepared chlorate of barytes by the method pointed out by Mr. Chenevix, which will be described in a subsequent part of this work. This salt was dissolved in water, and dilute sulphuric acid cautiously added to it as long as any precipitate continued to fall. By this method all the barytes was removed from the liquid without adding any excess of sulphuric acid, so that on filtring nothing remained but *chloric acid* held in solution by the water. This acid possesses the following properties.[†]

It has no sensible smell. Its solution in water is colourless, and it reddens vegetable blues without destroying them. Light does not decompose it. It may be concentrated by a gentle heat without undergoing decomposition, and without being volatilized along with the water. When concentrated it has somewhat of an oily consistency. When heated it is partly decomposed into chlorine and oxygen, and partly volatilized without alteration. Muriatic acid decomposes it in the same manner without the necessity of applying heat. It combines with the different bases and forms the genus of salts called *chlorates*, to be described in a subsequent part of this work.

When 100 parts of dry chlorate of potash are exposed to a red heat in a retort, a quantity of oxygen gas is driven off, which weighs 38·88 parts. The residue, weighing 61·12 parts, is a compound of 32·196 of potassium and 28·924 of chlorine.[‡] But 32·196 of potassium require, in order to be converted into potash (in which state they existed in the salt,) 6·576 of the oxygen. There remain 32·304 of oxygen, which must have been combined with 28·924 of chlorine, and this compound must have constituted chloric acid. According to this statement chloric acid is composed of

Chlorine	-	28·924	-	47·24	-	4·50
Oxygen	-	32·304	-	52·76	-	5·02
				100·00		

We see from the last column that it is a compound of one atom of chlorine and five atoms of oxygen. For the weight of an atom of chlorine is 4·5, and that of an atom of oxygen one.[§]

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[*] [As these numbers designate two volumes of the deutoxide, the specific gravity will be $2{\cdot}5 + 2{\cdot}222 = \frac{4722}{2} = 2361$. The protoxide containing a greater proportion of the heavier part of the compound, will of course have a greater specific gravity, and therefore it turns out to be 2·407 as stated in page 169.—C]

[†] Gay Lussac, Annals of Philosophy, vi. 129.

[‡] That this is the case will be shown in a subsequent part of this work. The evidence would not be understood here, if it were given.

[§] Sir H. Davy considers chloric acid as a compound of one atom chlorine and six atoms oxygen. The reason is that he believes the potash to exist in the salt in the state of potas-

4. The fourth compound of chlorine and oxygen is likewise an acid. We may distinguish it by the name of perchloric acid. It was lately discovered by Count Von Stadion, and may be obtained in the following manner.

When the deutoxide of chlorine is extricated from a mixture of sulphuric acid and chlorate of potash, a peculiar salt is formed which remains behind in the retort. We obtain this salt best when we use three or four grains of strong sulphuric acid for every grain of chlorate of potash employed. After the first violent action of the acid is at an end, heat is to be applied and continued till the yellow colour of the mass disappear. The salt formed in this way is mixed with bisulphate of potash,[*] which may be separated by a second crystallization. The purified salt possesses the following properties.

It is quite neutral,[†] is not altered by exposure to the air, and has a weak taste similar to that of muriate of potash.[‡] It dissolves in considerable quantity in boiling water; but water of the temperature 60°, dissolves only $\frac{1}{55}$th of its weight of it. In alcohol it is quite insoluble. Its crystals are elongated octahedrons similar to the primitive form of sulphate of lead, and resembling the variety which has two prismatic faces between the pyramids.[§] It detonates feebly when triturated in a mortar with sulphur. When heated to the temperature of 412° it is decomposed and converted into *chloride of potassium*[‖] and oxygen gas. When it is mixed with its own weight of sulphuric acid and exposed to a heat of 280° in a retort, it is decomposed, and the acid which it contains may be distilled over. The acid may likewise be formed artificially by exposing deutoxide of chlorine to voltaic electricity in an apparatus constructed with platinum wires. According to the experiments of Count Von Stadion when this salt is exposed to heat it yields 45·92 parts of oxygen gas, and there remain 54·08 parts of chloride of potassium. Now 54·08 of chloride of potassium are composed of—Potassium 28·49—Chlorine 25·59. But 28·49 parts of potassium require 5·819 parts of oxygen in order to be converted into potash. There remain 40·1 parts of oxygen. According to this result perchloric acid is composed of

Chlorine	25·59	38·96	4·500
Oxygen	40·1	61·04	7·012
		100·00	

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sium, and therefore adds the other atom of oxygen, which we have supposed in the text to be united to the potassium, to the chlorine.

[*] A salt which will be described in a subsequent part of this work.

[†] That is to say it does not affect the colour of vegetable blues.

[‡] Or *chloride of potassium*, a substance to be described in a subsequent part of this work.

[§] This variety is called *plomb sulphaté semi prismé* by Haüy, and is figured by him in his 69th plate, figure 73.

[‖] A combination of chlorine and potassium.

Hence it appears that this acid is a compound of one atom of chlorine and seven atoms of oxygen.*

Thus it appears that the four compounds of chlorine and oxygen are composed as follows.

	Chlorine.	Oxygen.
1. Protoxide of chlorine	1 atom	+ 1 atom
2. Deutoxide of chlorine	1	+ 4
3. Chloric acid	1	+ 5
4. Perchloric acid	1	+ 7

But if we were to take Count Von Stadion's analysis of deutoxide of chlorine as exact, it would be a compound of one atom chlorine with three atoms oxygen; and in that case all the compounds would consist of an atom of chlorine united with an odd number of atoms of oxygen.

SECTION III.

OF IODINE.

THIS substance was discovered, I conceive, in the year 1811 by M. Courtois, saltpetre manufacturer at Paris. After ascertaining some of its properties he gave a quantity of it to M. Clement, who undertook to prosecute the investigation. On the 6th of December 1813, M. Clement announced its existence to the Institute of Paris, and at the same time described some of its most remarkable properties. The investigation of it was immediately undertaken by M. Gay Lussac, and prosecuted with his accustomed activity and sagacity. Sir H. Davy, who was at that time at Paris, began likewise to make experiments upon it, and his results were made known to the Royal Society before any of Gay Lussac's papers were published, though the French chemist affirms that he preceded the British philosopher in demonstrating the peculiar nature of this substance. To these two gentlemen, especially to M. Gay Lussac, we are indebted for our knowledge of most of the facts which have been ascertained respecting this singular substance.

1. Iodine may be obtained by the following process. Reduce a quantity of *kelp* to powder, and digest it in water till every thing soluble is taken up. Then filter the solution and evaporate it till all the crystals of common salt that can be obtained have separated from it. Mix the mother liquor with sulphuric acid, and boil for some time.† Put the liquid into a small retort or flask, and mix it with as much black oxide of manganese as you have added of sul-

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* Gilbert's Annalen der Physik, lii. 213.

† By this means a great quantity of muriatic acid and of sulphureted hydrogen, which impede the collection of the iodine, are previously removed.

phuric acid. Apply heat. A violet coloured vapour immediately arises, which is to be driven into a proper receiver, against the sides of which it condenses into a black brilliant matter. This substance is the *iodine.* The process just described was first proposed by Dr. Wollaston. Waste soaper's ley (provided kelp has been used for soap making) may be employed instead of the solution of kelp. French kelp, it would seem, is much richer in iodine than the kelp of Great Britain.[*]

2. Iodine thus obtained is a solid substance of a greyish black colour and the metallic lustre, having very much the appearance of native sulphuret of antimony. It is usually in scales of a greater or smaller size; but it may be obtained in crystals. And Dr. Wollaston has ascertained that its primitive form is an octahedron, somewhat similar to the primitive form of sulphur. The axes of this octahedron are to each other, as nearly as can be determined, as the numbers, 2, 3, and 4.[†] Its specific gravity at 62½° is 4·948.[‡]

The smell of iodine is disagreeable and very similar to that of chlorine, though not nearly so strong. Its taste is acrid and hot, and continues for a long time in the mouth. Orfila has shown that when taken internally it possesses poisonous qualities.[§]

3. Like chlorine it possesses the property of destroying vegetable colours; though it acts with much less intensity. It stains the hand of a deep yellow colour; but the stain in a short time disappears. Paper receives a permanent reddish brown stain, and is at last corroded by it.

4. It melts when heated to the temperature of 224½°, and is volatilized under the common pressure of the atmosphere when raised to the temperature of 351½°.[‖] But if it be mixed with water and the liquid boiled, it may be distilled over with the water. When converted into vapour it has a very intense and very beautiful violet colour. It was from this colour that Gay Lussac imposed on it the name of *iode*[¶], which Sir Humphry Davy changed into *iodine,* as better suited to our language. Its specific gravity when in the state of vapour is 8·678.[**]

5. When iodine is thrown into water the liquid acquires an orange yellow colour and the peculiar small of iodine. But it continues tasteless, and holds in solution only about $\frac{1}{7000}$th part of its weight of iodine.[††] It is more soluble in alcohol, and still more in sulphuric ether.[††]

6. If a quantity of iodine be put into a thin glass tube shut at one end and a bit of phosphorus be thrown on it, the two substances

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[*] [All the iodine on sale in London hitherto (Feb. 1818) has been imported from Paris, as I am informed.—C.]

[†] Annals of Philosophy, v. 237.

[‡] Gay Lussac, Ann. de Chim. xci. 7.

[§] Toxicologie generale, tom. i. partie ii. p. 290. [Orfila's book must not be implicitly relied on. Read his account of Fox Glove.—C.]

[‖] Gay Lussac, Ann. de Chim. xci. 7. He fixes the temperature between 347° and 356°.

[¶] From ιωδης, violet coloured.

[**] Gay Lussac, Ann. de Chim. xci. 17.

[††] Ibid. xci. 7.

combine with great rapidity, and the evolution of a great deal of heat; but no light is visible. Sulphur and most of the metals likewise unite readily with iodine when the action of the two substances upon each other is assisted by heat. The new substances formed by this combination have received the name of *iodides*. Thus the beautiful red powder formed by the union of iodine and mercury is called *iodide of mercury*.

7. When any of these compounds is decomposed by the action of the galvanic battery the iodine attaches itself to the *positive* wire, and the substance with which it was united to the *negative* wire of the battery.

8. Iodine has the property of combining with oxygen.[*] This combination was first dicovered in a separate state by Sir H. Davy, and constitutes one of the many striking analogies that exist between chlorine and iodine. It may be obtained by the following process. Put 40 grains of iodine into a thin long-necked receiver. Into a bent glass tube shut at one end put 100 grains of chlorate of potash, and pour over it 400 grains of muriatic acid, of the specific gravity 1·105. Then make the bent tube communicate with the receiver, and apply a gentle heat to it. Protoxide of chlorine[†] is generated. As soon as it comes in contact with the iodine, a combustion takes place, and two new substances are formed: 1. A compound of iodine and chlorine; 2. A compound of iodine and oxygen. When heat is applied to this mixture the compound of chlorine and iodine, which is volatile, flies off and leaves the compound of iodine and oxygen in a state of purity.[‡] This substance possesses acid properties, and Gay Lussac has proposed for it the name of *iodic acid*, which we shall adopt.

Iodic acid, when pure, is a white semi-transparent solid. It is destitute of smell, but has a strong astringent sour taste. Its specific gravity is considerable, for it sinks rapidly in sulphuric acid. When heated a little below the temperature at which olive oil boils, it melts and is decomposed, being converted into iodine and oxygen gas. According to the mean of three experiments made by Sir Humphry Davy, a grain of iodic acid when decomposed gives out 176·1 grain measures of oxygen gas.[§] Now at the temperature of 60°, 176·1 grains of water are equal in bulk to 0·6968 cubic inch. But 0·6968 of a cubic inch of oxygen gas weighs 0·236 grain. Therefore, according to this result, iodic acid is composed of

Iodine - -	764 - -	15·625
Oxygen - -	236 - -	4·825
	1000	

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[*] [Can it be procured at all, unless by means of substances such as manganese or red lead, that give out their oxygen during the process?—C.]

[†] This gas ought to be made to pass through dry chloride of calcium (*muriate of lime*) before it comes in contact with the iodine, in order to deprive it of the water with which it is mixed when first generated.

[‡] Davy, Phil. Trans. 1815, p. 204.

[§] Phil. Trans. 1815, p. 206.

Now according to the experiments of Gay-Lussac, to be detailed in a subsequent part of this work, 15·625 represents the weight of iodine which enters into combinations, supposing the weight of oxygen to be denoted by 1. So that it follows from the preceding analysis of Sir Humphry Davy, that iodic acid is a compound of one atom iodine and about five atoms oxygen.

But the three experiments of Davy do not agree well with each other. By the first, iodic acid would be a compound of one atom of iodine and 4·588 atoms of oxygen. By the second, of one atom of iodine and 4·825 atoms of oxygen, nearly: and by the third, of one atom iodine and 5·375 atoms of oxygen. If we recollect that these experiments were made upon three grains, two grains, and one grain, of iodic acid respectively, we shall not be surprised at these little discrepancies, nor that the quantity of oxygen obtained fell a little below the truth. Gay-Lussac, who made his experiments upon a much larger scale, employing the compound of iodic acid and potash, found iodic acid composed exactly of one atom iodine and five atoms oxygen.* We may, therefore, consider this as its true composition. Accordingly the weight of ingredients of iodic acid may be represented by the following numbers:

Oxygen	24·24	100	5
Iodine	75·76	781·25	15·625

This iodic acid agrees exactly in point of composition with chloric acid. No other compound of iodine and oxygen has hitherto been discovered, though it is very probable that others exist. The analogy between chlorine and iodine is so close that we may almost look for similar combinations entered into by each.

Iodic acid is very soluble in water. When exposed to a moist atmosphere it gradually deliquesces. Its solution first reddens, and then destroys vegetable blues. It reduces other vegetable colours to a dull yellow. When this liquid is heated, the water gradually evaporates, and the acid acquires the consistence of a syrup. It then becomes pasty, and may be driven over unaltered, unless the heat applied be too great. In that case it acquires a purplish tint from a partial decomposition which sets a portion of the iodine free.

When mixed with charcoal, sugar, or other inflammable bodies, and heated, detonations take place. Its solution rapidly corrodes metallic bodies.

9. Iodine has the property, likewise, of combining with chlorine. We are indebted for the first discovery of this compound to the industry of Sir H. Davy; but it was likewise examined by Gay-Lussac, before he was aware that it had been the object of the investigation of the British chemist. Davy has given the compound the name of *chloriodic acid*, which we shall adopt.

It is easily obtained. When a current of chlorine gas is passed into a vessel containing iodine, the combination instantly takes

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* Ann. de Chim. xci. 48.

place. Chloriodic acid, when the iodine is saturated with chlorine, has a yellow colour, and becomes orange on fusion; but if there be an excess of iodine the colour is red.[*] To saturate the iodine in this way is attended with some difficulty; but is easily accomplished by dissolving the red substance in water, and passing through it a current of chlorine gas till it be saturated. The solution of chloriodic acid obtained in this way is colourless, provided there be no excess of chlorine; but if there be, it has a yellow colour.[†]

It is not easy to determine the composition of this compound; because saturation is difficult, and it seems even to affect an overdose of iodine. Davy made two trials to determine the quantity of chlorine absorbed, by a given weight of iodine. The results were as follows:[‡]

	Chlorine.
1. 20 grains of iodine absorbed 13·125 cubic inches. - - - - - - - -	= 9·984 grains
2. 20 grains of iodine absorbed 9·6 cubic inches. - - - - - - - -	= 7·32

According to these experiments, the composition of chloriodic acid is as follows:—1. 15·625 iodine + 7·8 chlorine—2. 15·625 iodine + 5·719 chlorine.

The reader will bear in mind, that 15·625 represents the weight of an atom of iodine, and 4·5 the weight of an atom of chlorine.

From these experiments Davy is disposed to infer, that chloriodic acid is a compound of one atom iodine + one atom chlorine. But when we consider that it is very difficult to saturate iodine by the direct absorption of chlorine, and that in the first experiment[§] the quantity of chlorine actually absorbed was only $\frac{1}{8}$th less than the weight of two atoms, we can scarcely hesitate to infer, that pure chloriodic acid is a compound of one atom iodine and two atoms chlorine. Supposing that opinion well founded, it will be a compound of

Iodine	15·625	63·45	100
Chlorine	9·000	36·55	57·6
		100·00	

Chloriodic acid is very volatile. When exposed to the air it deliquesces. Its solution in water, possesses acid properties. It gradually destroys vegetable blues. Even the solution of indigo in sulphuric acid is deprived of its colour by it. But it appears from the experiments of Gay-Lussac, that it is decomposed and converted into iodic acid and muriatic acid, (no doubt by the decomposition of water) whenever we attempt to combine it with a base. This has induced him to doubt whether it possesses acid

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[*] Davy. Phil. Trans. 1814, p. 498. Gay-Lussac. Ann. de Chim. xci. 48.

[†] Gay-Lussac. Ann. de Chim. xci. 50.

[‡] Phil. Trans. 1814, p. 499.

[§] In that experiment water was added to facilitate the absorption.

properties, and to suspect that it is decomposed whenever it is dissolved in water. On that account he has given it the name of *chloruret of iodine*. But Davy's experiments seem to me to prove, that it dissolves in water without decomposition, and consequently that it is an acid.

10. Iodine has the property of combining with starch, and of forming with it a compound which has a fine blue colour. This curious fact was first observed by MM. Colin, and Gaultier de Claubry.* The easiest way of forming this compound is to triturate starch with an excess of iodine, to dissolve the mixture in potash, and then to add a vegetable acid. The *iodide of starch* falls down in the state of a fine blue colour. Stromeyer, Professor of Chemistry at Gottingen, has found that starch is a most delicate test of the presence of iodine in liquids. He affirms, that the starch acquires a perceptibly blue tinge, when the iodine does not exceed $\frac{1}{450000}$ of the liquid.†

11. Iodine has been detected in various sea plants by Gaultier de Claubry. He found it in fucus saccharinus, fucus digitatus, fucus vesiculosus, fucus serratus, fucus siliquosus, and fucus filum.‡ Davy found indications of the presence of iodine in the ashes of fucus cartilagineus, fucus membranaceus, fucus rubens, fucus filamentosus, ulva pavonia, and ulva linza.§

12. It would appear that chlorine, oxygen, and iodine, separate each other from bases at a red heat in the following order: Chlorine—Oxygen—Iodine.

Chlorine drives off the other two, while oxygen disengages iodine. Hence, according to the present language of chemists, chlorine has the greatest *affinity* for the bases, oxygen the next greatest, and iodine the weakest. But to this rule there are many exceptions. Thus iodine disengages oxygen from potassium and sodium at a red heat.

SECTION IV.

OF FLUORINE.

THE mineral called *fluor spar*, and in this country frequently distinguished by the name of Derbyshire spar, is so common in lead mines, and is so beautiful in consequence of its transparency, its fine colours, and the large size of its cubic crystals, that it must have early attracted the attention of mankind. There can be little doubt that it is mentioned both by Theophrastus and Pliny under the name of *false emerald* (ψευδης σμαραγδος.) In the time of Agri-

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* Ann. de Chim. xc. 92.

† Annals of Philosophy, vi. 312.

‡ Ann. de Chim. xciii. 75, 113.

§ Phil. Trans. 1814, p. 505.

cola it was employed as a flux for ores, and is mentioned by him under the name of fluor.[*] Its property of corroding glass, when mixed with sulphuric acid, was known at Nuremberg as early as 1670. The first attempt to ascertain the composition of this mineral was made by Margraf. His experiments were published in the Memoirs of the Berlin Academy for 1768; but he informs us that they had been made in 1764. He reduced the mineral to powder, mixed it with its own weight of sulphuric acid, and distilled it in a retort. He obtained a white saline sublimate, and remarked with surprise that the retort was corroded into holes in several places.[†] In the year 1771, Scheele published a set of experiments on fluor spar, in the Memoirs of the Academy of Sciences of Stockholm. He showed that the mineral was a compound of lime, and of a peculiar acid, to which he gave the name of *fluoric acid.* He determined the properties of this acid, and showed it to differ from every other previously known.[‡] Dr. Priestley found that the acid when obtained by Scheele's process, is a gas possessed of peculiar properties which he investigated and described.[§]

It was shown by Wiegleb[‖] and Bucholz,[¶] and still more completely by Meyer,[**] that the fluoric acid of Scheele contained silica as a constituent, and Dr. John Davy ascertained the proportion of fluoric acid and of silica, that exist in the acid of Scheele,[††] and demonstrated that it is a peculiar compound of fluoric acid and silica, in which the constituents always exist in the same proportions. Gay-Lussac and Thenard, in their Recherches Physico-chimiques,[‡‡] published in 1811, pointed out a method of preparing pure fluoric acid, and were the first to determine its properties. It may be procured in the following manner.

A retort of pure lead must be procured, composed of two pieces which slip into each other. To this retort must be adapted a leaden receiver. This apparatus is represented in the figure. Take any quantity of pure white fluor spar, reduce it to a fine powder, and put it into the retort, then mix it well with twice its weight of concentrated sulphuric acid. Lute the joining of the retort and the beak where it enters the receiver with clay, then apply a moderate heat to the retort, taking care that it is not so great as to fuse the lead. The receiver is to be surrounded with a mixture of common salt and snow. The fluoric acid is disengaged, and collected in the receiver in a liquid state.[§§] This acid possesses the following properties.

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[*] Georg. Agricolæ Bermannus, p. 458. Basil's edition of 1558.

[†] Collection Academique, xvi. 281.

[‡] Memoires de Chymie de M. C. W. Scheele, i. 1.

[§] Priestley on Air, ii. 339.

[‖] N. Entd. in d. Chemie. Th. i. p. 1—15.

[¶] Ibid. Th. iii. p. 50.

[**] Schriften der Berliner Gesellschaft. naturf. Freunde, b. ii.

[††] Phil. Trans. 1812, p. 352.

[‡‡] Vol. ii. p. 1.

[§§] Recherches Physico-chimiques, ii. 2.

At 32° it is a colourless liquid like water. It does not congeal though cooled down to — 4°, and it continues liquid at the temperature of 60°. Its boiling point has not been determined, but it is low. When exposed to the air it smokes violently, giving out a smell similar to that of muriatic acid, but much stronger. It is very speedily dissipated in open vessels, and can only be preserved in metallic vessels. The best adapted for the purpose are those which are composed of pure silver, and they must have a silver stopper, which should be air tight.

When this acid is as concentrated as possible, it would appear from the experiments of Davy that it contains no water. Its specific gravity is then 1·0609. When united to a certain portion of water, its specific gravity becomes 1·25.[*] When a drop of it is let fall into water, a hissing noise takes place similar to what is heard when a red hot iron is plunged into that liquid. When a few drops of water are let fall into fluoric acid it enters into ebullition. A great deal of water may be added without destroying its fuming property. Care must be taken not to breathe the fumes of this acid, as they are very deleterious. When a drop of it falls upon the skin, it acts as a powerful corrosive, and occasions a sore which does not soon heal.

When this acid comes in contact with glass, it immediately corrodes it,[†] and is converted into a gaseous body, known by the name of silicated fluoric acid.[‡] This acid combines readily with the different bases, and forms a genus of salts called *fluates*.

From an experiment of Sir H. Davy it would appear, that the number which represents an atom of this acid is 1·0095, supposing an atom of oxygen to be 1.[§]

It had been the general opinion of chemists that fluoric acid is a compound of an unknown basis and oxygen, and this opinion was

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[*] Davy. Phil. Trans. 1813, p. 266.

[†] [The easiest method of shewing the characteristic property of fluoric acid gas, viz. its affinity to silex, is the following: procure a leaden bottle with a flat-bottom, it may be square or cylindrical, about four inches high, by two or three inches wide. Cover the bottom about one-fourth of an inch deep, with fluor spar (fluate of lime, Derbyshire spar) finely powdered. Add as much strong sulphuric acid (oil of vitriol) as is necessary to moisten the fluor spar thoroughly. Have ready a piece of window glass, previously covered with a thin coating of bees wax, on which with any pointed instrument you have traced a design, and cleared away the wax neatly from the glass where the design is traced; the other parts of the glass being covered with the wax. When you have added your oil of vitriol to the powdered fluor spar, smear the edge of the leaden bottle with warm wax, and place your glass on it, exposing the design thus traced to the action of the fluoric acid gas which will arise. Take care that the glass and the edge of the bottle are in complete contact, and that there is no vacancy for the gas to escape. Immerse the leaden bottle in hot water. In about half an hour the design will be completely etched on the glass, which can be cleared from the wax and washed.—C.]

[‡] This acid will be described in a subsequent part of this work.

[§] One hundred grains of fluate of lime, when repeatedly heated with pure sulphuric acid, were converted into 175·2 grains of sulphate of lime. Now 175·2 of sulphate of lime contains 73·582 of lime. Hence fluate of lime (supposing it composed of fluoric acid and lime) is composed of

Fluoric acid	26·418	1·0095
Lime	73·582	3·625
	100·000	

adopted and maintained by Gay-Lussac and Thenard, in their Recherches Physico-chimiques. But in the year 1810, M. Ampere, who had adopted the views of Sir Humphry Davy, respecting *chlorine* and the composition of *muriatic acid*,[*] was led to compare together the fluoric and muriatic acids, and to draw similar conclusions with respect to the composition of both. Now the base of muriatic acid is *hydrogen*, and the hydrogen in it is combined with *chlorine*, a supporter of combustion. Therefore, supposing the composition of both similar, fluoric acid must likewise be a compound of *hydrogen*, and an *unknown* supporter of combustion. This view of the subject he communicated to Sir H. Davy in 1810, who at first was rather inimical to the opinion; but, upon considering the subject, he was gradually led to change his notions,[†] and at last became a strenuous supporter of the hypothesis. He published two papers in succession on the subject, containing each many highly interesting experiments, and ingenious views and deductions;[‡] but he was unable to obtain the supposed supporter of combustion, in fluoric acid, in a separate state. I think, however, that the reasons adduced for its existence are sufficiently plausible, and on that account have been induced to give it a place among the supporters of combustion. Davy has given it the name of *fluorine*, which we shall adopt.[§] I shall now state the evidence for the existence of fluorine that has been brought forward by the experiments of Davy. I shall be under the necessity of making use of many substances which have not yet been described. Beginners, therefore, will find it convenient to peruse the two following chapters before they read the remainder of this section.

1. When fluoric acid and potassium are brought into contact, a violent action takes place; a solid white substance is formed, and a quantity of hydrogen gas is discharged. If the fluoric acid be free from water, it is obvious that this result is best explained by supposing the fluorine and the potassium to combine and form the solid substance, while the hydrogen, previously united to the fluorine in the acid, makes its escape in the form of gas. But it requires to be ascertained whether fluoric acid of the specific gravity 1·0609 contains any water. For this purpose Davy put a quantity of it into a platinum tray, and placed it in contact with ammoniacal gas till it was saturated with that alkali. By this means a white salt was formed, known by the name of fluate of ammonia. When any acid that contains water is combined in this manner with ammonia-

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[*] Namely, that it is a compound of equal volumes of chlorine and hydrogen gases.

[†] Ann. de Chim. et Phys. ii. 21.

[‡] Phil. Trans. 1813, p. 263, and 1814, p. 62.

[§] Ampere has given in the name of Phthorine, (Phthore) from the Greek word φθοριος, *destructive*. Ann. de Chim. et Phys. ii. 24. But it is quite evident that this new name cannot be adopted. There would be no end to names if every person at pleasure could coin new ones. The reason assigned by him for contriving this new name, namely, that he was the original starter of the hypothesis, is not valid. Mr. Gregor was the discoverer of *titanium;* yet the name imposed by Klaproth has kept its place, and even borne down the name *Menachane*, previously applied by Kirwan. Davy informs us that Ampere himself originally suggested the term *fluorine*.

cal gas, if we heat the salt formed, water is always disengaged. Thus sulphuric acid, or nitric acid, or phosphorous acid, when saturated with ammoniacal gas and heated, give out always abundance of water. But fluate of ammonia when thus treated gave out no water.[*] Hence we have no evidence that fluoric acid contains any water.

2. Muriatic acid is a compound of chlorine and hydrogen gas, the combination of it with ammonia is called *muriate of ammonia.* When potassium is heated with muriate of ammonia, chloride of potassium is formed, and a quantity of gas disengaged. This gas is a mixture of ammonia and hydrogen, and consists of two volumes of ammonia, and one volume of hydrogen gas. Now when fluate of ammonia is treated with potassium, a similar effect is produced. A white saline substance is formed, and gas is evolved consisting of ammonia and hydrogen, in the proportion of two volumes of the former to one volume of the latter.[†] Now since the effects in these two cases are similar, the fair inference seems to be that the products are similar. The dry substance is probably a fluoride of potassium, while the hydrogen was previously united with the fluorine, and constituted with it fluoric acid.

3. When fluoric acid is exposed to the action of galvanism, hydrogen gas is given out at the negative wire, and the positive wire (supposing it platinum) is coated with a chocolate powder.[‡] When muriatic acid is treated in the same way it is decomposed, its hydrogen being given off at the negative wire, while its chlorine unites with the positive wire. Is it not probable then that the chocolate powder is a compound of fluorine and platinum?

4. If fluate of silver or fluate of mercury be exposed to the action of chlorine, and heated in glass vessels, chloride of silver or of mercury is formed, while the vessel is corroded, and a quantity of silicated fluoric acid gas mixed with oxygen evolved.[§] Is it not probable that in this case the fluorine is disengaged, that it immediately acts upon the silica in the glass, disengaging its oxygen and forming silicated fluoric acid, which may be considered as a compound of fluorine and silicon?

Various attempts were made to obtain the fluorine in a separate state, by repeating this experiment in vessels of platinum and silver: but in both cases it combined with the metal. So that it seems fluorine has the property of combining with all bodies that can be employed as vessels. This precludes the possibility of obtaining it in a separate state.

5. If we suppose fluate of lime to be a compound of fluoric acid and lime, its composition will be—Fluoric acid 1·0095—Lime 3·625.—From this we see that the weight of an integrant particle of fluoric

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[*] Davy, Phil. Trans. 1813, p. 268. [But as the sulphuric acid and the fluor spar employed to form it, both contain water, it is highly probable that the gas does. Messrs. Davy, in operating on the salts formed by muriatic acid and ammoniacal gas, could not procure water, when Mr. Murray, Dr. Bostock, Dr. Trail, and Dr. Ure, did.—C.]

[†] Davy, Phil. Trans. 1813, p. 269. [‡] Ibid. p. 271. [§] Ibid. p. 275.

acid must be 1·0095. If it be supposed a compound of one atom of oxygen, and one atom of an unknown inflammable basis, then as the weight of an atom of oxygen is one, the weight of an atom of the inflammable base can be only 0·0095, which is only the 13 part of the weight of an atom of hydrogen. On that supposition fluoric acid would be composed of—Imflammable basis 1·00—Oxygen 105·67.—So very light a body, being contrary to all analogy, cannot be admitted to exist without stronger proofs than have hitherto been adduced. On the other hand if fluor spar be in reality a *fluoride of calcium*, then its composition will be—Fluorine 2·0095.—Calcium 2·625.—So that the weight of an atom of fluorine would be 2·0095, or almost exactly twice the weight of an atom of oxygen. This is surely a much more probable supposition than the former. But the question cannot yet be considered as fully decided.

CHAPTER II.

OF SIMPLE INCOMBUSTIBLES.

By *incombustible*, I mean a body, neither capable of *undergoing* combustion nor of *supporting* combustion. It unites to all the supporters; but the union is never attended with the evolution of heat and light. We are at present acquainted only with one such substance, namely, *azote*. It is a body of so singular a nature, that it cannot with propriety be classed along with any of the other simple bodies; but seems entitled to a place by itself.* In this chapter then we will confine ourselves to the description of the properties of azote.

SECTION I.

OF AZOTE.

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

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* Chemists have in general arranged *azote* along with the simple combustibles; but this place does not suit it according to the definition which we have given of combustion, see p. 129. In all probability azote is a compound, and the difficulty will be got rid of when we succeed in obtaining its constituents in a separate state. Till then it will be best to allow it a place by itself.

† This experiment was first made by Dr. Hales.

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, provided the temperature be about 60°. If 100 measures of common air be mixed over water in a wide vessel with about 80 measures of nitrous gas,[*] the mixture will acquire a brownish red colour, part of it will be absorbed by the water, and there will remain 79 measures of pure azotic gas. This is the easiest and the most elegant method of procuring azotic gas for the purposes of experiment.

This gas was discovered in 1772 by Dr. Rutherford, professor of botany in the university of Edinburgh.[†] Scheele procured it by the first mentioned process before the year 1777, and proved that it was a distinct fluid.[‡]

1. The air of the atmosphere contains about 0·79 parts (in bulk) of azotic gas; almost all the rest of it is oxygen gas. Mr. Lavoisier was the first philosopher who published this analysis, and who made azotic gas known as a component part of air. His experiments were published in 1773.[§] Scheele's Treatise on Air and Fire, in which his analysis is contained, was not published till 1777. His experiments were no doubt made some years before, but we do not know their exact date.

2. Azotic gas is invisible and elastic like common air, which it resembles in its mechanical properties. It has no smell. Its specific gravity, according to Biot and Arago, is 0·9691;[‖] according to Kirwan it is 0·985;[¶] according to Lavoisier 0·978;[**] air as usual being reckoned one. I am disposed to adopt the number 0·9722 as fixed upon by Dr. Prout, from theoretical considerations which I cannot explain here.[††] If this last estimate be correct, 100 cubic inches of it, at the temperature of 60°, and when the barometer stands at 30 inches, will weigh 29·652 grains.

3. It cannot be breathed by animals without suffocation. If obliged to breath it they die very soon, precisely as they would do if plunged under water. Hence the term *azote* given to this substance by the French chemists, which signifies "destructive of life."[‡‡]

No combustible will burn in it. Hence the reason that a candle

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[*] The method of obtaining this gas will be described in a subsequent part of this section.

[†] See his thesis De Aere Mephitico, published in 1772.—"Sed aer salubris et purus respirationem animali non modo ex parte fit mephiticus, sed et *aliam indolis suæ mutationem inde patitur*. Postquam enim omnis aer mephiticus (*carbonic acid gas*) ex eo, ope lixivii caustici secretus et abductus fuerit, *qui tamen restat* nullo modo salubrior inde evadit; nam quamvis nullam ex aqua calcis præcipitationem faciat haud minus quam antea *et flammam et vitam extinguit*," page 17. When Hauxbee passed air through red-hot metallic tubes, he must have obtained this gas; but at that time the difference between gases was ascribed to fumes held in solution. See Phil. Trans. Abr. v. 613.

[‡] On Air and Fire, p. 7.

[§] See his remarks on Scheele's work, Mem. Par. 1781, p. 397.

[‖] Mem. de l'Instit, 1806, p. 320.

[¶] On Phlogiston, p. 27.

[**] Lavoisier's Elements.

[††] Annals of Philosophy, 6, 322.

[‡‡] From α and ζωη.

confined in a given portion of air goes out as soon as the oxygen surrounding it is consumed.

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°.* According to Mr. Dalton the quantity of azote which 100 cubic inches of water takes up is 2½ cubic inches.†

II. Azote has the property of combining with oxygen in four different proportions, and of forming four compounds that deserve to be accurately understood, as they are of considerable importance in chemical experiments. These compounds have received the following names:—1. Protoxide of azote, or nitrous oxide—2. Deutoxide of azote, or nitrous gas—3. Nitrous acid—4. Nitric acid. The third of them is the only one that can be formed directly by uniting oxygen and azote. The first two are obtained by depriving nitric acid of a portion of its oxygen. The last is extracted from nitre by distilling it with sulphuric acid.

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 *nitrous acid*. Hence he inferred that nitrous acid is formed by the combination of these two bodies. This important discovery was communicated to the Royal Society on the 2d of June 1785. 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 nitrous 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 accuracy, I shall consider as

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* Phil. Trans. 1803, p. 274.

† Annals of Philosophy, vii. 219. Saussure makes the quantity 4·1 cubic inches, (Ann. of Philos. vi. 340.) but he seems to have overrated it.

‡ Priestley on Air, ii. 248.

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 $\frac{1}{32}$ part of azote, and 2588 measures of common air. Now if we suppose that common air contains 21 parts in the 100 of oxygen gas, and make the necessary corrections, we shall have 4505½ measures of oxygen gas, and 2172½ measures of azotic gas, or very nearly 2 measures of azotic gas, to 4 of oxygen. 450·55 inches of oxygen weigh 152·68 grains, and 217·25 measures of azote about 64·41 grains. According to this statement, we have nitrous acid composed of 100 parts by weight of azote united to 237 of oxygen; or in the hundred parts 29·68 azote—70·32 oxygen.* This result agrees almost exactly with the subsequent experiments of Davy, according to which the constituents of nitrous acid are in the hundred parts 29·5 azote—70·5 oxygen.†

But the number which represents the weight of an atom of azote seems, from a careful examination of the compounds into which it enters, to be 1·75 supposing an atom of oxygen to be 1. And nitrous acid seems to be a compound of 1 atom azote + 4 atoms oxygen. Hence its composition by weight is

Oxygen	4·00	228·5	69·56
Azote	1·75	100	30·44
			100·00

I cannot at present detail the reasons which induce me to pitch upon these numbers, but they will appear as we proceed.

2. Nitric acid, obtained by distilling a mixture of nitre and sulphuric 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 when a little heated gives up oxygen to them, and converts them into acids precisely as if the two bodies were subjected to combustion. In this case the nitric acid, by losing a portion of its oxygen, is changed into a species of gas called *nitrous gas*, which flies off and occasions the effervescence which attends the action of nitric acid on these simple combustibles. Nitrous gas is procured in greater abundance, as well as purity, by dissolving copper or silver in nitric acid. The gas may be received in a water trough in the usual way. It possesses the curious property of combining with oxygen the instant it comes in contact with it, and of forming nitric acid. Hence the yellow fumes which appear when nitrous gas is mixed with common air. This combination furnishes a sufficient proof that the constituents of nitrous gas are azote and oxygen, and that it contains less oxygen than nitric acid. It is therefore an *oxide of azote*.

Gay-Lussac has shown by satisfactory proofs, that this gas is composed of one volume of oxygen, and one volume of azotic gas united together without any condensation.‡ Hence its specific

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*Phil. Trans. 1788, p. 266. † Researches, p. 565. ‡ Mem. D'Arcueil. vol. ii. p. 216.

gravity is the mean of that of these two gases, or 1·0416: and at the temperature of 60°, and when the barometer stands at 30 inches, 100 cubic inches of it weigh 36·769 grains. Now 100 cubic inches of oxygen gas weigh 33·888 grains, and 100 cubic inches of azotic gas 29·652 grains. Hence nitrous gas is composed as follows:

Azote	29·652	1·75
Oxygen	33·888	2·0

Hence we see, that it is a compound of one atom of azote and two atoms of oxygen. It is therefore a deutoxide of azote. This composition, which seems sufficiently established, is one of the reasons for making the weight of an atom of azote 1·75.

It seems to be demonstrated by satisfactory experiments, that nitric acid may be formed by the combination of 100 volumes of oxygen, with 133 volumes of nitrous gas.* But 133 of nitrous gas are composed of $66\frac{2}{3}$ volumes of oxygen and $66\frac{2}{3}$ of azote. So that nitric acid is composed of $66\frac{2}{3}$ volumes of azote and $166\frac{2}{3}$ of oxygen, or of one volume of azote and $2\frac{1}{2}$ volumes of oxygen. Now these volumes being converted into weights, give the composition of nitric acid—Azote, 1·75—Oxygen, 5·00.

This was the reason for pitching upon 1·75, to represent the weight of an atom of azote.

3. When iron filings are kept for some days in nitrous gas, they deprive it of a portion of its oxygen, and convert it into a gas which no longer becomes yellow when mixed with common air, but in which phosphorus burns with great splendour, and is converted into phosphoric acid. This combustion and acidification is a proof that the new gas contains oxygen. Its formation demonstrates that it contains azote, and that it has less oxygen than nitrous gas. It is therefore an *oxide of azote* as well as the last described gas. The name *gaseous oxide of azote* has been given to it.

This gas is most easily obtained by exposing the dry salt called *nitrate of ammonia* to the heat of a lamp in a small glass retort. As it is absorbed with some rapidity by water, it must be either kept in phials furnished with ground stoppers, or in glass jars standing over mercury. It possesses the property of supporting combustion. Combustibles burn in it with nearly as much splendour as in oxygen gas; but the combustion lasts a much shorter time. When mixed with hydrogen gas, and an electric spark passed through the mixture, a violent detonation takes place. Davy found that 39 measures of this oxide require 40 measures of hydrogen for complete combustion. The residual gas was 41 measures of azote.† As the gases employed were not absolutely pure, we may safely reject one of the measures of azote, and consider the residue as consisting only of 40 measures. But 40 measures of hydrogen require for their combustion 20 measures of oxygen gas. From this experiment therefore, it follows, that oxide of azote is composed of

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* Dalton's New System of Chemistry, ii. 555. Gay-Lussac, Ann. de Chim. et Phys. i. 404.

† Davy's Researches, p. 291.

—Azote, 40 volumes or 2.—Oxygen, 20 volumes or 1.—condensed into 40 volumes. Hence its specific gravity ought to be 1·5277. Now M. Colin found it 1·5204,[*] which almost corresponds with the calculated gravity. It is composed by weight of

Azote	0·9722×2	1·75
Oxygen	1·111	1·00

But 1·75 is the weight of an atom of azote, and 1 the weight of an atom of oxygen. Hence it follows, that this gas is composed of 1 atom azote, + 1 atom oxygen, or it is a protoxide of azote.

4. Nitric acid can only be procured in quantities from the salt, called saltpetre or nitre, which is collected in great abundance from the surface of the earth. When this salt is mixed with sulphuric acid and heated in a retort, the nitric acid distils over, and may be collected in a proper receiver. Saltpetre melts in a low heat, and may be kept in that temperature without any alteration. But if the heat be increased, a quantity of oxygen gas is disengaged. If saltpetre which has been kept for some time in such a temperature, be dissolved in water, and the liquid mixed with acetic acid, red fumes are disengaged. But no such phenomenon takes place, if saltpetre be used that has not been subjected to such a process. The cause of this phenomenon was first explained by Scheele. The nitric acid in the saltpetre is altered by the heat, and it is converted into another acid, possessed of a much weaker affinity for potash than nitric acid has. Hence the reason, that it is disengaged by acetic acid, and flies off in the state of red fumes. As oxygen gas is driven off by the heat, the new acid was considered as possessing less oxygen than nitric acid, and was in consequence distinguished by the name of *nitrous acid.* If we dissolve lead in nitric acid, evaporate the solution to dryness, reduce it to powder, dry it as completely as possible, and then expose it to heat in a small retort fitted with a receiver, an orange-coloured liquid is obtained, which was first observed by Berzelius; but was particularly examined by Gay-Lussac[†] and afterwards by Dulong.[‡] Its specific gravity is 1·451, and it boils at the temperature 82°. Its taste is exceedingly acid, and when mixed with water, an effervescence takes place, and nitrous gas is evolved. Dulong analized it, by passing it through red hot iron, or copper wire, and collecting the gaseous product. The metal increased in weight by absorbing oxygen, and the gas was azote, very nearly in a state of purity. Hence it follows, that it is composed of azote and oxygen, and that it contains no water. The result of an experiment of which he gives us the details,[§] is that the acid is composed of

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[*] Ann. de Chim. et Phys. i. 218.

[†] Ibid. i. 405.

[‡] Ibid. ii. 317.

[§] The acid experimented on weighed 7·985 grammes = 122·54 grains.
The oxygen which united to the metal was 5·66 gram. = 87·41 grains.
But 3·82 cubic inches of hydrogen gas appeared indicating - - 0·65 gr. oxy.

Hence the oxygen from the acid was - - - - - - 86·76 grains.
The azotic gas evolved was 1·96 litres at 52°. It contained 3·22 per cent of hydrogen gas. Deducting this, the azote makes 115·76 cubic inches at 32° = 122·5 cubic inches at 60°. These weigh - - - - - 36·33 grains.
See Ann. de Chim. et Phys. ii. 320.

Azote	36·33	1·75
Oxygen	86·76	4·178

These numbers do not differ much from those determined by Gay-Lussac, who found, that 100 volumes of oxygen gas could be united with 200 volumes of nitrous gas, and that thus united they constituted nitrous acid.* According to this statement, nitrous acid is composed of 1 volume azote + 2 volumes oxygen, or by weight of

Azote	0·9722	1·75
Oxygen	2·2222	4

Hence we see that nitrous acid is a compound of 1 atom azote and of 4 atoms oxygen.

5. Gay-Lussac concludes from his experiments, that 100 volumes of oxygen gas may be likewise made to unite with 400 volumes of nitrous gas. The compound according to him is an acid, which has hitherto been overlooked by chemists, and to which he has given the name of *pernitrous acid.*† We see that it must be composed of 200 volumes of azote united to 300 volumes of oxygen, or in weight of

Azote	1·9444	1·75
Oxygen	3·3333	3·00

So that it must be a compound of 1 atom azote, and 3 atoms oxygen. But as this acid has never been obtained in a separate state, nor ever observed united to a base, its existence is still in some measure hypothetical.

Thus, we have five compounds of azote and oxygen; namely,

	Azote.	Oxygen.
1. Protoxide of azote composed of	1 atom	+ 1 atom
2. Deutoxide of azote	1	+ 2
3. Hyponitrous acid	1	+ 3
4. Nitrous acid	1	+ 4
5. Nitric acid	1	+ 5

III. Azote has the property likewise of combining with chlorine, and of forming a very singular compound, to which we may give the name of *chloride of azote*.

It seems to have been discovered about the beginning of 1812, by M. Dulong, who did not however publish any thing on the subject, having been deterred by two severe accidents, which prevented him from completing his investigation. In September 1812, Sir H. Davy received a letter from M. Ampere, in which he mentions the discovery, without saying any thing about the mode of preparing it. This information roused his curiosity, and induced him to set about a series of experiments in order to obtain it. But before he had proceeded far, Mr. Children put him in mind of an oily substance, that had been observed about a year before by Mr. Burton, at Cambridge, when he passed a current of chlorine through a solution of nitrate ammonia. This information enabled Davy to

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* Ann. de Chim. et Phys. i. 401.

† Ann. de Chim. et Phys. i. 400. *Hyponitrous acid* would be a better name.

procure the substance, and to investigate its properties.* A very numerous set of experiments was made upon it about the same time, by Messrs. Porrett, Wilson, and Rupert Kirk.† There was lastly an abridgement of Dulong's original paper, drawn up and published by Thenard and Berthollet.‡ The chloride of azote may be procured in the following manner.

Dissolve in water of about 110°, a quantity of nitrate of ammonia, or sal ammoniac, so as to make a moderately strong, but not saturated solution. Put it into a flat dish, and invert over it a phial or cylindrical glass jar, previously filled with chlorine gas. The gas is slowly absorbed; a yellowish oily looking matter collects on the surface of the liquid within the jar, and gradually falls to the bottom. It is the *chloride of azote*. Care must be taken not to collect more at one time than a globule or two; and no experiments ought to be made upon a quantity of it, exceeding a grain in weight. For the explosions which it occasions are so violent as to be dangerous, unless the quantity employed be very small. Chloride of azote possesses the following properties.

Its colour is nearly similar to that of olive oil. It is as transparent, and has little or none of the adhesiveness of oils. Its smell is peculiar and strong, though not so disagreeable nor injurious to the lungs, as that of chlorine.§ It is very volatile, and is soon dissipated when left in the open air. It may be distilled over at 160° without danger; but is partially decomposed by the heat. The temperature of 200° only increases the rapidity of its evaporation; but when heated to 212°, it explodes with prodigious violence. In a vacuum it is converted into vapour, and is again condensed into a liquid when the pressure of the atmosphere is restored. If this vapour be heated sufficiently, it explodes with as much violence as the liquid itself.‖ The specific gravity of chloride of azote is 1·653.¶ When exposed to cold, the water in contact with it congeals at about 40°, but it remains fluid itself, though exposed to the cold produced by a mixture of ice and muriate of lime.**

When left in water it speedily disappears, while a quantity of azotic gas is disengaged. When put into strong muriatic acid, a quantity of gas is extricated, considerably exceeding the whole weight of the chloride. This gas is chlorine; muriate of ammonia remains in the solution.

When chloride of azote comes in contact with phosphorus or oils, a violent detonation immediately takes place; the effect is so instantaneous and so great, that it has not been possible to collect the products. Messrs. Porrett, Wilson, and Rupert Kirk, brought 125 different substances in contact with it. The following were the only ones which caused it to explode.††

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* Davy. Phil. Trans. 1813, p. 1 and 242.

† Nicholson's Journal, xxxiv. 180 and 276. March and April 1813.

‡ Ann. de Chim. lxxxvi. 37.

§ Davy compares it to the smell of phozgene gas.

‖ Porrett, Wilson, and Rupert Kirk.

¶ Davy.

** Davy. This temperature was probably as low as — 40°.

†† Nicholson's Journal, xxxiv. 277.

Super-sulphureted hydrogen.
Phosphorus.
Phosphuret of lime.
Caoutchouc.
Myrrh.
Phosphureted camphor.
Palm oil.
Ambergris.
Whale oil.
Linseed oil.
Olive oil.
Camphoreted olive oil.
Sulphureted olive oil.
Oil of turpentine.
Oil of tar.
Oil of amber.
Oil of petroleum.
Oil of orange peel.
Naphtha.
Soap of silver.
Soap of mercury.
Soap of copper.
Soap of lead.
Soap of manganese.
Fused potash.
Solution of pure ammonia.
Phosphureted hydrogen gas.
Nitrous gas.

Metals, resins, sugar, and most of the gases did not explode with this substance.

M. Dulong placed chloride of azote in contact with pieces of copper. The chloride disappeared, azotic gas was disengaged, and there was formed a solution of muriate of copper.[*] From this experiment it follows, that the substance is a compound of azote and chlorine. Davy found, that when it was exploded in an exhausted vessel, the only products were chlorine and azote.[†] This farther corroborates the nature of its constituents. When made to act upon mercury, a mixture of calomel and corrosive sublimate[‡] is formed, and azote disengaged. In one experiment 0·7 grain of the chloride produced 49 grain measures, or 0·193 cubic inch of azote. This quantity weighs 0·057 grain. According to this estimate the chloride is composed of azote 57 - 1·75—chlorine 643 - 19·74.

Supposing it a compound of 4 atoms chlorine, and 1 atom azote, its constituents would be azote 1·75—chlorine 4·5 × 4 = 18. The volumes of chlorine and azote according to the preceding experiment, are azote 19—chlorine 81. If we suppose that the whole azote was not obtained, as is very probable; we may state the volumes at azote 20—chlorine 80.

This would make the chloride exactly a compound of 1 atom azote and 4 atoms chlorine. Davy made several other experiments, which all corroborate this supposition and render it highly probable.

IV. Azote has the property likewise of combining with iodine, and of forming a compound which may be called *iodide of azote*. It was discovered by M. Courtois, and may be prepared in the following manner.

Put a quantity of iodine into a solution of ammonia in water. It is gradually converted into a brownish black matter which is the *iodide of azote*.

When left in the open air it gradually flies off in vapour without leaving any residue. It detonates with great violence when slight-

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

[†] Phil. Trans. 1813, p. 244.

[‡] These are compounds of mercury and chlorine.

ly touched, or when heated. If the detonation be performed in an exhausted glass vessel the only products are azotic gas and iodine.* Hence it is obvious that it is composed of these two substances. The attempts which have been made to determine the proportion of the constituents of this substance have not succeeded. Gay-Lussac calculates from theory† that it is a compound of one atom of azote and three atoms of iodine, or by weight of—Azote, 1·75—Iodine, 15·625 × 3 = 46·875. But the basis of this theoretical calculation is quite uncertain. From the fact that chloride of azote is a compound of 1 atom azote + 4 atoms chlorine, we see that it is not a general law that azote combines with other bodies in the proportion of one to three atoms.

Various attempts have been made to decompose azote, and to reduce it into simpler elements; but hitherto these attempts have not been attended with success. Berzelius has endeavoured by an ingenious process of reasoning to show that it is a compound of oxygen and an unknown substance, to which he has given the name of *nitricum*.‡ But his reasoning, being founded upon a supposed law§ which has been since found not to hold in many cases, cannot be admitted as valid. Mr. Miers published a numer of ingenious experiments in order to show that azote is a compound of oxygen and hydrogen.‖ These experiments are of a very curious nature: but it would be requisite that they should be repeated with more exactness and on a greater scale, before we can venture to draw any consequences from them. There is a third set of experiments on an amalgam made by exposing mercury to the action of galvanism in contact with a moist ammoniacal salt. I shall give a particular account of these experiments in a subsequent part of this work. They appeared to me at first to demonstrate the compound nature of azote. But, upon considering the subject with greater attention, I think it would be hazardous at present to draw any such conclusion from them. Upon the whole, then, as no sufficient proof has yet been adduced that azote is a compound, we must continue to class it among the simple bodies.

CHAPTER III.

OF SIMPLE COMBUSTIBLES.

By *combustible* is understood substances which have the property of uniting with the supporters of combustion, and of emitting light and heat whenever that union is rapid. There are at present 43 such substances known. It is of great importance to reduce these

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* Davy, Phil. Trans. 1814, p. 86.

† Ann. de Chim. xci. 30.

‡ Annals of Philosophy, ii. 276.

§ That, in all neutral salts, the oxygen in the acid is a multiple by a whole number of the oxygen in the base.

‖ Annals of Philosophy, iii. 364, and iv. 180, 260.

substances into distinct genera. The present method of confounding every thing under the name of metal has introduced much confusion into the science. I conceive they may be very conveniently classed under the three following genera.

I. Bodies forming *acids* by uniting with the supporters of combustion or with hydrogen. The substances belonging to this genus are the eight following.[*]

1. Hydrogen
2. Carbon
3. Boron
4. Silicon
5. Phosphorus
6. Sulphur
7. Arsenic
8. Tellurium.

All these bodies, except arsenic and tellurium, have been hitherto classed apart from the metals under the name of *simple combustibles*.

II. Bodies forming *alkalies* or *bases* capable of constituting neutral salts with acids, by uniting with the supporters of combustion.

These bodies are 28 in number. They are all metals, and may be arranged under five families or groups.

I. FAMILY.

1. Potassium
2. Sodium
3. Calcium
4. Barium
5. Strontium
6. Magnesium.

II. FAMILY.

1. Yttrium
2. Glucinum
3. Aluminum
4. Zirconium.

III. FAMILY.

1. Iron
2. Nickel
3. Cobalt
4. Manganese
5. Cerium
6. Uranium.

IV. FAMILY.

1. Zinc
2. Lead
3. Tin
4. Copper
5. Bismuth
6. Mercury
7. Silver.

V. FAMILY.

1. Gold
2. Platinum
3. Palladium
4. Rhodium
5. Iridium.

III. Bodies producing by their union with the supporters of combustion imperfect acids or substances intermediate between acids and alkalies.

These bodies are six in number, and belong all to the class of metals.

1. Antimony
2. Chromium
3. Molybdenum
4. Tungsten
5. Columbium or tantalum
6. Titanium.[†]

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[*] I class along with them likewise *osmium* from analogy. It has not been sufficiently examined to enable us to decide where it ought to be placed.

[†] [Upon this arrangement it will be proper to observe, 1st. That whether hydrogen be acidifiable, depends on the truth of the theory which the author has adopted respecting the constitution of chlorine and muriatic acid gas. There is, as yet, no proof that hydrogen is acidifiable.

2. It is impossible to force any oxide of silicon into the class of acids, according to the definition given of acids in vol. ii. which it is worth while to consult on this occasion.

3. It seems to me a strange perversion of language to class 18 of the metals, iron, gold, silver, copper, lead, tin, &c. &c. among the alkalies.

4. It is even yet extremely dubious whether the alkalies, with a metallic appearance,

The description of these different bodies will occupy the following sections.

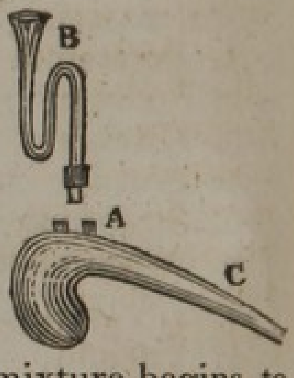
GENUS I. ACIDIFIABLE COMBUSTIBLES.

Every one of these combustibles, except the first, can be exhibited in a solid state. But they all become gaseous by uniting either with hydrogen or with a supporter of combustion.

SECTION I.

OF HYDROGEN.

HYDROGEN may be procured by the following process.*



Into a retort having an opening at A† 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 in-

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(metalloids) ought to be ranked as metals; for, 1st. They want the characteristic weight of metals. 2. They are extremely soluble in water. 3. Their oxides are heavier than the substance before it be oxided. Properties that, until Sir H. Davy forced these substances into company with metals, metals were never allowed to possess. 4. Dr. Clarke's experiments at Cambridge on the metallization of the earths, have obtained but little credit in London: 8 Brande's Journ. 317.

Again, his 3d genus consists of bodies that are intermediate between acids and alkalies, a description hitherto usually applied to neutral salts; but no one who has procured the acids, so called, of chrome, molybdena, and tungsten, can doubt of the propriety of classing them among acids according to the usual meaning affixed hitherto by chemists to that word. To class silicon among the acidifiable bases, and to reject chrome, is indeed a classification that facts will not justify.

The whole of this arrangement appears to me to be formed on considerations too theoretical: they may possibly be verified by future experiments, but they are not to be taken for granted in the present state of our knowledge, especially in an elementary system of the science of chemistry.—C.]

* [I see no necessity for this safety tube marked B. Put into a common retort, some iron filings, turnings, or small nails; or still better, some granulated zinc: pour on them some oil of vitriol of commerce, previously diluted with about four or five times its bulk of water; the retort should not be above half full. Let the effervescence proceed till all the common air is expelled: then place the beak of the retort under a receiver; that is, a cylindrical glass jar filled with water, and inverted in water on the shelf of the common pneumatic trough.—C.]

† Such retorts are called *tubulated* by chemists.

verted jar on the pneumatic shelf over the beak of the retort. The bubbles rise in abundance and soon fill the jar. The gas 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 by causing the steam of water to pass through a 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.[†] 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.

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.

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 described by Biot and Arago, is 0·0732.[**] Dr. Prout has shown from the specific gravity of ammoniacal gas, which is composed of three volumes of hydrogen and one of azote condensed into two volumes, that its specific gravity must be 0·0694.[††] According to this estimate 100 cubic inches of hydrogen gas, when the temperature is 60° and the barometer stands at 30 inches, weigh 2·117 grains.

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

4. When animals are obliged to breathe it, they soon die. The death is occasioned merely by depriving the animal of oxygen. The animal dies precisely as it would do if plunged under water.

5. 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

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[*] [The gas thus emitted is not hydrogen, but carburetted hydrogen.—C.]

[†] See an instance related in Phil. Trans. Abr. i. 169.

[‡] Tractatus Quinque, p. 163.

[§] Shaw's Boyle, iii. 21.

[‖] Cramer's Elementa Docimasia, i. 45. This book was published in 1739.—Wasserberg relates a story of an accidental explosion which terrified Professor Jacquin's operator. Wasserberg's Insitutiones Chemia, i. 184.

[¶] Phil. Trans. 1766, vol. lvi. p. 141.

[**] Mem. de l'Instit. 1806, p. 320.

[††] Annals of Philosophy, vi. 322.

inches of hydrogen gas at the temperature of 60°.[*] According to Saussure water absorbs 4·6 per cent. of hydrogen gas and alcohol 5·1 per cent.[†]

II. 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°.

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 two 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 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 one volume of oxygen to two volumes of hydrogen. But the specific gravity of oxygen gas is 1·1111, and that of hydrogen gas 0·0694. So that oxygen gas is 16 times heavier than hydrogen gas.[§] Therefore water is composed by weight of oxygen[‖] 8 - 1· —hydrogen 1 - 0·125. If therefore we suppose water to be composed of one atom of oxygen and one atom of hydrogen, and represent the weight of an atom of oxygen by 1, the weight of an atom of hydrogen will be 0·125.[¶]

If 100 measures of air be mixed with 42 measures of hydrogen, and an electric spark passed through the mixture, a detonation takes place, and the residual gas amounts to 79 volumes, and is

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[*] Henry, Phil. Trans. 1805, p. 274.

[†] Annals of Philosophy, vi. 340.

[‡] Scheele on Air and Fire, p. 57; and Crell's Annals, iii. 101. Eng. Trans.

[§] [These numbers are taken from Dr. Prout's paper, which I insert at the end of this volume.—C.]

[‖] [This would be stated more intelligibly thus, oxygen 16 - 8 - 1—hydrogen 2 - 1 - 0·125.—C.]

[¶] [There is no reason to believe, as yet, that oxygen and hydrogen combine in any other proportion Dr. Thomson, after Dr. Prout, corrects the common relative weights of these two substances in water, from 85 and 15, to 80 and 10, or 8 and 1.—C.]

pure azotic gas. This shows us that air is a compound of 21 oxygen and 79 azotic gas. For the 42 measures of hydrogen require just 21 measures of oxygen to convert them into water. This experiment is often used to ascertain the purity of hydrogen gas. Mix any quantity of hydrogen gas with its bulk of oxygen, and fire it by means of an electric spark; note the diminution of bulk that takes place; two thirds of that diminution is hydrogen. Suppose we mix 20 measures of hydrogen and 20 of oxygen, and fire them by means of electricity. Suppose the residual gas after the experiment 10 measures. Thirty measures have disappeared. Two thirds of that or 20 measures were hydrogen. Therefore in such a case the hydrogen examined would be considered as pure.

III. Hydrogen has the property also of combining with chlorine gas. The compound formed is known by the name of *muriatic acid.* [Qu. for the reasons advanced, p. 155.—C.]

If equal volumes of chlorine and hydrogen be put into a glass tube and exposed to the direct rays of the sun, an explosion takes place. This curious fact was first observed by Gay-Lussac and Thenard.* When two equal glass vessels, ground so as to fit each other and filled, the one with dry chlorine and the other with hydrogen, are placed in contact and exposed to the light of day, but not to sunshine, the yellow colour gradually disappears and the mixture becomes colourless. If it be now examined it will be found converted into pure muriatic acid gas, equal in bulk to the volume of the two gases before combination.† Hence it follows that this gas is a compound of chlorine and hydrogen. The experiments which led to this conclusion were first made by Gay-Lussac and Thenard. But the consequence was first drawn by Sir Humphry Davy, who thus revived the original opinion of Scheele, the discoverer of chlorine gas.

Muriatic acid, called *hydrochloric acid* by Gay-Lussac, is a gaseous body, invisible and elastic like common air, and having a peculiar smell and a very sour taste. Water absorbs it with great avidity, so that it can be preserved only over mercury. No combustible body will burn in it: and it destroys life instantly when an attempt is made to breathe it. Indeed it cannot be drawn into the lungs; the glottis being spasmodically shut whenever it comes in contact with this gas.

Its specific gravity is the mean of that of chlorine and hydrogen, or 1·2847. Hence 100 cubic inches of it weigh 39·162 grains.

Its constituents are as follows:

Hydrogen	0·125	1
Chlorine	4·5	36

IV. Hydrogen combines with iodine, and forms a compound which has received the name of *hydriodic acid.* It seems to have

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* Recherches Physico-Chimiques, ii. 129. The discovery was likewise made by Dalton, who communicated it to me by letter before the publication above quoted appeared.

† Ibid. p. 128.

been first discovered by M. Clement; but its nature and properties were first investigated by Davy[*] and Gay-Lussac.[†]

It may be obtained by mixing together four parts of iodine and one part of phosphorus, moistening the compound with water and heating it in a small retort. A gas comes over which must be received over mercury. This gas is hydriodic acid.

It is colourless and elastic like common air. It has a smell similar to that of muriatic acid and a very acid taste. Its specific gravity, according to the experiments of Gay-Lussac, is 4·443.[‡] The real specific gravity ought to be 4·3749, which is the mean between the specific gravity of iodine vapour and hydrogen gas. Hence at the temperature of 60°, and when the barometer stands at 30 inches, 100 cubic inches of it weigh 133·434 grains.

When this acid is left in contact with mercury it is decomposed, the mercury combines with the iodine and forms an iodide, while a quantity of hydrogen gas is disengaged exactly equal to half the bulk of the hydriodic acid gas. It is decomposed likewise by chlorine, muriatic acid is formed and the iodine is deposited. These experiments leave no doubt about its composition. It consists of one volume of vapour of iodine united to one volume of hydrogen gas without any change of bulk. Hence it is composed by weight of

Iodine - -	8·6804 - -	16·625
Hydrogen - -	0·0694 - -	0·125

We see from this that it is composed of an atom of iodine united to an atom of hydrogen.

Water absorbs this acid with avidity. When exposed to a heat below 262° the water is driven off and the acid becomes concentrated. In this way its specific gravity may be increased to 1·7. At 262° the acid boils and may be distilled over. It readily dissolves iodine, and becomes of a darker colour. It becomes dark coloured also by exposure to the air, being partly decomposed.

V. Hydrogen has the property of combining with fluorine, and forming a very powerful acid known by the name of *fluoric acid*.[§]

This acid, in a state of purity, was first made known to chemists by Gay-Lussac and Thenard.[‖] It is obtained by putting a mixture of pure fluor spar and sulphuric acid into a retort of lead and silver, and distilling into a leaden or silver receiver.

Fluoric acid is a colourless liquid, of the specific gravity 1·0609. It smokes strongly when exposed to the air. It acts with prodigious energy upon the skin. The smallest speck occasioning sores. We are not acquainted with the proportions in which the constituents of this acid are combined. If we conclude from an analogy

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[*] Phil. Trans. 1814, p. 74. [†] Ann. de Chim. xci. 9. [‡] Ann. de Chim. xci. 16.

[§] [May not the hydrogen combine with part of the oxygen of these acids and form water? The acid properties of muriatic acid gas, are lessened or rendered latent, by the dose of oxygen that converts it into chlorine; and when this oxygen is abstracted from chlorine by hydrogen, the acid properties of the muriatic acid gas are developed.—C.]

[‖] Recherches Physico-Chimiques, ii. 2.

that it is a compound of an atom of hydrogen and an atom of fluorine, its proportions will be 1 of hydrogen to 16 of fluorine. For an atom of fluorine seems to weigh two. According to this notion fluoric acid will be composed of

Hydrogen	0·125	1
Fluorine	2·000	16

The affinity of hydrogen for the supporters of combustion is in the following order:—*Hydrogen*—Oxygen—Chlorine—Iodine. Oxygen separates hydrogen from chlorine and iodine; while chlorine separates it from iodine.

VI. Hydrogen has the property of combining with azote and of forming a gaseous substance distinguished by the name of *ammonia*.

This substance was unknown to the ancients. It seems to have been discovered by the Arabian chemists; though we are ignorant who the discoverer was. When animal substances are distilled, a white saline substance is obtained, having a strong and peculiar odour, to which the name of *hartshorn* and *volatile alkali* were given. This salt is a compound of *ammonia* and another gaseous substance called *carbonic acid*. The method of obtaining it is described by Basil Valentine. If this salt or *sal ammoniac* be mixed with twice its weight of quicklime, put into a flask and exposed to the heat of a lamp, a gas comes over which must be received over mercury, and which is ammoniacal gas. This gas was first discovered by Dr. Priestley. Its composition was first ascertained by Scheele. Berthollet determined it by pretty correct experiments. The subsequent experiments of Henry, A. Berthollet, and Davy, ascertained the proportion of the constituents with rigid accuracy. Ammoniacal gas is transparent and colourless, and possesses the mechanical properties of air. Its smell is very pungent; though rather agreeable when sufficiently diluted. Its taste is acrid and caustic, and if drawn into the mouth it corrodes the skin. Animals cannot breathe it without death. When mixed with oxygen gas, and an electric spark passed through the mixture, it detonates, as was first discovered by Dr. Henry. It converts vegetable blues into green. Its specific gravity is 0·590. Hence at the temperature of 60°, and when the barometer stands at 30 inches, 100 cubic inches of it weigh 18 grains.

Water absorbs 780 times its bulk of this gas, and is converted into liquid ammonia, a substance very much employed in chemical experiments. When this liquid is heated to 130° the ammonia separates in the form of gas.

When electric sparks are passed for a considerable time through dry ammoniacal gas its bulk is just doubled, and it is completely decomposed. The new gaseous product consists of a mixture of three volumes of hydrogen gas and one volume of azotic gas. It is obvious from this that ammonia is composed of three volumes of hydrogen and one volume of azote compressed into two volumes. Hence its constituents by weight are

Hydrogen	0·1947	0·125 + 3	1
Azote	0·9722	1·75	$4\frac{2}{3}$

Thus we see that ammonia is a compound of three atoms of hydrogen and one atom of azote. Hence the weight of an atom of it is 2·125.*

SECTION II.

OF CARBON.

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.†‡

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 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 clothes which have contracted a disagreeable odour, effectually detroys 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.‖

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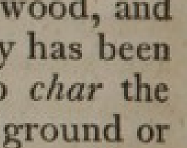
[*] [Yet Dr. Prout, whom our author is so well inclined to follow, says, "Thus ammonia has been stated to be composed of one atom of azote and three of hydrogen; whereas, it is evidently composed of one atom of azote and only one and a half of hydrogen, which are condensed into two volumes, equal therefore to one atom." Annals of Phil. v. 6, p. 330. I fear we are not yet ripe for substituting arithmetical deductions in the place of accurate experiments.—C.]

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

[‡] [A new method of making charcoal of an uniform quality has lately been introduced among the manufacturers of gunpowder, for which a Mr. Kurtz has taken out a patent. The billets to be charred are put into a sheet-iron chest which has a cover that fits tight, and a tube that descends nearly to the bottom: thus Fire is at first applied underneath; the whole mass of wood is kept perpetually immersed in vapour always of the same temperature, because it can only make its escape from the bottom, as is evident. Hence one piece cannot be more charred than another. When the vapour ceases to escape, and nothing comes out of the tube but carburetted hydrogen, the process is stopped.—C.]



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

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

When putrid water at sea is mixed with about $\frac{1}{9}$th of its weight of charcoal powder it is rendered quite fresh, and a much smaller quantity of charcoal will serve if the precaution be taken to add a little sulphuric acid previously to the water. If the water casks be charred before they are filled with water, the liquid remains good in them for years. This precaution ought always to be taken for long sea voyages. The same precaution when attended to for wine casks will be found very much to improve the quality of the wine.*

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°.†

3. When freed from the air which it may contain, either by heat or by being placed under an exhausted receiver, it has the property of absorbing a certain quantity of any gaseous body in which it may be placed. Lametherie made some experiments on this subject many years ago.‡ Count Morozzo made many curious observations on the quantity of different gases absorbed by charcoal.§ These were varied and extended still farther by Messrs. Rouppe and Van Noorden of Rotterdam.|| But the most complete and satisfactory set of experiments on the absorption of gases, by charcoal, has been made by M. Theodore de Saussure.¶ His method was to heat the bit of charcoal red hot, to plunge it while in that state under mercury, and then to introduce it when cold into the gas to be examined. He always employed box wood charcoal. The following table exhibits the bulk of the various gases absorbed by a volume of charcoal reckoned one.

	Volumes.		Volumes.
Ammoniacal gas -	90	Olefiant gas - -	35
Muriatic acid -	85	Carbonic oxide -	9·42
Sulphurous acid -	65	Oxygen - -	9·25
Sulphureted hydrogen	55	Azote - -	7·5
Nitrous oxide -	40	Oxy-carbureted hydrogen**	5·
Carbonic acid - -	35	Hydrogen - -	1·75

The absoption of all these gases terminated at the end of 24 hours, and was not increased by allowing the charcoal to remain in contact with the gas. From Saussure's experiments it seems clear that this absorption of the gases, by charcoal, is analagous to the capillary attraction of liquids by very small tubes.

When charcoal already saturated with any gas is put into another gas, it gives out a portion of the gas already absorbed, and absorbs a portion of the new gas. The proportions vary according to the relative absorbability of the two gases.

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* Berthollet, Ann. de Chim. lix. 96; and xciii. 150.

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

‡ Jour. de Phys. xxx. 309.

§ Jour. de Phys. 1783, p. 376. Nicholson's Journal, ix, 255, and x. 12.

|| Ann. de Chim. xxxii. 3.

¶ Annals of Philosophy, vi. 241 and 331.

** Gas from moist charcoal of the specific gravity 0·3326.

4. There is a substance found *native*, in different parts of the world, that possesses most of the properties of charcoal. This substance is known by the name of *plumbago*, *graphite*, *black lead*. It is employed for making pencils, for making crucibles, and for rubbing bright the surface of cast iron utensils. It serves likewise to diminish friction when interposed between rubbing surfaces. The finest specimens of this mineral are found in the celebrated mine of Barrowdale, in the county of Cumberland. This mine has been worked since the time of Queen Elizabeth, and is said to be the only one which supplies plumbago of sufficient purity to be made into pencils. Pencils of this substance existed in 1565, as they are mentioned by Conrade Gesner in his book on fossils published that year. But the nature of plumbago was first determined by Scheele in his *experiments on plumbago*, published in the *Memoirs of the Stockholm Academy*, for 1779. Dr. Lewis, indeed, had previously made some considerable advances towards the results obtained by Scheele.*

Plumbago is a mineral of a dark steel grey colour, and a metallic lustre; it is soft and has a greasy feel; it leaves a dark coloured line when drawn along paper; it is a conductor of electricity. When kept red hot it gradually wastes away in the open air, and it burns with great splendour when thrown into red hot saltpetre.

The *diamond* is another substance which possesses many of the properties of charcoal, though it differs from it in others. It is the hardest and most beautiful of all the precious stones. Hitherto it has been found only in India and Brazil. It is always crystallized, and usually of a small size. The figure of its crystal is the octahedron, but the faces are usually curved, and the most common figure is a kind of 48 sided figure; the faces are curved, and the whole figure approaches somewhat to a sphere. Its specific gravity is about 3·5. It is a non-conductor of electricity.

This mineral was long considered as incombustible. But Newton, from its property of refracting light so powerfully, conjectured that it was capable of burning. This conjecture was verified in 1694, in the presence of Cosmo III. Grand Duke of Tuscany. By means of a burning glass the Florentine Academicians consumed several diamonds.† In 1751, Francis I. Emperor of Germany, witnessed the destruction of several more diamonds in the heat of a furnace.‡ These experiments were repeated by Darcet, Rouelle, Macquer, Cadet, and Lavoisier, who proved that the diamond was not merely evaporated but actually burnt, and that if air was excluded it underwent no change.§

Mr. Lavoisier prosecuted these experiments with his usual pre-

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* Philosophical Commerce of the Arts, p. 326.

† Giornale de Litterati d'Italia, Tom. viii. Art. 9. The experiments were performed by Averani.

‡ Das Neueste aus der enmuthigen gelehrsamkeit. Aus das Jahr, 1751, S. 540.

§ Mem. Par. 1766, 1770, 1771, 1772.

cision; burnt diamonds in close vessels by means of powerful burning glasses; ascertained that, during their combustion, carbonic acid gas is formed; and that in this respect there is a striking analogy between them and charcoal, as well as in the affinity of both when heated in close vessels.[*] A very high temperature is not necessary for the combustion of the diamond. 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.[§]

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 analogous 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 nine grains. But nine 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.

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; but his experiments were inaccurate, as was afterwards admitted by himself; his consequences, of course, are entitled to no attention. The combustion of the diamond in oxygen gas was repeated in 1807, with every requisite precaution, by Messrs. Allen and Pepys, and their results agree very nearly with those of Tennant.[**] It has been repeated still more lately by Sir H. Davy,

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[*] 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.

[||] Encyc. Method. Chim. i. 742.

[¶] Phil. Trans. 1797, p. 123.

[**] Ibid. 1807.

with nearly the same result.* It seems, therefore, demonstrated that the diamond and charcoal are composed of very nearly the same basis.

II. When charcoal is heated to about 800° in the open air it becomes red hot, and continues to burn (supposing it pure) till it is wholly consumed. 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 oxygen which disappeared during the combustion. Hence he concluded, that carbonic acid is a compound of charcoal and oxygen, and that the combustion of charcoal is nothing else than its combination with oxygen.†

2. As oxygen gas may be converted into carbonic acid gas by burning charcoal in it without undergoing any change of bulk; it is obvious that we shall obtain the quantity of *carbon* contained in carbonic acid gas, by subtracting the specific gravity of oxygen from that of carbonic acid. By *carbon* is meant the pure basis of charcoal, free from all the hydrogen and earthy or metallic particles which charcoal usually contains. Now, according to the experiments of Arago and Biot, the specific gravity of carbonic acid gas is 1·5196.‡ We shall consider the true specific gravity as 1·527, which differs very little from the preceding estimation. The specific gravity of oxygen gas is 1·111. Therefore carbonic acid is composed of

Oxygen	1·111	1·000	72·73
Carbon	0·416	0·375	27·27
			100·00

3. When chlorine is passed through charcoal, previously exposed to the strongest heat that can be raised in a furnace, a portion of it is converted into muriatic acid.§ Hence it follows that charcoal, however carefully made, always contains a small portion of hydrogen from which it cannot be freed by heat. Davy found that when charcoal or plumbago were burnt in dry oxygen gas, there was always an evident deposition of moisture.‖ Hence it is obvious that

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* Phil. Trans. 1814, p. 557.

† Mem. Par. 1781, p. 448.

‡ Mem. de l'Inst. 1806, p. 320.

§ Gay-Lussac & Thenard. Recherches Physico-Chim. ii. 98.

‖ Phil. Trans. 1814, p. 565.

plumbago, likewise, contains a minute quantity of hydrogen in its composition. When diamond is burnt nothing is formed but pure carbonic acid gas.*

4. 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 obtained is 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 oxide gas* has been given it by chemists, and Cruikshanks has shown that it is a compound of oxygen and carbon.

This gas possesses the mechanical properties of air. Its specific gravity, according to Cruikshanks, is 0·956, that of air being 1·000. We shall consider its true specific gravity as 0·972. In that case 100 cubic inches of it will weigh 29·652 grains, when the barometer stands at 30 inches and the temperature is 60°.

It burns with a deep blue flame and gives out but little light. When mixed with oxygen gas, and an electric spark passed through the mixture, it detonates: 100 measures of it require for complete combustion 50 measures of oxygen gas, and the product is 100 measures of carbonic acid gas.† Hence it follows that it contains just half the oxygen that exists in the same volume of carbonic acid gas. It is therefore composed of

Oxygen	0·555	1·000	57·14
Carbon	0·416	0·750	42·86

If we compare this table with that which exhibits the composition of carbonic acid, we shall find that the constituents of these two bodies are in the following proportions:

	Carbon.	Oxygen.
Carbonic oxide composed of	0·75	+ 1
Carbonic acid	0·75	+ 2

If, therefore, one denote the weight of an atom of oxygen, 0·75 will be the weight of an atom of carbon; and carbonic oxide will be a compound of one atom carbon + one atom oxygen, and carbonic acid of one atom carbon + two atoms oxygen.

III. Carbon does not combine with chlorine; but chlorine has the property of combining with carbonic oxide, and of forming a gaseous compound, which has received the name of *phosgene gas*. It was discovered by Dr. John Davy, to whom we are indebted for every thing at present known respecting its properties.‡ The method of procuring it is as follows.

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* Davy. Phil. Trans. 1814, p. 565.

† Gay-Lussac. Mem. d'Arcueil, ii. 218.

‡ Phil. Trans. 1812, p. 144.

Into a glass flask, previously exhausted of air and well dried, introduce equal volumes of carbonic oxide and chlorine gases, both well dried by being left in contact with fused *chloride of calcium.*[*] Expose this mixture to sunshine for about a quarter of an hour. The colour of the chlorine disappears, and the volume of the mixture diminishes one half. The new gas, thus formed, is *phosgene gas.*

It is colourless, and possesses the mechanical properties of common air. It possesses a strong smell, which has been compared to what would be produced by a mixture of the odours of chlorine and ammonia. It is more disagreeable and suffocating than that of chlorine, and affects the eyes in a peculiar manner, producing a rapid flow of tears, and occasioning painful sensations. It possesses the properties of an acid, reddening vegetable blues, and combining with, and neutralizing, four times its volume of ammoniacal gas. When tin, zinc, antimony, or arsenic, are heated in this gas, they decompose it, absorbing the chlorine and setting at liberty the carbonic oxide. Water decomposes it, and converts it into muriatic acid and carbonic acid.

As it is composed of equal volumes of chlorine and carbonic oxide gases, reduced to half their original bulk, it is obvious that its specific gravity must be equal to that of these two gases united together, or 3·472. So that at the temperature of 60°, and when the barometer stands at 30 inches, 100 cubic inches of it weigh 105·896 grains. Its constituents by weight, are,

Chlorine - -	2·5 - -	4·5
Carbonic oxide -	0·972 - -	1·75

That is to say, of one atom chlorine and one atom carbonic oxide. Or its composition may be thus stated:—Chlorine 4·5—Oxygen 1·0—Carbon 0·75.

Or an atom of carbon united to an atom of chlorine, and an atom of oxygen. So that it is analogous to carbonic acid. Carbonic acid is a compound of one atom carbon, united to two atoms of a supporter. Phosgene gas is the same. Only there are two distinct supporters. The atom of chlorine in it replaces one of the atoms of oxygen in the carbonic acid. The term *chloro-carbonic acid*, or *chloroxy-carbonic acid*, would be applied to it with greater propriety than *phosgene gas*. Of these I consider the first to be the best.

IV. Carbon has not the property of combining with iodine. It would be curious to know whether iodine be capable, like chlorine, of uniting with carbonic oxide, and of forming *iodo-carbonic acid.* Sir H. Davy tried the experiment, but could not succeed in forming any combination.[†]

V. Nothing is known respecting the combination of carbon and fluorine.

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[*] [Muriat of Lime.—C.]

[†] Phil. Trans. 1814, p. 504.

VI. Carbon has the property of combining with azote, and of forming a curious compound, which was discovered by Gay-Lussac in 1815, and to which he has given the name of *cyanogen.*[*] It is easily obtained by exposing dry *prussiate of mercury* in a small retort, to a heat rather under redness: the salt blackens, and a gaseous fluid is extricated in abundance: it must be received over mercury. This gas is *cyanogen.*

This gas is colourless, and possesses the mechanical properties of common air. Its smell is quite peculiar, and excessively strong and disagreeable. Its specific gravity as determined by Gay-Lussac is 1·8064. I am disposed to consider 1·8042 as the true number. On that supposition 100 cubic inches of it, at the temperature of 60°, and when the barometer stands at 30 inches, will weigh 55·028 grains. It is inflammable, and burns with a purplish blue flame.[†] It is not decomposed by exposure to a red heat. Water dissolves 4½ times its volume, and alcohol 23 times its volume of this gas. It reddens tincture of litmus. Phosphorus, sulphur, and iodine, may be volatilized in it without alteration. Potassium burns in it and absorbs it. For complete combustion it requires twice its volume of oxygen. The products are twice its volume of carbonic acid, and its own volume of azotic gas. Hence it is obviously composed of two volumes carbon and one volume azote, condensed into one volume, or by weight of

Azote	0·9722	1·75
Carbon	0·832	0·75 × 2 = 1·5

Or of two atoms of carbon united to one atom of azote.

VII. Carbon combines with hydrogen in two proportions, and forms two compounds which have received the names of *olefiant gas* and *carbureted hydrogen.* The terms *hydroguret of carbon,* and *bihydroguret of carbon,* would be more systematic.

1. Olefiant gas was discovered in 1796 by the associated Dutch chemists Bondt, Dieman, Van Troostwick, and Lauwerenburg.[‡] Some experiments were afterwards made upon it by Cruikshanks, Berthollet, and Dr. Henry; and its composition was accurately investigated by Mr. Dalton. I published a set of experiments on it in 1811.[§] About the same time an analysis of it was published by M. Theodore de Saussure.[‖]

It is easily obtained by mixing together in a retort four parts of sulphuric acid, and one part of alcohol, and applying the heat of a lamp while the beak of the retort is plunged into a water trough. A gas comes over in abundance, which may be received in glass jars inverted over water.

Olefiant gas, thus prepared, is invisible, and possesses the mechanical properties of common air. It is destitute both of taste

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[*] Ann. de Chim. xcv. 172.

[†] [Hence its name of Cyanogen from κυανος *blue.*—C.]

[‡] Their Memoir was published in the Jour. de Phys. xlv. 178, and an abstract of it in the Ann. de Chim. xxi. 48.

[§] Memoirs of the Wernerian Natural History Society, i. 504.

[‖] Ann. de Chim. lxxvii. 57.

and smell. Its specific gravity, according to my experiments, is 0·9745;[*] according to Saussure, it is 0·9852.[†] From theory its specific gravity should be 0·974, which almost agreeing with my determination, I shall consider as correct. Hence at the temperature of 60°, and when the barometer stands at 30 inches, 100 cubic inches of it weigh 29·72 grains. This gas burns with greater splendour than any other known gas, and detonates very loudly when mixed with thrice its bulk of oxygen gas, and an electrical spark is passed through it. It requires for its complete combustion three times its volume of oxygen gas, and produces, when burnt, twice its volume of carbonic acid gas. The only other product is water. Now two of the three volumes of oxygen gas must have gone to the formation of carbonic acid. The remaining volume must have gone to the formation of water, and it must have combined with a quantity of hydrogen, which in an uncombined state would have amounted to two volumes. Hence (supposing each volume to be a cubic inch) olefiant gas is composed by weight of

Carbon	0·832	0·75	6	100
Hydrogen	0·1388	0·125	1	16·66

That is to say, it is composed of an atom of carbon, and an atom of hydrogen, united together.

Water, according to the experiments of Mr. Dalton, absorbs one twelfth of its bulk of olefiant gas.[‡] According to Saussure, 100 cubic inches of water absorb 15·3 cubic inches of olefiant gas.[§]

2. When olefiant gas and chlorine gas are placed in contact with each other, a diminution of bulk takes place, and a liquid substance is formed which has somewhat the appearance of an oil, when the condensation takes place over water. The formation of this substance was first observed by the Dutch chemists, and it induced them to contrive the term *olefiant gas* for the hydroguret of carbon. I examined this compound in 1810, and ascertained that it is a compound of olefiant gas and chlorine.[‖] Its properties and composition were still more accurately investigated in 1816, by M. M. Robiquet and Colin.[¶]

It is formed by the union of equal volumes of chlorine and olefiant gas. If a current of the two gases from separate vessels meet in a large glass globular vessel, they combine and form the liquid in question, which collects at the bottom of the globe. To render it pure there must be rather an excess of olefiant gas. When there is an excess of chlorine, the liquid absorbs it, acquires a greenish colour and acid properties. But it may be rendered pure by washing it with a little water, and then distilling it off chloride of calcium. It is limpid and colourless like water, has an agreeable smell similar to that of muriatic ether, and a peculiar, sharp,

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[*] Memoirs of the Wernerian Society, i. 516.

[†] Ann. de Chim. lxxviii. 63.

[‡] Phil. Mag. xxiv. 15.

[§] Annals of Philosophy, vi. 340.

[‖] Memoirs of the Wernerian Society, i. 516.

[¶] Ann. de Chim. et Phys. i. 337, and ii. 206.

sweetish, agreeable taste. Its specific gravity at 45° is 1·2201, the specific gravity of water being 1. It boils at 152°. At the temperature of 49°, its vapour is capable of supporting a column of mercury 24·66 inches in length. The specific gravity of this vapour is 3·4434, that of air being 1. Now the specific gravity of chlorine and olefiant gas, added together, make 3·474. Hence it is obvious that this body is formed by a volume of chlorine and a volume of olefiant gas, condensed each into half its volume. Hence its constituents by weight are,

Chlorine	2·5	-	4·5	-	100
Olefiant gas	0·974	-	0·875 × 2		38·88

Hence it appears, that it is a compound of one atom of chlorine, and two atoms of olefiant gas. Or its composition may be stated in this manner: chlorine 1 atom = 4·50 - 18—carbon 2 atoms = 1·50 - 6—hydrogen 2 atoms = 0·25 - 1.

This liquid burns with a green flame, giving out copious fumes of muriatic acid and much soot. It is decomposed by being passed through a red hot porcelain tube, and converted into muriatic acid, and an inflammable gas, containing hydrogen and carbon; while a copious deposite of charcoal is made in the tube. The inflammable gas appears to contain no other constituent but carbon and hydrogen. The liquid is decomposed, likewise, when passed through red hot oxide of copper.

There is some reason for believing that the different substances called *ethers* consist of olefiant gas, united either to water, or to an acid, or to a supporter of combustion. Supposing this opinion well founded, the liquid just described ought to be called *chloric ether*.

3. From an experiment made by Sir H. Davy, there is reason to suspect, that iodine combines with olefiant gas. A reddish brown volatile fluid was formed which did not possess acid properties.* It is not unlikely that this liquid is the same with regard to hydriodic ether, that chloric ether is to muriatic ether.

4. *Carbureted hydrogen*, or *bihydroguret of carbon*, the other compound of hydrogen and carbon, is a gaseous substance which exhales in hot weather from stagnant water, especially ditches in the neighbourhood of towns. This gas was examined by Dr. Priestley and by Mr. Cruikshanks. But it was Mr. Dalton who first determined its composition with accuracy. I published a set of experiments on it in 1811.†

It may be collected by attaching a large glass phial to a piece of wood, so that it shall float on the surface of the stagnant water, with its mouth just under the surface. Into this mouth should be fixed a funnel (a piece of stout oiled paper will answer). Fill the phial with water, and set it afloat with its mouth undermost. Then stir the mud at the bottom of the pond or ditch. Air bubbles rise in abundance, and soon fill the phial. The gas, thus collected, should be washed with a solution of potash, or with lime water, in

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[*] Phil. Trans. 1814, p. 504.

[†] Memoirs of the Wernerian Society, i. 506.

order to separate a quantity of carbonic acid with which it is mixed. It usually contains, also, some common air. But I shall suppose it pure in the following description.

Carbureted hydrogen, thus obtained, is colourless, and possesses the mechanical properties of common air. It has neither taste nor smell. Its specific gravity is 0·555. Hence at the temperature of 60°, and when the barometer stands at 30 inches, 100 cubic inches of it weigh 16·99 grains. When a jet of it issuing from a tube is kindled in the open air, it burns with a yellow flame, giving out a good deal of light. When mixed with oxygen gas, and when an electrical spark is passed through the mixture, it detonates with considerable violence. It does not burn unless the bulk of the oxygen rather exceeds its own bulk; and it ceases to burn when the oxygen is more than $2\frac{1}{4}$ times its own bulk. If we mix it with common air, it burns if it amounts to $\frac{1}{12}$th of the air, and it ceases to burn if it exceeds $\frac{1}{6}$th of the air. In all proportions between these two extremes, it burns with violence. For complete combustion it requires twice its volume of oxygen gas, and produces exactly its own volume of carbonic acid gas. The only remaining product is water. Now it is obvious that one-half of the oxygen went to the formation of carbonic acid, and the other half to the formation of water. This last portion must have combined with a quantity of hydrogen which, if it had been in an uncombined state, would have amounted to twice the volume of the original gas. Therefore carbureted hydrogen is composed by weight of

Carbon	-	0·416	- -	0·750	-	3
Hydrogen	-	0·0694 × 2	-	0·125 × 2	-	1

Hence, it is evident that, in this compound there are united one atom of carbon and two atoms of hydrogen. It is, therefore, a *bihydroguret of carbon*.

The gas which exhales in such abundance in some coal mines, and which has been long the dread of miners, under the name of *fire damp*, is pure carbureted hydrogen. This was ascertained by Dr. Henry in 1807;* and Sir H. Davy, who repeated his experiments in 1815, came to the same conclusion.†

5. When moist charcoal, wood, pit-coal, or almost any animal or vegetable substance, is distilled in a retort, abundance of inflammable gases are extricated. They differ very much in their specific gravity, in the colour of their flame, and in the quantity of oxygen gas which they require for combustion, according to the degree of heat applied, the substance distilled, and the period of the distillation in which the gases are collected. Many experiments have been made on these gases, especially by Berthollet, Henry, Dalton, Saussure, and myself. They seem to be all mixtures of two, three, or four gases, according to circumstances. These gases are *hydrogen*, *bihydroguret of carbon*, *carbonic oxide*, and *hydroguret of carbon*. On that account the term *oxycarbureted*

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* Nicholson's Journal, xix. 149.

† Phil. Trans. 1816, p. 1.

hydrogen, which has been applied to them by Berthollet and Saussure, and by the French chemists in general, does not seem to be very appropriate, and is altogether unnecessary. That the gases in question are mixtures is obvious from this circumstance, that you never find any two of them exactly like one another. They are perpetually varying in their specific gravity, and in the quantity of oxygen necessary to consume them. Now this could not be the case if they were true chemical compounds.

The gas, from pit coal, which is now employed for illuminating the streets and for lighting manufactures, appears, from the experiments of Dr. Henry, to consist chiefly of bihydroguret of carbon, mixed with some hydroguret of carbon, and probably some carbonic oxide.* Mr. Murdoch, of Birmingham, was the person who first thought of this very useful application of coal gas.†

6. It is difficult to determine whether carbon or hydrogen have the strongest affinity for oxygen. Their affinity for each other interferes, and promotes the decomposition of those bodies to which they are applied. When red-hot charcoal is plunged into water, the liquid is decomposed; but bihydroguret of carbon is formed, so that this is not a case of the simple displacement of hydrogen by carbon. Hydrogen has the property of decomposing carbonic acid gas at a red heat. But in this case, also, the phenomena are complicated; for the acid is not completely decomposed, but merely reduced to carbonic oxide. The opinion at present entertained by chemists is, that hydrogen has a stronger affinity for oxygen than carbon has; but this opinion is not supported by any facts that can be considered as decisive.

SECTION III.

OF BORON.

THE saline substance called *borax* has been long familiar to European artists, being employed to facilitate the fusion of the precious metals, and in the formation of artificial imitations of the precious stones. It comes from the East Indies, and is said to be found chiefly in certain lakes in Thibet and China. The word *borax* occurs first in the writings of Geber, an Arabian chemist of the tenth century. In the year 1702, Homberg, by distilling a mixture of borax and green vitriol, obtained a peculiar substance in small white shining plates, which he called *sedative* or *narcotic salt*, and which was considered as an efficacious remedy in continued fevers.‡ Lemery, the younger, in the year 1727, found

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* Nicholson's Journal, xi. 73.

† [Mr. Murdoch appears to have discovered the gas in 1792, but did not apply it to the lighting of apartments until 1798. M. Le Bon applied this gas to that purpose, in Paris, in 1797.—Cooper on gas lights, 189.]

‡ Histoire de l'Acad. 1702, p. 50.

that this substance could be separated from borax by the mineral acids.[*] In 1731, Geofroy ascertained that sedative salt gave a green colour to the flame of alcohol, and that borax contains in it the same alkaline substance that constitutes the basis of common salt.[†] In the year 1752, Baron demonstrated by satisfactory experiments, that borax is composed of sedative salt and soda.[‡] Sedative salt was found to possess the properties of an acid: it was therefore called *boracic acid.* But the composition of this acid remained altogether unknown. Crell, indeed, published a set of experiments on it in the year 1800, in which he endeavoured to show, that its basis was a substance very similar to charcoal in its properties.[§] But when his experiments were repeated by Sir H. Davy, they did not succeed. Davy, in the year 1807, exposed a quantity of boracic acid to the action of the galvanic battery, and observed that a black matter was deposited upon the negative wire, which he considered as the basis of this acid, but he did not prosecute the discovery farther at the time. In the summer of 1808, MM. Gay-Lussac and Thenard succeeded in decomposing this acid by heating it in a copper tube along with *potassium.* They examined the properties of its base, to which the name of *boron* has been given, and published a detailed account of its properties.[||] Davy, in 1809, decomposed the acid by the process of the French chemists, and published, likewise, an account of the properties of boron.[¶] Boron may be obtained by the following process.

1. One part of pure boracic acid, previously melted and reduced to powder, is to be mixed with two parts of potassium[**] and the mixture put into a copper, or iron tube, and gradually heated till it is slightly red, and kept in that state for some minutes. At the temperature of 300° the decomposition begins, and the mixture becomes intensely red hot, as may be perceived by making the experiment in a glass tube. When the tube is cold, the matter in it is to be washed out with water, the potash formed is to be neutralized with muriatic acid, and the whole thrown upon a filter. The *boron* remains upon the filter. It may be washed and dried in a moderate heat.[††] *Boron*, thus prepared, possesses the following properties.

2. It is a powder of an olive brown colour, without either taste or smell. In close vessels it may be exposed to the most violent heat that can be raised, without undergoing any other change, except an increase of density. When first prepared it does not sink

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[*] Mem. Par. 1728, p. 273.

[†] Mem. Par. 1732, p. 398.

[‡] Savans Etrangers, ii. 412.

[§] Ann. de Chim. xxxv. 202.

[||] Mem. d'Arcueil, ii. 311, and afterwards in Recherches Physico-chimiques, i. 276.

[¶] Phil. Trans. 1809.

[**] A metallic body to be described in a subsequent section of this chapter.

[††] A better way of obtaining it is to put the liquid containing the boron into a glass vessol, to allow the boron to subside, and then to draw off the liquid with a syphon. Water is then to be poured on, the boron allowed to subside, and the liquid again drawn off. This process is repeated till the water comes off quite clear. The boron may now be put into a glass capsule, and dried by a moderate heat.

in sulphuric acid of the density 1·844; but after being thus exposed to a violent heat, it sinks rapidly in that acid. It is insoluble in water, alcohol, ether, and oils, whether cold or hot. It does not decompose water even when heated in that liquid to the temperature of 176°. Probably at a red heat the decomposition would take place. Boron is a non-conductor of electricity.

3. Boron is not altered in common air, or oxygen gas, at the ordinary temperature of the atmosphere; but when raised to a heat not quite so high as 600°, it takes fire and burns with great splendour, absorbing at the same time oxygen. By this combustion, a portion of the boron is converted into boracic acid, which undergoing fusion coats the boron, and keeping it from coming in contact with the oxygen, puts an end to the combustion. If this boracic acid be washed off, the boron will burn again, but requires a higher temperature. A great number of successive combustions and washings are requisite, in order to convert the whole of the boron into boracic acid. Several experiments have been made to determine the quantity of oxygen which combines with boron, and converts it into boracic acid; but none of them seem entitled to much confidence. Gay-Lussac and Thenard acidified a portion of boron by heating it in nitric acid. Five parts of boron, by this process, were converted into 7·5 parts of boracic acid.* According to this statement, boracic acid is composed of boron - - 100 - - 2—oxygen 50 - - 1; but they do not put much confidence in its accuracy.

Davy found that when 30 grains of potassium were converted into potash 2·375 grains of boron were evolved.† Now 30 grains of potassium require six grains of oxygen to convert them into potash. If we suppose the whole of this to have been in combination with the boron, it will follow that boracic acid is composed of boron 2·375 - - 2—oxygen 6 - - 5·05.

The difference between this and the preceding result is enormous. But it is obvious that this mode of experimenting is liable to great uncertainty. As hydrogen gas is given out during the decomposition of the boracic acid by potassium, it is clear that all the oxygen in the potash was not derived from the decomposed acid. Besides it is very unlikely that the whole of the boron could be collected and weighed. Davy found that one grain of boron when converted into boracic acid absorbed 5.125 cubic inches of oxygen gas.‡ Now 5·125 cubic inches of oxygen gas weigh 1·74 grain. According to this estimate boracic acid is composed of boron 1 - - 2—oxygen 1·74 - - 3·48. This mode of experimenting is probably better than the preceding, but the experiment was made on so small a scale, and agrees so ill with the two others just stated, that we cannot put full confidence in it.

There is another method by which we can acquire tolerably correct ideas respecting the proportion of the constituents of this acid.

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* Recherches Physico-chimiques, i. 307.

† Davy's Lecture on some new Analytical Researches on the Nature of certain Bodies, p. 43. Phil. Trans. 1809.

‡ Ibid. p. 44.

Berzelius ascertained[*] by experiment, that boracic acid and ammonia combine with each other in the portion of boracic acid 37·95—ammonia 30·32. Now the weight of an atom of ammonia is 2·125, and in neutral compounds one atom of ammonia is found united to one atom of acid. But 30·32 : 37·95 :: 2·125 : 2·66. So that 2·66 represents the weight of an atom of boracic acid. This acid is a compound of boron and oxygen, and it must consist of one atom of boron, united either to one or to two atoms of oxygen. From the observations of Davy there is reason to conclude that the black matter which appears when boron is imperfectly burnt is an oxide of boron. In that case boron in boracic acid must be combined with two atoms of oxygen. But the weight of two atoms of oxygen is two. Therefore boracic acid must be composed of boron[†] 0·66 - - 0·33 - - 1—oxygen 2·00 - - 1·00 - - 3. This deduction, which is probably near the truth, agrees best with the first experiment of Davy. We see from it that the weight of an atom of boron is 0·66.[‡] The principal source of uncertainty is the difficulty of making a correct analysis of borate of ammonia. But from the precautions taken by Berzelius, there is reason to believe that the error must be inconsiderable.

4. When boron is introduced into chlorine gas, it takes fire and burns with a brilliant white flame. A white substance coats the vessel in which the experiment is made, and the boron is covered with a white substance, which by washing yields boracic acid.[§] It is probable that the substance thus formed is a *chloride of boron*. But it has not hitherto been examined.

5. We do not know whether boron be capable of combining with iodine; no experiments having been hitherto made on the subject.

6. Boron has the property of combining with fluorine, and of forming with it a powerful acid to which the name of *fluoboric acid* has been given. It was discovered by Gay-Lussac and Thenard in 1808, who published a detailed account of its properties.[‖] Some additional facts respecting it were afterwards published by Dr. John Davy.[¶] It may be procured by the following process.

Mix together in a retort one part of finely pounded fused boracic acid, two parts of fluor spar in powder, and 12 parts of sulphuric acid. Apply the heat of a lamp. A gas comes over which

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[*] Annals of Philosophy, iii. 57.

[†] [In general remarks, No. 1. it is stated as 0·875. I repeat, the time has not yet arrived when we may place full confidence in any of these calculations.—C.]

[‡] From the composition of hydrate of boracic acid (which will be given when treating of that acid) compared with that of borate of ammonia, there is reason for believing that the true weight of an atom of boracic acid is 2·875. Hence an atom of boron weighs 0·875, and boracic acid is composed of boron 0·875 - - 100—oxygen 2· - - 228·57.

[§] Davy's Lecture on some new Analytical Researches on the Nature of certain Bodies, p. 41. Phil. Trans. 1809. Gay-Lussac and Thenard affirm that boron does not burn in dry chlorine gas. Recherches Physico-chimiques, i. 303. Is this difference to be ascribed to the presence of water in Davy's chlorine? I can hardly believe it.

[‖] Mem. d'Arcueil, ii. 317. And Recherches Physico-chimiques, ii. 37.

[¶] Phil. Trans. 1812, p. 365.

must be collected over mercury. It is fluoboric acid gas. For this process we are indebted to Dr. John Davy.

Fluoboric acid thus obtained is colourless, and possesses the mechanical properties of common air. Its smell is similar to that of muriatic acid, and it has an exceedingly acid taste. It instantly gives a red colour to vegetable blues. Its specific gravity, as determined by Dr. Davy, is 2·3709. Hence at the temperature of 60°, and when the barometer stands at 30 inches, 100 cubic inches of it weigh 72·312 grains. Water, according to Dr. Davy, absorbs 700 times its volume of this gas. The liquid thus obtained is of the specific gravity 1·77. Hence it follows that a cubic inch of water when saturated with this gas is expanded to 1·697 cubic inch. This liquid acid has a certain degree of viscidity, similar to that of sulphuric acid; and, like it, requires a high temperature to cause it to boil. It smokes at first, and gives out about the fifth part of the gas which it contains, but no more, when heated; like sulphuric acid it chars animal and vegetable substances. It forms also an *ether* when distilled with alcohol. It combines with the different bases, and forms salts called *fluoborates*. It may be passed over red hot iron without undergoing any change. But potassium burns in it and appears to be converted into fluoride of potassium, while boron is disengaged. Sulphuric acid has the property of absorbing it in considerable quantities.

7. Davy did not succeed in his attempts to unite boron with azotic gas.*

8. He was equally unsuccessful when he heated boron in hydrogen. But Gmelin appears to have obtained borureted hydrogen gas by the following process. He mixed together four parts of iron filings and one part of boracic acid, and exposed the mixture to a strong heat for half an hour in a crucible. The fused mass was dissolved in diluted muriatic acid. An effervescence took place, and borureted hydrogen gas was extricated.† This gas had the smell of common hydrogen gas from iron, mixed with somewhat of the smell of garlic. When kindled it burned with a reddish yellow flame surrounded by a green border, and white fumes made their appearance in the vessel in which the combustion took place. These were the only characters by which the presence of boron was indicated. Gmelin neither determined the specific gravity of the gas nor made an analysis of it. His experiments therefore are sufficient only to show us that *borureted hydrogen gas* may be formed. His gas seems to have been pure hydrogen mixed with only a small proportion of borureted hydrogen.

9. Boron, as far as we know at present, does not combine with carbon.

10. Descotils‡ has shown that it combines with iron, and his

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* Davy's Lecture on some new Analytical Researches on the Nature of certain Bodies, p. 42, Phil. Trans. 1809.

† Schweigger's Journal, xv. 246.

‡ Recherches Physico-chimiques, i. 306.

experiments have been verified by Gmelin.[*] Davy has found that it has the property of combining with potassium,[†] and forming a grey metallic mass. But as far as the experiment has been hitherto tried, it does not unite with any of the other metals.

11. Its affinity for oxygen appears to be greater than either that of hydrogen or carbon. Accordingly at a red heat it decomposes water and carbonic acid. Indeed it has a stronger affinity for oxygen than any of the *acidifiable bases*, unless silicon constitute an exception. Accordingly it separates oxygen from all of them when assisted by a sufficiently high temperature.

SECTION IV.

OF SILICON.

There is a rock, which occurs in great abundance in the primitive mountains, sometimes forming immense beds, or even whole mountains: sometimes mixed with other stony bodies, as in granite. This rock is known by the name of *quartz*. As this stone and several others which resemble it, as *flint*, *calcedony*, &c. have the property of melting into a *glass* when strongly heated with potash or soda, they were classed together by mineralogists under the name of *vitrifiable stones*. Mr. Pott, who first described the properties of these minerals in 1746, gave them the name of *siliceous stones*, supposing them all chiefly composed of a peculiar earth called *siliceous earth* or *silica*. This earth was known to Glauber, who describes the method of obtaining it from quartz. But it was long before its properties were accurately ascertained. Geoffroy endeavoured to prove that it might be converted into lime,[‡] and Pott,[§] and Baume,[‖] that it might be converted into alumina: but these assertions were refuted by Cartheuser,[¶] Scheele,[**] and Bergman.[††] To this last chemist we are indebted for the first accurate description of the properties of *silica*.[‡‡]

1. Silica is the most common ingredient in stony bodies, and exists in them, combined with various earths and metallic oxides. Mr. Smithson[§§] suggested that in these compounds the silica performs the function of an acid; an opinion which has been demonstrated in a satisfactory manner by Berzelius.[‖‖] It is easily obtained pure by fusing quartz or flint with twice its weight of potash in a silver crucible, dissolving the compound formed in water, supersaturating the liquid with muriatic acid, and evaporating it slowly

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[*] Schweigger's Journal, xv. 245.

[†] Davy, ubi supra, p. 45.

[‡] Mem. Par. 1746, p. 286.

[§] Lithogeogn. p. iii. Preface.

[‖] Man. de Chim.

[¶] Miner. Abb.

[**] Scheele, i. 191.

[††] Sur les Terres Geoponiques; Opusc. v. 59.

[‡‡] Ibid. ii. 26.

[§§] Phil. Trans. 1811, p. 176.

[‖‖] Attempt to establish a pure Scientific System of Mineralogy, p, 27, and the sequel.

to dryness. When concentrated to a certain extent, the liquid assumes the form of jelly. The dry residue is to be well washed with water and then dried.

It is a white powder, without taste or smell; but feeling gritty between the teeth. It is not sensibly soluble in water, owing to its great cohesive power. But when the compound of silica and potash is dissolved in water, and diluted with a sufficient quantity of that liquid, the silica cannot be precipitated from it by any addition of acid: showing that in this state of division it is in reality soluble in water.

2. Sir H. Davy, after having succeeded in decomposing the fixed alkalies and alkaline earths by the action of the galvanic battery, was naturally led to try the effects of the same powerful agent upon silica. But his experiments were not attended with success.* But the analogy between silica and other bodies containing oxygen is so great, that it was universally considered as a compound of oxygen and a combustible base. Berzelius succeeded in separating this basis from silica, and uniting it to iron;† and his experiments were successfully repeated by Professor Stromeyer.‡ About the end of 1813, Sir H. Davy succeeded in obtaining the basis of silica in a separate state, although he was not able to collect it and examine its properties in detail.§ The base of silica has been usually considered as a metal, and called *silicium*. But as there is not the smallest evidence for its metallic nature, and as it bears a close resemblance to boron and carbon, it is better to class it along with these bodies, and to give it the name of *silicon*.

3. Davy decomposed silica, by passing potassium in excess through it in a platinum tube. The potassium was converted into potash, through which was scattered the *silicon* under the form of a dark-coloured powder.

4. Silicon seems capable of bearing a very high temperature without undergoing any change. In this respect it resembles boron and carbon. Potash seems to dissolve a portion of it, and the solution acquires an olive colour. Silicon has the property of decomposing water, and of being converted into silica when it comes in contact with that body. Hence it was impossible to wash off the potash and obtain it in a separate state.

5. Silicon readily unites with oxygen, and is converted into silica. The object of the experiments of Berzelius and Stromeyer was to determine the quantity of oxygen which exists in silica. They mixed together iron filings from the purest iron that could be procured, silica, and charcoal,‖ in the proportions of 3 iron, 1·5 silica, and 0·66 charcoal. This mixture was put into a covered

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* Phil. Trans. 1808.

† Afhandlingar i Fysik, Kemi och Mineralogi, iii. 117. Published in 1810.

‡ Gilbert's Annalen, xxxvii. 335, and xxxviii. 321. Published in 1811.

§ Phil. Trans. 1814, p. 67.

‖ Stromeyer used lamp black to get rid of the alkali which charcoal contains.

crucible, and exposed for an hour to the greatest heat that could be raised in a blast furnace. By this means a combination of iron, silicon, and carbon, was formed. It was in the state of globules that had undergone complete fusion. When freed from the charcoal they were white and ductile, unless when they contained a great proportion of carbon. When dissolved in muriatic acid they gave out a greater proportion of hydrogen gas than the same weight of pure iron would have furnished. A substance remained undissolved, which retained the form of the globules, and which was silica, still mixed with some iron and carbon, from which it was separated by repeated calcination and digestion in muriatic acid. According to Stromeyer's experiments, the globules containing most silicon were composed of

Iron	85·3528
Silicon	9·2679
Carbon	5·3793
	100·0000

and the globules that contained the least silicon where composed of

Iron	96·1780
Silicon	2·2124
Carbon	1·6096
	100·0000*

The specific gravity of the iron was considerably reduced by combining it with silicon. The specific gravity of the iron employed by Stromeyer was 7·8285. The specific gravity of the alloy was never higher than 7·3241, nor lower than 6·7777. Its specific gravity was inversely as the proportion of silicon which it contained.

There could be no doubt, that in the alloy the silicon existed in a state of purity; but when the compound was dissolved in muriatic acid, the silicon combined with oxygen and was converted into silica. Both Berzelius and Stromeyer endeavoured to determine the quantity of oxygen which unites with silicon, and converts it into silica, by decomposing a given weight of the alloy, and then weighing each of the constituents separately. The excess of weight was considered to be the oxygen which had united with the silicon. This method would answer, if these experiments could be performed with rigid accuracy. But where an error amounting only to a small fraction of a grain would make a very material difference in the result, it is impossible to have much confidence in the conclusions. According to the experiments of Berzelius silica is composed of

Silicon -	54·66	to 52·25	-	53·455	-	100
Oxygen -	45·34	to 47·75	-	46·555	-	87·09
	100·00	100·00		100.000		

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* Gilbert's Annalen, xxxviii. 330.

According to Stromeyer, silica is composed of

Silicon	46·0069	100
Oxygen	53·9931	117·4
	100·0000	

The mean of these two sets of experiments gives us silica composed of Silicon 100—Oxygen 102·245.

Davy found that more than three parts of potassium were required to decompose one part of silica.[*] If we could be certain, that the whole of the oxygen that converts the potassium into potash is derived from the silica, it would follow from this experiment, that 100 parts of silica contain at least 60 of oxygen. Upon the whole, I conceive, that at present we may consider silica without any material error, as containing exactly half its weight of oxygen. From the analogy of carbonic acid and boracic acid, it is not improbable, that it consists of one atom of silicon united to two atoms of oxygen. In that case an atom of silicon would weigh two. But the natural silicates point out two as the weight of an atom of silica. Therefore silica must contain only one atom of oxygen, and an atom of silicon can weigh only one.

6. Nothing is known respecting the action of silicon on chlorine and iodine. No experiments having been hitherto made on the subject.

7. Silica has the property of combining with fluorine, and of forming a compound, which has received the name of *silicated fluoric acid.* But the term *fluosilicic acid* being more systematic, and being preferable in other respects, we shall make choice of it.

Fluosilicic acid was first discovered by Scheele.[†] It was afterwards obtained in the gaseous state by Dr. Priestley, and many of its properties investigated.[‡] A valuable set of experiments was published on it in 1812, by Dr. John Davy.[§]

To obtain this gas we have only to put a mixture of equal quantities of pounded fluor spar and glass into a retort, and to pour over it sulphuric acid in sufficient quantity to convert the whole into a paste. On the application of a gentle heat, the gas comes over in abundance, and may be collected in glass jars standing over mercury.

Fluosilicic acid gas is colourless, and possesses the mechanical properties of common air. It has a smell similar to muriatic acid, a very acid taste, and occasions a white smoke when it is allowed to escape into the atmosphere. It changes vegetable blues to red. No animal can breathe it, and no combustible will burn in it. Its specific gravity as determined by the experiments of Dr. John Davy is 3·5735.[‖] Hence at the temperature of 60°, and when the barometer stands at 30 inches, 100 cubic inches of it weigh 108·992 grains.

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[*] Phil. Trans. 1814, p. 67.

[†] Scheele's Memoires de Chimie, i. 24.

[‡] Priestley on Air, ii. 339.

[§] Phil. Trans. 1812, p. 352.

[‖] Ibid. p. 354.

Dr. John Davy found that water was capable of absorbing 263 times its bulk of this gas. But as water has the property of decomposing it and of precipitating silica, this circumstance doubtless diminishes the action of the liquid. From other circumstances, he concludes that water absorbs as much of this gas as of muriatic acid gas. In that case water will be capable of absorbing 515 times its bulk of this gas.

Dr. J. Davy analysed this gas by passing it into liquid ammonia, which has the property of throwing down the whole of the silicon that it contains in the state of silica. From 40 cubic inches of the gas, he procured 27·2 grains of silica. Now 40 cubic inches weigh 43·597 grains. Hence he concluded that the gas is composed of

Silica	27·2	62·4	165·88
Fluoric acid	16·397	37·6	100·00

But if this acid be a compound of silicon and fluorine, as has been rendered probable by Sir H. Davy, then in order to have its composition, we must subtract the oxygen from the silica, and add it to the fluoric acid, in order to convert it into fluorine. The acid will then be composed of

Silicon	13·6	100
Fluorine	29·997	220·6

If the weight of an atom of silicon be a little less than one, and that of fluorine a little more than two, as is probably the case, it will follow from this analysis, that fluosilicic acid is a compound of one atom of silicon and one atom of fluorine.

When fluosilicic acid gas comes in contact with water, it is absorbed by that liquid, and at the same time deposites a portion of its silicon in the state of silica. From the experiments of Dr. J. Davy it appears that 44 cubic inches of the gas when thus absorbed by water deposit 7·33 grains of silica, equivalent to 3.665 grains of silicon. Now 44 cubic inches of fluosilicic acid gas weigh 47·956 grains, and must be composed of silicon 14·96—fluorine 32·996. Hence the acid portion absorbed by the water must be composed of

Silicon	11·295	100
Fluorine	32·996	292·1

Which perhaps may be two atoms of silicon united to three atoms of fluorine. But on this obscure subject nothing better than conjecture can be at present offered.

SECTION V.

OF PHOSPHORUS.

Phosphorus may be procured by the following process: Let a quantity of bones be burnt, or, as it is termed in chemistry, *calcined*, till they cease to smoke, or to give out any odour, and let them afterwards be reduced to a fine powder. Put 100 parts of this powder into a basin of porcelain or stoneware, dilute it with four times its weight of water, and then add gradually (stirring the mixture after every addition) 40 parts of sulphuric acid. The mixture becomes hot, and a vast number of air bubbles are extricated.[*] Leave the mixture in this state for 24 hours; taking care to stir it well every now and then with a glass or porcelain rod to enable the acid to act upon the powder.[†]

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 basin; 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 basin below, being of no use, may be thrown away.

Into the liquid contained in the porcelain basin, 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 an earthenware retort. 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 the appearance of melted wax, and which congeals under the water. This substance is *phosphorus*.

It was accidentally discovered by Brandt, a chemist of Hamburgh, in the year 1669,[§] as he was attempting to extract from human urine a liquid capable of converting silver into gold. He showed a specimen of it to Kunkel, a German chemist of considerable eminence, who mentioned the fact as a piece of news to one Kraft, a friend of his at Dresden. Kraft immediately repaired to Hamburgh, and purchased the secret from Brandt for 200 dollars, exacting from him at the same time a promise not to reveal it to any other person. Soon after, he exhibited his phosphorus publicly in Britain and France, expecting doubtless that it would make his fortune. Kunkel, who had mentioned to Kraft his intention of getting possession of the process, being vexed at the treacherous

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

[†] 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.

[§] Homberg, Mem. Par. x. 84. An account of it is published in the Philosophical Transactions for 1681, first by Sturmius, and then by Dr. Slare.

conduct of his friend, attempted to discover it himself; and about the year 1674 he succeeded, though he only knew from Brandt that urine was the substance from which phosphorus had been procured.[*] Accordingly he is always reckoned, and deservedly too, as one of the discoverers of phosphorus.

Boyle likewise discovered phosphorus. Leibnitz indeed affirms, that Kraft taught Boyle the whole process, and Kraft declared the same thing to Stahl. But surely the assertion of a dealer in secrets, and one who had deceived his own friend, on which the whole of this story is founded, cannot be put in competition with the affirmation of a man like Boyle, who was not 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 for 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 stoneware 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 devoted himself at a very early period to the investigation of phosphorus, soon after published a much more expeditious and productive process; for the first hint of which he was indebted to Henkel. It consisted in mixing a salt consisting chiefly of lead with the inspissated urine. He even found that urine contained a peculiar salt,[¶] which yielded phosphorus when heated with charcoal.[**]

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

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

[†] 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.

[‖] Mem. Par. 1737, p. 342.

[¶] Known at that time by the name of fusible salt of urine, now called phosphate of ammonia.

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

[††] Bergman's Notes on Scheffer, p. 208. I quote the edition of 1796.

usual process followed by manufacturers of phosphorus is an improvement on that of Scheele.

Soon after the discovery of phosphorus, many experiments on it were made by Slare and Boyle. Hoffman published a dissertation on it, containing some curious facts, in 1722; but Margraf was the first who investigated its effects upon other bodies, and the nature of the combinations which it forms. The subject was resumed by Pelletier, and continued with much industry and success. Lavoisier's experiments were still more important, and constitute indeed a memorable era in chemical science.

Many important experiments on phosphorus have been made still more lately by Davy, and by Gay-Lussac and Thenard. Thenard[*] and Vogel[†] have made researches on the red powder which remains when phosphorus is burnt, and upon the changes produced on it by the action of light. Dulong[‡] and Berzelius[§] have examined its combination with oxygen; while I have made some experiments on the compounds which it forms with hydrogen.[‖]

1. Phosphorus is usually of a light amber colour and semi-transparent; though when carefully prepared it is nearly colourless and transparent.[¶] 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, according to Pelletier, when heated to 99°.[**] In my trials I found that a temperature of 108° was requisite to produce complete fusion. 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°.[††]

3. Phosphorus is dissolved in a small proportion by alcohol, ether, and oils. The solutions are transparent. When the alcohol or ether is mixed with water, the phosphorus separates and burns

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[*] Ann. de Chim. xxxvi. 109.

[†] Ibid. xxxv. 225.

[‡] Ann. de Chim. et Phys. ii. 141.

[§] Ibid. p. 151, 218, and 329.

[‖] Annals of Philosophy, viii. 87.

[¶] Thenard informs us that when melted and then suddenly cooled, it becomes quite black. But again resumes its original appearance when kept melted for a short time. Ann. de Chim. lxxi. p. 109. There seems to have been something peculiar about the phosphorus which he employed.

[**] Jour. de Phys. xxxv. 380.

[††] Pelletier, Jour. de Phys. xxxv. 381.

on the surface of the liquid. When the oily solution of phosphorus is poured upon paper and carried into a dark room, it shines vividly, provided the temperature be above 60°. But at lower temperatures the light is scarcely perceptible.

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

II. Phosphorus has the property of combining with oxygen at least in four proportions, and of forming four compounds, which have received the following names.

1. Oxide of phosphorus. 3. Phosphorous acid.
2. Hypophosphorus acid. 4. Phosphoric acid.

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

2. 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.

3. 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 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

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[*] Ann. de Chim. xxvii. 87.

[†] Nicholson's Journal, iii. 85.

[‡] [It seems to have been of use in typhoid disorders.—C.]

[§] Fourcroy and Vauquelin, Ann. de Chim. xxi. 196.

[||] Stahl's Three Hundred Experiments.

1740. He attempted to produce phosphorus by combining together phlogiston and muriatic acid: but 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.

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 Lavoisier published those celebrated experiments which threw so much light on the nature and composition of acids.†

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

Lavoisier drew, as a conclusion, from his experiments that phosphoric acid is composed of 100 phosphorus and 154 parts of oxygen. But his mode of experimenting was not sufficiently precise to merit confidence. Rose endeavoured to obtain more accurate results by acidifying phosphorus by means of nitric acid. According to him phosphoric acid is composed of 100 phosphorus and 114·75 oxygen.§ But this mode of experimenting is worse than that employed by Lavoisier. I have repeated Rose's experiment at least a dozen of times, and no two results coincided with

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* Margraf's Opusc. i. 56.

† Mem. Par. 1778 and 1780.

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

§ Gehlen's Journal fur die Chemie, Physik und Mineralogie, ii. 309.

each other. But there is another method by which we can obtain the composition of this acid with considerable accuracy, by examining the composition of the neutral salts which it forms with the different bases. It will be seen in a subsequent part of this work that the numbers which represent the weight of an atom of each of the following bodies are

Yellow oxide of lead	14	Soda - - -	4
Barytes - - -	9·75	Lime - - -	3·625

From the analyses of Berzelius, and my own analyses, it follows that the neutral salts formed of these bases and phosphoric acid are composed as follows:

Phosphate of lead.

Acid	100	4·45
Base	314	14

Phosphate of barytes.

Acid	100	4·54
Base	214·46	9·75

Phosphate of soda.

Acid	100	4·57
Base	87	4

Phosphate of lime.

Acid	100	4·53
Base	80	3·625

In these little tables the number above the weight of an atom of the base represents the weight of an atom of phosphoric acid. Now the greatest of these numbers is 4·57, and the smallest of them is 4·45. The mean of the whole four is 4·527, which must be very nearly the true weight of an atom of phosphoric acid. We shall therefore take 4·5 as representing that weight. It will appear in a subsequent part of this section that 1·5 represents the weight of an atom of phosphorus; therefore phosphoric acid must be a compound of

Phosphorus	1·5	100
Oxygen	3	200

Probably the reason why the quantity of oxygen found experimentally to combine with phosphorus is so small, has been that the whole phosphorus was not converted into phosphoric acid.

4. Phosphorus acid was first obtained in a state of purity by Sir H. Davy. When phosphorus is made to pass through *corrosive sublimate*[*] a liquid is obtained which was first discovered by Gay-Lussac and Thenard, and which Davy showed to be a protochloride of phosphorus. When this liquid is mixed with water it is decomposed and converted into muriatic acid and phosphorous acid. The muriatic acid is driven off by a moderate heat, and pure phosphorous acid remains behind, combined with some water.[†] It will appear in a subsequent part of this section that phosphorous acid is composed of 1·5 phosphorus and 2 oxygen. Hence its constituents are—Phosphorus, 100—Oxygen, 133⅓.

5. Hypophosphorus acid was discovered in 1816 by Dulong.[‡] When phosphorus is united to lime or barytes it forms a well known compound called *phosphuret of lime* or *of barytes*, which will be described hereafter. When these compounds are thrown into wa-

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[*] A substance which will be described in a subsequent section.

[†] Phil. Trans. 1812, p. 407.

[‡] Ann. de Chim. et Phys. ii. 141.

ter that liquid is decomposed, two acids are formed by the combination of the oxygen of the water with a portion of the phosphorus; while another portion of the phosphorus unites to the hydrogen and flies off in the state of gas. The two acids are the phosphoric and hypophosphorous, both of which combine with the lime or barytes, forming *phosphate* and *hypophosphite* of lime or barytes. The first of these salts is insoluble in water; but the second dissolves in that liquid. M. Dulong put a quantity of phosphuret of barytes into water. After the evolution of phosphureted hydrogen gas was at an end, he filtered the liquid. It then contained a quantity of hypophosphite of barytes in solution. Into this solution he dropt cautiously sulphuric acid as long as any precipitate fell. By this means he threw down the whole of the barytes without adding any excess of sulphuric acid. The clear liquid being decanted off consisted of a solution of hypophosphorous acid in water. Dulong endeavoured to determine the composition of this acid by converting it into phosphoric acid by the action of chlorine. He considers it as composed of—Phosphorus, 100—Oxygen, 37·44—But his method does not seem susceptible of much precision, and indeed is too complicated for accuracy. I have little doubt, from experiments to be related in a subsequent part of this section, that hypophosphorous acid is composed of

Phosphorus	-	1·5	-	100
Oxygen -	-	1	-	66·66

Thus the three acids of phosphorus are composed as follows:

		Phosphorus.		Oxygen.
Hypophosphorous acid	- -	1·5	-	1
Phosphorous acid	- - -	1·5	-	2
Phosphoric acid	- - -	1·5	-	3

Or the first consists of one atom phosphorus united to one atom oxygen; the second of one atom phosphorus united to two atoms oxygen; and the third of one atom phosphorus united to three atoms oxygen.

6. Though pure phosphorus does not take fire till it be heated to 141°, 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 converted into an acid liquor.* When a little phosphorus is thus oxidized in a small tin box by heating it, the oxide acquires the property of taking fire when exposed to the air. In this state it is often used to light candles under the name of *phosphoric matches;* the phosphorus being sometimes mixed with a little oil, sometimes with sulphur.

When phosphorus is long acted on by water, it is covered at last with a white crust, which is also considered as an oxide of phosphorus; but it differs considerably from the oxide just described. It is brittle, less fusible, and much less combustible than phosphorus itself.† Phosphorus, when newly prepared, usually contains some of this last oxide of phosphorus mixed with it; but it may be easily separated by plunging the mass into water heated to about 100°. The phosphorus melts, while the oxide remains unchanged, and swims upon the surface of the melted phosphorus.

The red substance formed when phosphorus burns in a confined place, and which remains behind after combustion in glass jars, is also considered as an oxide of phosphorus. All these bodies contain very little oxygen. I have endeavoured to determine the proportion, but my attempts were not attended with success.

III. Phosphorus has the property of uniting in two proportions with chlorine, and of forming two compounds, which have received the names of *protochloride* and *perchloride* of phosphorus.‡

1. When phosphorus is introduced into chlorine gas it takes fire and burns with a pale bluish white flame, giving out but little light. A white matter sublimes and coats the inside of the glass vessel. If the quantity of phosphorus be considerable there is formed at the same time towards the end of the combustion a small quantity of liquid. The combustion of phosphorus in chlorine had been repeated a great number of times by almost every chemist ever since the discovery of chlorine gas. But nobody thought of examining the nature of the products till Sir H. Davy advanced the theory that chlorine is a simple body.

2. The *protochloride of phosphorus* was first prepared in quantities, and examined by Gay-Lussac and Thenard.§ But Davy first ascertained its constituent parts.‖ It is easily obtained by passing phosphorus through *corrosive sublimate* heated in a glass or porcelain tube. The method is to take a glass tube shut at one end, to put into its bottom a quantity of phosphorus, and then to fill up a considerable part of the tube with corrosive sublimate. Heat the portion of the tube containing the sublimate; then, by applying a few bits of red hot charcoal to the extremity of the tube cause the phosphorus to pass in vapour through the sublimate. A bent

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

[†] Ibid.

[‡] Sir H. Davy has given to these bodies the names of *phosphorane* and *phosphorana*. But his momenclature has not been adopted by chemists. See Phil. Trans. 1812, p. 412.

[§] Recherches Physico-chimiques, ii. 98, 176.

[‖] Phil. Trans. 1812, p. 406.

tube must be luted to the other extremity of the glass tube, which must pass into a proper receiver. A liquid collects in this receiver, which is the *protochloride of phosphorus.*

This liquid is colourless like water, smokes strongly when it comes into the atmosphere, and has an acid and very caustic taste. Its specific gravity is 1·45.[*] It may be kept in close vessels without alteration. But in the open air it is speedily dissipated, leaving behind it a quantity of phosphorus. It has the property of dissolving phosphorus. When paper is dipped into this solution and exposed to the air it speedily evaporates, leaving a quantity of phosphorus which soon takes fire and burns the paper. It was in this state that it was first obtained by Gay-Lussac and Thenard. When dropped into water it is converted into muriatic and phosphorus acids. This liquid by evaporation furnishes a thick fluid, which crystallizes on cooling and forms transparent parallelopipedons. These crystals are compounds of phosphorus acid and water. When these crystals are distilled in close vessels they give out a gas which is a compound of hydrogen and phosphorus, and which may be called *bihidroguret of phosphorus.* Phosphoric acid remains behind in the retort. From Davy's experiments it follows, that these crystals are composed of 4 parts phosphorus acid and 1 part of water.[†] He endeavoured to ascertain the composition of protochloride of phosphorus by dissolving a given quantity of it in water, and throwing down the muriatic acid formed by means of nitrate of silver. 13·6 grains of protochloride treated in this way gave 43 grains of horn silver.[‡] Now 43 grains of horn silver contain 10·62 grains of chlorine. Hence the protochloride is composed of

Chlorine	10·62	5·34	4·5
Phosphorus	2·98	1·5	1·26

This analysis shows us that the protochloride is a compound of 1 atom chlorine and 1 atom phosphorus. But the numbers which we have fixed upon for the weight of an atom of chlorine (4·5) and of phosphorus (1·5) do not correspond well with the experiment of Davy. Had the quantity of horn silver been only 41$\frac{1}{3}$ instead of 43 grains, the experiment would have tallied exactly with our numbers. Now this is an error that might have been easily committed in an experiment made upon so small a scale.

3. The perchloride of phosphorus may be formed by burning phosphorus in dry chlorine gas, in the proportion of one grain of the former to about 12 cubic inches of the latter. It is a snow-white substance, exceedingly volatile, rising at a temperature below that of boiling water. Under pressure it may be fused, and then crystallizes in prisms that are transparent. When thrown into water it acts with great violence, the water is decomposed, and phosphoric acid and muriatic acid formed. It seems to possess

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[*] Davy, Phil. Trans. 1812, p. 406.

[†] Ibid. p. 408.

[‡] Ibid. p. 407.

acid properties, for its vapour reddens paper stained blue with litmus, and burns when lighted in the open air. When passed through a red hot tube with oxygen gas it is decomposed, phosphoric acid being formed and chlorine disengaged. From the experiments of Davy, to whom we are indebted for all the preceding facts, it follows that 1·5 grain of phosphorus, when converted into perchloride, combines with 10 grains of chorine.* Hence we see that it is a compound of 1 atom phosphorus and 2 atoms chlorine. If our numbers for the weight of an atom of phosphorus (1·5) and of chlorine (4·5) be accurate, then it ought to be a compound of—Phosphorus 1·5—Chlorine 4·5 × 2 = 9—Now this differs but little from the results obtained by Davy.

IV. Phosphorus has the property of combining in two proportions with iodine, and of forming two compounds, which may be called *protiodide of phosphorus* and *periodide of phosphorus*. These substances were first mentioned by Sir H. Davy;† but for the first accurate examination of them we are indebted to Gay-Lussac.‡

1. When one part of phosphorus and 10·41 parts of iodine are mixed together in a thin glass tube they unite with great rapidity, producing much heat but no light. The compound is a solid body of a reddish brown colour. It melts at 212° and is volatilized when the temperature is raised somewhat higher. When thrown into water it dissolves, and is converted into hydriodic acid and phosphorous acid.§ This compound is obviously composed of

Phosphorus	1	1·5
Iodine	10·41	15·625

Or of one atom of phosphorus and one atom iodine. It is therefore a *protiodide of phosphorus*.

2. When 1 part of phosphorus and 20·82 parts of iodine are mixed together, they combine likewise with violence and the evolution of a great deal of heat. The compound formed is black, and melts at the temperature of 115°. It dissolves in water with great heat, but the solution usually has a dark colour; owing, I believe, to the whole of the phosphorus not entering into combination. The consequence is an excess of iodine which is dissolved by the hydriodic acid formed. For, in my trials, there always remained a small portion of phosphorus undissolved after the action of the water. This compound, supposing it in the proportions above stated, is composed of

Phosphorus	1	1·5
Iodine	20·82	15·625 × 2 = 31·25

Or it is composed of 1 atom phosphorus united to 2 atoms iodine.

V. Nothing is known respecting the combination of phosphorus and fluorine.

VI. Phosphorus plunged into azotic gas is dissolved in a small

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* Phil. Trans. 1812, p. 406. † Ibid. 1814, p. 79. ‡ Ann. de Chim. xci. p. 9.

§ Gay-Lussac's proportions are 1 phosphorus and 8 iodine. But this is too small a proportion of iodine, as I find by experiment. To this I ascribe the phosphureted hydrogen gas which exhaled in his experiments.

proportion. Its bulk is increased about $\frac{1}{40}$,[*] 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°.[†]

VII. Phosphorus combines with hydrogen in two proportions and forms, two gaseous compounds which have received the names of *phosphureted hydrogen* and *hydrophosphoric gas*. But the terms *hydroguret of phosphorus* and *bihydroguret of phosphorus* would be more systematic.

1. Phosphureted hydrogen gas, the first of these compounds, was discovered in 1783 by M. Gengembre, while heating a mixture of liquid potash and phosphorus in a small retort. He made some experiments on this remarkable gas, and published an account of its properties.[‡] Some experiments were made upon it in 1786 by Mr. Kirwan,[§] who discovered it without being aware that it had been already made known to chemists by M. Gengembre. In 1791, M. Raymond pointed out a method of preparing it in greater quantities by heating a mixture of phosphorus and quicklime.[‖] And, in 1799, he described the properties of a solution of this gas in water.[¶] Mr. Dalton, in his *New System of Chemical Philosophy*, published in 1810, gives an account of a set of experiments to which he subjected it in order to determine its nature and composition.[**] And, in 1816, I published a set of experiments which I had made on it.[††]

2. Phosphureted hydrogen may be obtained pure by the following process: Fill a small retort with water, acidulated by muriatic acid, and then throw into it a quantity of phosphuret of lime in lumps. Plunge the beak of the retort under water, and place over it an inverted jar filled with that liquid. Phosphureted hydrogen gas is extricated in considerable quantity and soon fills the glass jar. Half an ounce of phosphuret of lime yields about 70 cubic inches of this gas.[‡‡]

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[*] Berthollet.

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

[‡] Memoires des Savans Etrangers, x. 651.

[§] Phil. Trans. 1786, p. 118.

[‖] Ann. de Chim. x. 19.

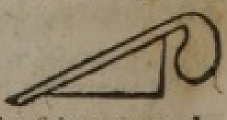
[¶] Ibid. xxxv. 225.

[**] Vol. II. p. 457.

[††] Annals of Philosophy, viii. 87.

[‡‡] [This is a troublesome and expensive mode of procuring it; for it is not easy to make good phosphuret of lime, or in other than small quantities.

Into a small glass retort capable of holding about a quarter of a pint, put a moderately strong solution of caustic potash, the causticum commune of the shops: let the solution fill the retort about three parts full: put in about a quarter of an inch of the common sticks of phosphorus: it is not necessary to cut it. Let the retort be fastened on a wooden stand and a lamp heat applied under the retort. The beak of the retort should be immersed in a hot solution of potash in a basin, so that when the gas ceases for a short time to come over, the retort may not break by means of cold water filling the vacuum. In this way the gas is easily and safely procured.



Mr. John Dalton (Ann. of Phil. for Jan. 1818, p. 8.) observes, that the phosphureted hydrogen is not obtained pure by this means, if the phosphuret of lime has been exposed for a few hours to the atmosphere, in which case, the gas procured will contain from 50 to 80 per cent. of free hydrogen. The pure phosphureted hydrogen, may be separated by liquid oxymuriat of lime, and the hydrogen left behind.—C.]

3. Phosphureted hydrogen gas is colourless and possesses the mechanical properties of air. It has a smell similar to that of onions, and an exceedingly bitter taste. It may be kept in pure water without alteration; but in water containing common air it soon loses a portion of its phosphorus, and its properties are altered in consequence. Its specific gravity is 0·9022. Hence at the temperature of 60°, and when the barometer stands at 30 inches, 100 cubic inches of it weigh 27·517 grains.

When electric sparks are passed through this gas for some time the phosphorus is deposited, and pure hydrogen gas remains. But the volume of the gas is not altered by this process. Hence it follows that phosphureted hydrogen gas consists of hydrogen gas, holding a quantity of phosphorus in solution. This quantity is discovered by subtracting the specific gravity of hydrogen gas from that of phosphureted hydrogen.

Specific gravity of phosphureted hydrogen	0·9022
——————hydrogen gas - -	0·0694
Phosphorus - - - - - =	0·8328

Therefore phosphureted hydrogen gas is composed of hydrogen 694 or 1—phosphorus 8328 or 12; so that phosphureted hydrogen contains $\frac{1}{13}$th of its weight of hydrogen and $\frac{12}{13}$ths of phosphorus. Now, if we reckon the weight of an atom of hydrogen 0·125, and that of an atom of phosphorus 1·5; it is obvious that phosphureted hydrogen is composed of 1 atom hydrogen and 1 atom phosphorus, for ·125 × 12 = 1·5.

When phosphureted hydrogen comes in contact with common air, it takes fire and burns with great splendour. Yet in a narrow tube it may be mixed with oxygen gas without undergoing spontaneous combustion. But it is deprived of its phosphorus without undergoing any alteration in its bulk. For complete combustion, it requires either 1 volume of oxygen gas or 1½ volume.* In both cases the two gases over water disappear altogether. Now half a volume of the oxygen gas, in both cases, must unite to the hydrogen and form water. So that the phosphorus, in phosphorated hydrogen, combines either with ½ volume or with 1 volume of oxygen gas. In the first case, I suppose that hypophosphorous acid is formed: In the second case, phosphorous acid.

When a volume of phosphureted hydrogen gas is mixed with 3 volumes of nitrous gas, and an electric spark passed through the mixture, a detonation takes place, and there remains 1½ volume of azotic gas. Now nitrous gas contains half its bulk of oxygen. Therefore, in this case, the phosphureted hydrogen has combined

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* [According to Dalton, Ann. of Ph. Jan. 1818, p. 8, it requires two volumes of oxygen. Phosphoric acid and water are formed. Water absorbs $\frac{1}{8}$th of the pure gas. This gas explodes when mixed with 3½ volumes (not 3, as Thomson says) of nitrous gas, when an electric spark is passed through it, or when a bubble of oxygen is let up to the mixed gases. Dalton.—C.]

with 1½ volume of oxygen. If these two gases be mixed over water and a bubble of oxygen gas be let up to them, a detonation immediately takes place.

When 1 volume of phosphureted hydrogen is mixed with 3 volumes of protoxide of azote, and an electric spark passed through the mixture, a detonation takes place, and there remains 3 volumes of azotic gas. But protoxide of azote is composed of 1 volume of azote + half a volume of oxygen condensed into 1 volume; so that 3 volumes, if decomposed, would constitute 3 volumes of azote and 1½ volume of oxygen gas. Hence, in this case also, phosphureted hydrogen has combined with 1½ volume of oxygen.

When phosphureted hydrogen gas is mixed with chlorine gas, it burns with a greenish yellow flame; and when the two gases are mixed in the proportion of 1 volume of the former to 3 of the latter, they disappear entirely, being converted into muriatic acid, and a brown matter which speedily dissolves in water, and which is doubtless a bichloride of phosphorus.

When iodine is heated in phosphureted hydrogen gas, iodide of phosphorus is formed, and probably hydriodic acid; for when water is present the bulk of the gas diminishes 1 third.

Water, according to the experiments of Dr. Henry, dissolves rather more than 2 per cent. of this gas. The water acquires a yellow colour, an intensely bitter taste, and a smell similar to that of the gas. It produces no alteration on vegetable blues, but precipitates silver, mercury, and copper, from their solutions, of a dark colour.

4. Hydrophosphoric gas or bihydroguret of phosphorus was first particularly examined by Sir H. Davy, in 1812.*

He obtained it by heating crystallized phosphorous acid. It may be procured, also, by exposing phosphureted hydrogen to the direct rays of the sun. A quantity of phosphorus is deposited, and the gas is changed into *bihydroguret of phosphorus*.

This gas is colourless, and possesses the mechanical properties of common air. Its smell is similar to that of phosphureted hydrogen, but not so disagreeable. When sulphur is sublimed in this gas the volume is doubled, and 2 volumes of sulphureted hydrogen gas are formed. When potassium is heated in it, the volume is also doubled. The potassium combines with phosphorus, and the residual gas is pure hydrogen. Hence it is obvious that it is a compound of two volumes of hydrogen gas, united with the same quantity of phosphorus that exists in a volume of phosphureted hydrogen gas, and condensed into 1 volume. Hence its composition must be, phosphorus 12 - - 1·5—hydrogen 2 - - 0·125 × 2. Thus we see that it is a compound of 1 atom phosphorus and 2 atoms hydrogen.

It is obvious, also, that its specific gravity must be equal to the

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* Phil. Trans. 1812, p. 406.

specific gravity of phosphureted hydrogen gas, added to that of hydrogen gas, or $0{\cdot}9022 + 0{\cdot}0694 = 0{\cdot}9716$. Sir Humphry Davy found it 0·87. But his experiment was made upon a small scale, and only once repeated. Hence an error of $\frac{1}{10}$ can hardly be considered as excessive.

This gas does not burn spontaneously when it comes into common air or oxygen gas; but if it be mixed with oxygen and heated to 300°[*] it explodes. 1 volume of this gas requires either $1\frac{1}{2}$ or 2 volumes of oxygen gas for complete combustion. If the first proportion be used, some phosphorus is apt to be precipitated. Now as the gas contains 2 volumes of hydrogen, it is obvious that 1 volume of the oxygen goes to the formation of water. The remaining $\frac{1}{2}$, or 1 volume of oxygen, must have united with the phosphorus. Now this is just the quantity which the phosphorus in a volume of phosphureted hydrogen gas requires. Hence the reason for estimating the quantity of phosphorus in a volume of hydroguret, and bihydroguret of phophorus as the same.

When mixed with chlorine gas it burns spontaneously with a white flame. According to Davy, 1 volume of bihydroguret of phosphorus requires 4 volumes of chlorine gas for complete combustion. Two of these volumes uniting to the hydrogen go to the formation of muriatic acid. The other two must combine with the phosphorus, and form a perchloride of phosphorus which would be speedily converted into muriatic acid and phosphoric acid, by decomposing water. So that the products, in this case, are precisely the same as when phosphureted hydrogen is burnt in chlorine.

According to Davy, water absorbs $\frac{1}{8}$th of its volume of this gas. So that the absorbability of this gas and olefiant gas, by water, is the same.

Thus we have two compounds of phosphorus and hydrogen, composed as follows,

	Phosphorus.	Hydrogen.
Hydroguret of phosphorus of	1 atom	+ 1 atom
Bihydroguret of phosphorus of	1	+ 2

VIII. Phosphorus has the property likewise of uniting with carbon, and of forming a compound, called *phosphuret of carbon.* Its existence was first recognised by M. Proust. He gave that name to the red substance which remains when new made phosphorus is strained through shamois leather.[†] It is not improbable that this red substance may frequently contain phosphuret of carbon, especially as the same assertion has been subsequently made by Thenard.[‡] But I have never been able to find any such substance in it.[§] The experiments of Vogel appear to have been equally unsuccessful.[||] But I have never failed to procure it by the following method.

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[*] Davy. [†] Ann. de Chim. xxxiv. 44. [‡] Ann. de Chim. lxxxi. 109.

[§] Twice indeed on distilling this substance I obtained a residue of charcoal. But I never could succeed in obtaining the phosphuret in a separate state.

[||] Ann. de Chim. lxxxv. 225.

Allow phosphuret of lime to remain in water till it has given out all the phosphureted hydrogen gas which it is capable of evolving. Then add to the liquid a considerable excess of muriatic acid, agitate for a few moments, and throw the whole upon a filter. Phosphuret of carbon will remain upon the filter. Let it be properly washed and dried.

Phosphuret of carbon thus obtained is a soft powder of a dirty lemon yellow colour, without either taste or smell. When left in the open air it very slowly imbibes moisture, emits the smell of carbureted hydrogen, and acquires an acid taste. Hence it decomposes the water which it absorbs, and its phosphorus is slowly converted into phosphorous acid. It does not melt when heated; nor is it altered, though kept in a temperature higher than that of boiling water. It burns below a red heat, and when heated to redness, gradually gives out its phosphorus. The charcoal remains behind in the state of a black matter, being prevented from burning by a coating of phosphoric acid with which it is covered. When the powder is thrown over the fire in small quantities at a time, it burns in beautiful flashes. It is composed of 1 atom phosphorus, and 1 atom carbon, or by weight of

Phosphorus -	1·5 -	200
Carbon -	0·75 -	100

The substance, when distilled, gives no traces of water.*

IX. Nothing is known respecting the combination of phosphorus with boron and silicon.

SECTION VI.

OF SULPHUR.

Sulphur, distinguished also by the name of brimstone, was known in the earliest ages. Considerable quantities of it are found native, especially in the neighbourhood of volcanoes, and it is procured in abundance by subjecting the mineral called *pyrites* to distillation. The ancients used it in medicine, and its fumes were employed in bleaching wool.†

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

It is a non-conductor of electricity, and of course becomes electric by friction. Its specific gravity is 1·990. The specific gravity of native sulphur is 2·0332.‡

Sulphur undergoes no change by being allowed to remain exposed to the open air. When thrown into water, it does not melt

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* Annals of Philosophy, viii. 157.

† Pliny, lib. xxxv. c. 15.

‡ Brisson. Lavoisier's Elements, p. 577.

as common salt does, but falls to the bottom, and remains there unchanged: It is therefore insoluble in water.

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

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

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.

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 experiment be made in a glass vessel, or upon a flat plate of iron, the crystals will be perceived beginning to shoot when the temperature sinks to 220°. Sulphur is frequently found native in fine large crystals. The primitive form of the crystals is an octahedron, with scalene triangular faces. It consists of two pyramids joined together, base to base. These bases constitute a rhomboid, the longer diagonal of which is to the shorter, as 5 to 4. The perpendicular drawn from the centre of this rhomboid to the edge is to the height of the pyramid as 1 to 3.‡

4. Alcohol dissolves a small portion of sulphur. So does sulphuric ether and oils.

II. Sulphur combines, at least, in two proportions with oxygen, and forms two compounds which have been long known, and which have received the names of *sulphurous* and *sulphuric acids.*

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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.

† Such vessels are usually called *receivers* or *flasks* by chemists.

‡ Haüy's Mineralogie, iii. 278.

1. When sulphur is heated to the temperature of 560° in the open air, it takes fire spontaneously, and burns with a pale blue flame, and at the same time emits a great quantity of fumes of a very strong suffocating odour. When set on fire, and then plunged into a jar full of oxygen gas, it burns with a bright violet coloured flame, and at the same time emits a vast quantity of fumes. If the heat be continued long enough, the sulphur burns all away without leaving any ashes or residuum. If the fumes be collected, they are found to consist of sulphurous acid. By combustion, then, sulphur is converted into acid. This fact was known several centuries ago; but no intelligible explanation was given of it till the time of Stahl.

According to him, sulphur is a compound of sulphuric acid and phlogiston. By combustion the phlogiston is driven off, and the acid remains behind. The experiments by which he endeavoured to establish these opinions were long considered as satisfactory. But it was observed that sulphur will not burn unless air be present, and that sulphuric acid is heavier than the sulphur from which it was produced. These facts were incompatible with the hypothesis of Stahl. Lavoisier first explained them by showing that, during combustion, sulphur unites with the oxygen of the air, and that the acid formed is exactly equal to the weight of the sulphur and oxygen which disappeared. Hence he concluded that the acid formed is a compound of these two bodies—an opinion which is now universally acceded to.

2. Sulphurous acid is formed, when sulphur is burnt, either in the open air, or in oxygen gas. But the best way to procure it in quantities, is to heat a mixture of sulphuric acid and mercury in a small retort, and receive the gaseous product over mercury. This gas is sulphurous acid.

This acid was first examined by Stahl, who gave it the name of *phlogisticated sulphuric acid.* Scheele in 1774 pointed out a method of procuring it in quantities.* Dr. Priestley, about the same time, obtained it in the gaseous form, and ascertained many of its properties.† Berthollet examined it in 1782 and 1789.‡ Fourcroy and Vauquelin published a detailed set of experiments on it in 1797.§ Some experiments on it by me were published in 1803.||

Sulphurous acid gas is colourless, and possesses the mechanical properties of common air. Its smell is exceedingly suffocating and disagreeable, being precisely similar to the smell of burning sulphur. Its taste is intensely acid and sulphureous. It converts vegetable blues to red, and then gradually destroys them. Its specific gravity, according to Davy's experiments, is 2·2293.¶ If we suppose it composed of a volume of vapour of sulphur, and a volume of oxygen gas, condensed into one volume, its specific gravity ought to be 2·2222. Hence 100 cubic inches of it at the tempera-

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* Scheele's Memoires de Chymie, i. 43.

† Priestley on Air, ii. 295.

‡ Mem. Par. 1782, and Ann. de Chim. ii. 54.

§ Ann. de Chim. xxiv. 229.

|| Nicholson's Journal, vi. 93.

¶ Phil. Trans. 1812, p. 412.

ture of 60°, and when the barometer stands at 30 inches, will weigh 67·771 grains.

Water absorbs 33 times its bulk of this gas, according to my experiments; but according to Theodore de Saussure, that liquid takes up 43·78 times its bulk of it.*

I ascertained, by experiment, that the quantity of oxygen in sulphurous acid is $\frac{2}{3}$ of that in sulphuric acid.† Now we shall see immediately that sulphuric acid is composed of 100 sulphur + 150 oxygen. Hence it follows that sulphurous acid is composed of 100 sulphur + 100 oxygen. There is another experiment which demonstrates, in a very satisfactory manner, the composition of this acid. Sulphureted hydrogen is a gas which will be described in the subsequent part of this section. It contains its volume of hydrogen, holding a quantity of sulphur in solution. Now a volume of this gas requires 1½ volume of oxygen for complete combustion. The substances formed are water and sulphurous acid. The half volume of the oxygen goes to the formation of water, and combines with the hydrogen. The one volume of oxygen combines with all the sulphur, and forms sulphurous acid. The sulphur, in a volume of sulphureted hydrogen, is obtained by subtracting the specific gravity of hydrogen gas from that of sulphureted hydrogen.

Sp. gravity of sulphureted hydrogen - -	1·180
——————— hydrogen gas - - -	0·069
Sulphur in the gas - - - - =	1·111

But the specific gravity of oxygen gas is 1·111. Hence it follows that sulphurous acid is composed of—Sulphur 1·111 or 1—Oxygen 1·111 or 1.

3. Sulphuric acid is obtained by burning a mixture of 7 parts sulphur and 1 part nitre, in large chambers lined with lead. By this combustion, sulphurous acid and nitrous gas are formed. The nitrous gas absorbs oxygen from the atmosphere, and is converted into nitrous acid. Both the acids are absorbed by water. The nitrous acid gives out part of its oxygen to the sulphurous acid, and converts it into sulphuric acid, and being reduced to the state of nitrous gas again flies off, unites to oxygen, is converted into nitrous acid, and absorbed by the water. This process goes on till the whole of the sulphurous acid is converted into sulphuric acid.‡ The water, thus acidulated, is evaporated in leaden vessels to a certain point. The evaporation is then continued in glass retorts, till the acid acquires the requisite degree of strength. By this evaporation a very considerable portion of the water is driven off. But by this process, sulphuric acid cannot be deprived of the whole of its water.

This acid was discovered in the middle ages, either by the Ara-

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* Annals of Philosophy, vi. 340.

† Nicholson's Journal, vi. 95.

‡ Clement and Desormes. Ann. de Chim. lix. 329—Dalton, New System of Chemical Philosophy, ii. 396—Davy, Elements of Chemical Philosophy, p. 276.

bian chemists, or the alchemists. But nothing is known respecting the exact period of the discovery. It is mentioned by Basil Valentine, who wrote in the early part of the fifteenth century. It was long procured by distilling green vitriol, and this process is still followed in Germany. Sulphur and nitre were afterwards burnt under a glass bell, and the product evaporated: hence it was called *oleum sulphuris per campanam*. Dr. Roebuck first contrived the method of making it in leaden chambers, and established the original manufactory at Prestonpans, in Scotland.

Sulphuric acid is colourless like water. It has somewhat of a glutinous consistency: is destitute of smell, but has an exceedingly acid taste. It speedily chars animal and vegetable substances, when placed in contact with them. It converts vegetable blues to red. Acid, of the specific gravity 1·85, boils, according to Mr. Dalton, at the temperature of 620°. The boiling point diminishes with the strength. Acid, of the specific gravity 1·780, boils at 435°, and acid, of the specific gravity 1·650, at 350°.*

Many experiments have been made to determine the proportion of oxygen contained in sulphuric acid. It is unnecessary to state the old trials of Berthollet, Trommsdorf, Lavoisier, Chenevix, and Thenard, because they are very inaccurate. Bucholz, Klaproth, and Richter, approach much nearer to the truth. Their estimates are as follows:

Bucholz	100 sulphur	+ 135·3 oxygen.
Klaproth	100	+ 138·1
Richter	100	+ 138·1

Berzelius made a set of experiments, with every attention to accuracy, on purpose to determine this point. He found that 10 parts of sulphuret of lead, when boiled in nitric acid, were converted into 12·645 parts of sulphate of lead. Now sulphate of lead is a compound of 10 sulphuric acid, + 28 yellow oxide of lead. Therefore the 12·6450 of sulphate of lead formed, are composed of, Yellow oxide of lead 9·3174—Sulphuric acid 3·3276.

In this experiment both the lead and the sulphur had united with oxygen. But Berzelius has shown, that yellow oxide of lead contains $\frac{1}{14}$th of its weight of oxygen. Now $\frac{1}{14}$th of 9·3174 is 0·6655. If we subtract this quantity from 2·645, the whole increase which the sulphuret acquired, there will remain 1·9795, indicating the quantity of oxygen which exists in 3·3276 parts of sulphuric acid.† Therefore sulphuric acid is composed of—Sulphur 1·3485 or 100—Oxygen 1·9795 or 146·85.

These numbers are much nearer the truth than those of preceding experimenters. But it is easy to show, that the quantity of oxygen, thus stated by Berzelius, is a little below the truth. Most of the metals have the property of uniting either with oxygen or sulphur, constituting with the one *oxides*, with the other *sulphurets*. Now the weight of sulphur, nccessary to convert any metal into a

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* Dalton's New System of Chemical Philosophy, ii. 404.

† Ann. de Chim. lxxviii. 21.

protosulphuret, is just double the weight of oxygen necessasy to convert the same metal into a protoxide. From this it follows, that the weight of an atom of sulphur, is exactly twice that of an atom of oxygen. Most of the sulphates have been analysed with great care. The following table represents the component parts of some of these salts:

Sulphate of lead.			Sulphate of barytes.			Sulphate of potash.		
Acid	10	5	Acid	100	5·02	Acid	42·2	5·05
Base	28	14	Base	194	9·75	Base	50·1	6

Sulphate of lime.			Sulphate of copper.			Sulphate of soda.		
Acid	100	5·006	Acid	100	5	Acid	100	5·07
Base	72·41	3·625	Base	200	10	Base	78·82	4

The second set of numbers, after the bases, represent the weights of the atoms of the different bases. For these weights are as follows:

Yellow oxide of lead	14	Lime	3·625
Barytes	9·75	Black oxide of copper	10
Potash	6	Soda	4

The numbers above these represent the weight of an atom of sulphuric acid, resulting from the analysis of the salt. Now these numbers agree very nearly with each other, and the mean of the whole of them is 5·024. Is it not evident from this, that 5 is the number which represents the weight of an atom of sulphuric acid? It must be composed of—Sulphur 2, or 1 atom—Oxygen 3, or 3 atoms.

Sulphuric acid, then, is composed of—Sulphur 100—Oxygen 150. Proportions which differ but little from Berzelius' analysis. The error is probably owing to a minute quantity of the sulphuret of lead having been carried off by the nitric acid fumes.

4. Thus we see that the two acid combinations of sulphur are composed as follows:

	Sulphur.		Oxygen.		Sulphur.		Oxygen.
Sulphurous acid	100	+	100 or		1 atom	+	2 atoms.
Sulphuric acid	100	+	150 or		1	+	3

We shall see afterwards that sulphur is capable of combining with one atom of oxygen, and of forming an acid, which has not hitherto been obtained in a separate state; but which may be distinguished by the name of *hyposulphurous acid.*

5. If sulphur be kept melted in an open vessel, it becomes gradually thick and viscid. When in this state, if it be poured into a basin 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. 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. This substance has

been considered as an oxide of sulphur. But it produces the same quantity of sulphuric acid as common sulphur, and sulphur undergoes the same change in its appearance, even when oxygen and common air are carefully excluded. We cannot therefore consider it as an oxide.

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. This substance has been considered as an oxide of sulphur by some. But 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 dropped 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.*

III. Sulphur combines readily with chlorine, and forms a liquid compound which has received the name of *chloride of sulphur*. This substance was first described by me in 1804.† It was examined by M. Berthollet Junior in 1807,‡ and by Mr. Buchols in 1810.§

It is easily obtained by passing a current of chlorine gas through flowers of sulphur. It may be obtained also, as Davy first observed, by heating sulphur in a dry glass vessel filled with chlorine gas.

It is a liquid of a brownish red colour when seen by reflected light; but appears yellowish green when seen by transmitted light. Its smell is strong and somewhat similar to that of sea plants, or which we perceive when walking along the sea shore. The eyes when exposed to it are filled with tears and acquire the same painful feeling as when exposed to wood or peat smoke. The taste is acid, hot, and bitter, affecting the throat with a painful tickling. It does not change the colour of dry litmus paper; but if the paper be moist it immediately becomes red. I found the specific gravity 1.623. But Berthollet found it 1·7 and Bucholz 1·699. We must therefore consider 1·7 as the true gravity. It readily dissolves sulphur, and acquires a brown colour. It dissolves phosphorus with facility. The solution has a fine amber colour and is permanent. Chloride of sulphur smokes violently in the open air and soon flies off, leaving crystals of sulphur if it contains that substance in solution. When dropped into water it is decomposed, sulphur being evolved. When dropped into nitric acid a violent effervescence is produced, and sulphuric acid formed.

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* Nicholson's Journal, vi. 102. † Ibid. p. 104. ‡ Mem. d'Arcueil, i. 161.

§ Gehlen's Journal, fur die Chemie, Physik und Mineralogie, ix. 172.

According to Davy 10 grains of sulphur absorb 30 cubic inches or 22·875 grains of chlorine. Hence it is composed of

Sulphur	1	2
Chlorine	2·2875	4·575

It is evident from this that it is a compound of 1 atom sulphur and 1 atom chlorine. Had the absorption been 29·5 instead of 30 cubic inches, the chloride would have been composed of 2 sulphur + 4·5 chlorine. Now as the glass in which the experiment was made had a metallic stop-cock, some of the chlorine would be absorbed by it.

IV. Sulphur has the property of combining with iodine, and of forming a compound which has been called *iodide of sulphur*. It was first discovered by Gay-Lussac.*

It is easily formed by mixing together the two constituents in a glass tube and exposing them to a heat sufficient to melt the sulphur. This iodide is greyish black, and has a radiated structure like that of sulphuret of antimony. When distilled with water iodine is disengaged. When heated sufficiently to produce fusion a portion of the iodine is likewise disengaged.

This iodide has not hitherto been analysed. But from analogy we may conclude that it is composed of 1 atom iodine + 1 atom sulphur, or by weight of

Sulphur	2	100
Iodine	15·625	781·25

V. Nothing is known respecting the combination of sulphur with fluorine. Neither has it been hitherto possible to form a compound of sulphur and azote.

VI. Sulphur has the property of combining with hydrogen, and of forming a gaseous compound which has received the name of sulphureted hydrogen gas. Gay-Lussac has given it the name of *hydrosulphuric acid.*

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.

Berzelius published an elaborate analysis of it in 1807;†† and

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* Ann. de Chim. xci. 22.

† Macquer's Dict. i. 520.

‡ Scheele on Air and Fire, p. 186. Eng. Trans.

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

‖ Phil. Trans. 1786, p. 118.

¶ Ann. de Chim. xiv. 294.

** Ibid. xxv. 233.

†† Afhandlingar i Fysik, Kemi och Mineralogi, ii. 78.

Gay-Lussac, Thenard,* and Sir H. Davy,† have ascertained several of its properties with precision.

It may be obtained by pouring diluted sulphuric or muriatic acids on a mixture of three parts iron filings and two parts sulphur melted together in a crucible. But when procured in this way it is always mixed with hydrogen gas. It may be obtained quite pure by digesting sulphuret of antimony in powder in muriatic acid.

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 Gay-Lussac and Thenard, is 1·1912.‡ According to Sir H. Davy it is 1·1967. I conceive that its true specific gravity is 1·180. Supposing this to be its gravity, then 100 cubic inches of it, when the barometer stands at 30 inches, and when the temperature is 60°, will weigh 35·89 grains.

This gas is rapidly absorbed by water. According to Dr. Henry 100 cubic inches of this liquid absorb, at the temperature of 50°, 108 cubic inches of sulphureted hydrogen.§ But the gas must have been impure. Theodore de Saussure found that 100 cubic inches of water absorb 253 cubic inches of pure sulphureted hydrogen gas.‖ Alcohol of the specific gravity 0·84 absorbs, according to the same chemist, 6·06 times its volume of gas. Mr. Higgins has shown likewise that it dissolves in ether. The water thus impregnated is colourless, but it has the smell of the gas, and a sweetish nauseous taste. It converts vegetable blue colours to red, and has many other properties analogous to those of acids. When the liquid is exposed to the open air the gas gradually makes its escape.

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 spark is passed through it, sulphur is deposited, but its bulk is scarcely altered.¶ It deposits sulphur also when agitated with nitric acid, or when that acid is dropped 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. For complete combustion it requires 1½ volume of oxygen gas. It is converted into water and sulphurous acid. The half volume of the oxygen goes to the formation of water, and the whole volume to the formation of sulphurous acid.

When electrical sparks are made to pass for a long time through this gas the whole sulphur is deposited, and the bulk of the gas is

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* Phil. Trans. 1812, p. 412.

† Recherches Physico-chimiques, i. 191.

‡ Ibid.

§ Phil. Trans. 1803, p. 274.

‖ Annals of Philosophy, vi. 340.

¶ Austin, Phil. Trans. 1788, p. 385.

** Scheele, on Air and Fire, p. 190.

not altered; but it is converted into pure hydrogen gas. When sulphur is strongly heated in hydrogen gas a quantity of sulphureted hydrogen gas is formed: but the bulk of the gas is not altered. It is obvious from these facts that it consists of hydrogen gas, holding a quantity of sulphur in solution. To determine its composition we have only to subtract the specific gravity of hydrogen gas from that of sulphureted hydrogen gas. The remainder will give us the weight of sulphur.

Specific gravity of sulphureted hydrogen gas -	1·180
——————— hydrogen gas - - -	0·069
Sulphur - - -	= 1·111

Hence it is composed by weight of

Sulphur -	1·111 -	2
Hydrogen -	0·0694 -	0·125

Or of an atom of sulphur united to an atom of hydrogen.

When sulphureted hydrogen gas and sulphurous acid gas are mixed together, they mutually decompose each other, as was first observed by Berthollet.

VII. Sulphur has the property of combining with carbon, and of forming a very remarkable compound, distinguished by the name of sulphuret of carbon.

The phenomena which take place when sulphur is brought in contact with red hot charcoal 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 wide 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, 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.*

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 later 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

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* Ann. de Chim. xlii. 136. † Crell's Annals, 1796, ii. 136. ‡ Gehlen's Jour. ii. 192.

us, that when it is exposed to evaporate in open vessels, a portion of charcoal remains behind. Berthollet Junior, who made some experiments on it, adopted the opinion of Lampadius.[*] But the subject was resumed by Cluzel,[†] who published an elaborate set of experiments on it in 1812. Berthollet, Thenard, and Vauquelin, who were appointed by the French Institute to examine Cluzel's paper, repeated some of his experiments, and drew, as a conclusion, that the liquid in question is a compound of about 15 carbon and 85 sulphur.[‡] Soon after a very complete set of experiments on it were published by Professor Berzelius, and Dr. Marcet.[§] Their results almost exactly agreed with those of the French chemists, and leave no doubt that this liquid is a compound of sulphur and carbon, and that it contains no other ingredient.

Sulphuret of carbon, when prepared by the process of Clement and Desormes, has at first a yellow colour, owing to an excess of sulphur which it contains. But when rectified, by being distilled in a retort at a temperature not exceeding 110°, it is obtained in a state of purity.

Sulphuret of carbon is a liquid as transparent and colourless as water. Its taste is acrid, pungent, and somewhat aromatic. Its smell is nauseous and fetid, though quite peculiar. Its specific gravity, according to Berzelius and Marcet is 1·272,[‖] according to Cluzel 1·263,[¶] the specific gravity of water being 1. Its expansive force at the temperature of 63·5° is equal to a pressure of 7·36 inches of mercury. So that air, to which it is admitted at that temperature, will be dilated by about $\frac{1}{4}$ of its volume.[**] It boils briskly at a temperature between 105° and 110°. It does not congeal when cooled down to — 60°. It is one of the most volatile liquids known, and produces a greater degree of cold, by its evaporation, than any other substance. The bulb of a thermometer being enveloped in fine lint, dipped in this liquid, and suspended in the air, sinks from 60° to about zero. If it be introduced under the receiver of an air-pump, and the receiver rapidly exhausted, the thermometer will sink to — 82° in less than two minutes.[††]

Sulphuret of carbon takes fire in the open air, at a temperature scarcely exceeding that at which mercury boils. It burns with a blue flame, giving out the smell of sulphurous acid. Its vapour detonates when mixed with oxygen gas, and an electric spark is passed through it. The products are sulphurous acid and carbonic acid, and carbonic oxide, if the oxygen be in small proportion; but if six or seven times the bulk of the vapour, the whole of the carbon is converted into carbonic acid.

Sulphuret of carbon is scarcely soluble in water, but alcohol and ether dissolve it readily. Ether is capable of taking up three times its bulk of this liquid without becoming turbid. It readily unites

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[*] Mem. d'Arcueil, i. 304.

[†] Ann. de Chim. lxxxiv. 72, 113.

[‡] Ibid. lxxxiii. 252.

[§] Phil. Trans. 1813, p. 171.

[‖] Ibid. p. 175.

[¶] Ann. de Chim. lxxxiv. 83.

[**] Berzelius & Marcet, Phil. Trans. 1813, p. 175.

[††] Marcet, Phil. Trans. 1813, p. 252.

with chloride of azote, and prevents that liquid from detonating, when it comes in contact with oils or phosphorus.[*]

When passed through red-hot copper, it combines with that metal, forming a carbosulphuret of metal. By this method, Berthollet, Thenard, and Vauquelin, succeeded in ascertaining its composition. When passed very slowly through red oxide of iron, it is also completely decomposed, and converted partly into sulphuret of iron, and partly into sulphurous acid and carbonic acid gases. By this process, Berzelius succeeded in decomposing it, and ascertained it to be a compound of

Sulphur	84·83	100·00
Carbon	15·17	17·89

This result almost coincides with that of the French chemists. Now we have found that an atom of sulphur weighs 2 and an atom of carbon 0·75. On the supposition that sulphuret of carbon is a compound of 2 atoms sulphur, and 1 atom carbon, its constituents would be

Sulphur	4	84·21	100
Carbon	0·75	15·79	18·75

But these numbers approach so nearly to Berzelius' analysis, that we may safely consider them as exact. The liquid then is in fact a bisulphuret of carbon. It is not improbable that a sulphuret of carbon may likewise be formed.

VIII. We do not know whether sulphur combines with boron and silicon: no experiments on the subject having been hitherto made.

IX. 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 secured from the air. The sulphuret of phosphorus, thus prepared, is more combustible than phosphorus. If it be set on fire by means of a hot wire, allowed to burn for a little, and then extinguished by excluding the air, the phosphorus, and perhaps the sulphur, seem to be oxidized, and the mixture acquires the property of taking fire spontaneously as soon as it comes in contact with air.[**]

The combination may be procured also by putting the two bodies

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[*] Berzelius and Marcet, Phil. Trans. 1813, p. 175.

[†] Opusc. i. 11.

[‡] Jour. de Phys. xxxv. 382.

[§] Nicholson, vi.

[‖] Ibid. vii. 58.

[¶] Briggs, Nicholson, vii. 58.

[**] Briggs, Ibid.

into a retort, or flask, filled with water, and applying heat cautiously and slowly. They combine together gradually as soon as the phosphorus is melted. It is necessary to apply the heat cautiously, because the sulphuret of phosphorus has the property of decomposing water, as had been observed by Margraf, and ascertained by Pelletier. The rate of decomposition increases very rapidly with the temperature, a portion of the two combustibles being converted into acids by uniting to the oxygen: the hydrogen at the moment of its evolution unites with sulphur and phosphorus, and forms sulphureted and phosphureted gases. This evolution, at the boiling temperature, is so rapid as to occasion violent explosions.*†

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 1 Sulphur	congeals at 77°	8 Phosphorus 8 Sulphur	congeals at 41°
8 Phosphorus 2 Sulphur	. . at 59°	4 Phosphorus 8 Sulphur	. . at 54·5°
8 Phosphorus 4 Sulphur	. . at 50°	2⅔ Phosphorus 8 Sulphur	. . at 99·5°

From Pelletier's experiments it is probable, that the most intimate combination of phosphorus and sulphur consists of 1 atom of sulphur and 1 atom of phosphorus, or by weight of

Sulphur	2	4	100
Phosphorus	1·5	3	75

But they doubtless combine in other proportions.§

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* [I have had it explode in my hand, by the mere heat of my hand.—C.]

† [By a paper of Mr. Faraday's, in 8 Brande's Journal, 361, it should appear, that the best mode of combining phosphorus with sulphur is the following: boil some distilled water to get rid completely of any air it may contain; then put into the boiling water 8 parts of phosphorus, and let it melt therein: then add 4 parts of sulphur, and wait till they are incorporated. It had best be done in an open phial placed in some vessel where an explosion may take place with impunity. When cold, add some ammonia and wash the substance by shaking the phial. Then transfer the substance into fresh water previously boiled and cork the phial. The combination of phosphorus and sulphur, which at first is of a reddish brown colour, becomes of a light yellow after washing with ammoniated water.

On repeating Mr. Faraday's experiment, I find it succeeds best in the proportions of three phosphorus to two sulphur.—C.]

‡ Ann. de Chim. iv. 10.

§ [Concentrated sulphuric acid, that is, oil of vitriol of commerce, of specific gravity 1·85 at 60 of Fah. combines with water with violent heat and condensation. According to Dr. Ure the greatest condensation is when 73 parts of oil of vitriol are mixed with 27 parts (by weight) of water. In this case 100 parts in volume, become 92·14 parts. 8 Brande's Journ. 298.—C.]

SECTION VII.

OF ARSENIC.

I. THE word *arsenic* (αρσενικον) occurs first in the works of Dioscorides, and of some other authors who wrote about the beginning of the Christian era. It denotes in their works the same substance which Aristotle had called σανδαραχη,[*] and his disciple Theophrastus αρρενικον, which is a reddish coloured mineral, composed of arsenic and sulphur, used by the ancients in painting, and as a medicine.

The *white oxide of arsenic*, or what is known in commerce by the name of arsenic, is mentioned by Avicenna in the 11th century; but at what period the metal called arsenic was first extracted from that oxide is unknown. Paracelsus seems to have known it; and a process for obtaining it is described by Schroeder in his Pharmacopœia, published in 1649.[†] But it was only in the year 1733 that this metal was examined with chemical precision. This examination, which was performed by Mr. Brandt,[‡] demonstrated its peculiar nature; and since that time it has been always considered as a distinct metal, to which the term *arsenic* has been appropriated. Its properties were still farther investigated by Macquer in 1746,[§] by Monnet in 1773,[‖] and by Bergman in 1777.[¶] To the labours of these philosophers, and to those of Mr. Scheele,[**] we are indebted for almost every thing known about the properties of this metal. Its combinations with oxygen have been carefully examined by Proust,[††] Bucholz,[‡‡] Berzelius,[§§] and some other chemists.[‖‖]

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.[¶¶]

2. It is the softest of all the metallic bodies, and is so brittle that it may be easily reduced to a fine powder by trituration in a mortar. Its specific gravity, when melted, is 5.7633.[***]

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[*] Pliny seems to make a distinction between sandaracha and arsenic. See lib. xxxiv. cap. 18.

[†] Bergman, ii. 278.

[‡] His paper was published in the Memoirs of the Philosophical Society of Upsala, for 1733, p. 39. He describes the properties of arsenious acid with precision, and gives the first accurate process for procuring arsenic in the metallic state. He mixed white arsenic with potash and volatile alkali, and fused the mixture in a well luted crucible. Bergman seems to have taken many of his facts respecting arsenic from Brandt's paper.

[§] Mem. Par. 1746, p. 223, and 1748, p. 35.

[‖] Sur l'Arsenic.

[¶] Opusc. ii. 272.

[**] Scheele, i. 129.

[††] Jour. de Phys.

[‡‡] Jour de Chim. iv. 5.

[§§] Ann. de Chim. lxxx. 9, and Annals of Philosophy, iii. 93.

[‖‖] See Annals of Philosophy, iv. 171.

[¶¶] [It volatilizes with heat in a white vapour, that whitens copper. The common flystone of the shops is tarnished metallic arsenic.—C.]

[***] Lavoisier's Elements, p. 572. I found its specific gravity when sublimed 5·235. Bergman states the specific gravity of arsenic to be 8·31, (Opusc. ii. 279) and Brandt makes it 8·308. But the specimens which they tried must have been impure.

3. 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 Haüy has demonstrated to be the form of its integrant particles.

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 possess acid properties, and which have been denominated *arsenious* and *arsenic acids*.

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 now denominated *arsenious acid*. It is seldom prepared by chemists, because it exists native, and is often procured abundantly during the extraction of the other metals from their ores.

When obtained by these processes, it is a white, brittle, compact substance, of a glassy appearance. It has a sharp acrid taste, which at last leaves an impression of sweetness, and is one of the most virulent poisons known. It has an alliaceous smell.

According to the experiments of Klaproth, 1000 parts of cold water dissolve only 2½ parts of this acid, while 1000 parts of boiling water dissolve 77¾ parts of it.† 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 acid 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 3·699;‡ that of the acid in its usual state is 3·706.§

Many experiments have been made to determine the composition of this acid. The following table exhibits the results obtained by the different experimenters.

Proust‖	100 arsenic	+ 32·979 oxygen
Thenard¶	100	+ 34·694
Berzelius**	100	+ 34·263
Thomson††	100	+ 34·930

We shall be better able to judge of these experiments when we know the composition of arsenic acid.

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* Bergman, ii. 279.

† Annals of Philosophy, iv. 132.

‡ According to the experiments of Dr. Wollaston.

§ Bergman, ii. 286.

‖ Jour. de Phys.

¶ Ann. de Chim. l. 123.

** Ann. de Chim. lxxx. 9.

†† Annals of Philosophy, iv. 176.

When arsenious acid is mixed with black flux,* and slowly heated to redness in a matrass or retort, the arsenic is reduced to the metallic state, and slowly sublimes. By this means the metal may be procured 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 arsenious acid above described.

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 arsenious acid 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 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 arsenious acid, 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.† But the easiest method of procuring this acid is to dissolve arsenic in nitric acid, and evaporate the solution to dryness.

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 arsenious acid.

The following table exhibits the experiments hitherto made on the composition of this acid.

Proust	100 arsenic	+ 52·905 oxygen
Thenard	100	+ 56·250
Berzelius	100	+ 51·428
Thomson	100	+ 52·4

In order to be able to judge of the accuracy of these experiments let us endeavour to ascertain the number which denotes the weight of an atom of arsenic acid. We have two analyses of arseniates which appear accurate; the arseniate of lead by Berzelius,‡ and the arseniate of lime by Laugier.§ They are as follows:

Arseniate of lead.		Arseniate of lime.	
Base 194·11	14	Base 33	3·625
Acid 100	7·212	Acid 67	7·36

We see from these, that if 14 and 3·625 represent respectively the weight of an atom of oxide of lead and of lime, the weight of an atom of arsenic acid is represented by 7·214 and 7·36, the mean of which numbers is 7·286, which must represent the weight of an

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* [Black flux is a carbonaceous alkaline mass produced by deflagrating 2 parts of argol or crude tartar, with one part of nitre.—C.]

† Van Mon's Journal de Chimie, iv. 16.

‡ Annals of Philosophy, iii. 93.

§ Ann. de Chim. lxxxv. 58.

atom of arsenic acid very nearly. Perhaps the number 7·25, which is a multiple of 0·125 (the weight of an atom of hydrogen) is nearest the truth. This number must contain the atoms of oxygen and weight of an atom of arsenic. Let us suppose that the oxygen in this number is represented by 2·5. In that case the weight of an atom of arsenic will be 4·75, and arsenic acid will be a compound of

Arsenic	4·75	100
Oxygen	2·5	52·631

Now this is almost exactly the mean of the experiments of Proust and my own. I am therefore disposed to consider it as accurate.

If we suppose the weight of oxygen in arsenious acid to be 1·5, that acid will be composed of

Arsenic	4·75	100
Oxygen	1·5	31·6

Now this number differs but little from the determination of Proust, the only chemist who made direct experiments on the subject. The determination of Thenard, Berzelius, and myself, was only from analogical reasoning. I conceive, therefore, that the oxygen in these two acids is as the numbers 1·5 and 2·5, or 3 and 5; or that arsenious acid is a compound of 2 atoms arsenic and 3 atoms oxygen, and arsenic acid of 2 atoms arsenic and 5 atoms oxygen.

III. Arsenic combines with chlorine and forms a compound, which we shall call *chloride of arsenic*.

It has been long known and described in chemical books, under the name of *butter of arsenic*. It may be obtained by introducing arsenic into a sufficient quantity of chlorine gas. It burns spontaneously with considerable brilliancy, and forms the chloride. But the easiest method of procuring this chloride in considerable quantity, and pure, is the old one. It is as follows: Mix together 6 parts of corrosive sublimate and 1 part of arsenic, and distil with a gentle heat in a retort, a liquid passes over into the receiver which is the chloride of arsenic.

This chloride is transparent and of the consistence of oil. It is very volatile. Its specific gravity has not been ascertained. When heated it readily dissolves phosphorus and sulphur; but allows these bodies to precipitate on cooling. It likewise dissolves rosin, and combines with olive oil and oil of turpentine.[*] When mixed with water it is decomposed, and arsenious acid precipitates. According to the experiments of Dr. John Davy, 2 grains of arsenic, when converted into chloride, absorb 4 cubic inches of chlorine gas.[†] Now 4 cubic inches of chlorine gas weigh 3·05 grains. Hence the chloride of arsenic is composed of

Arsenic	2	4·75
Chlorine	3	7·125

These numbers approach 1 atom of arsenic, and 1½ atom of chlorine, or 2 atoms arsenic and 3 atoms chlorine.

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[*] Dr. John Davy, Phil. Trans. 1812, p. 186.

[†] Ibid. p. 188.

IV. Arsenic combines readily with iodine, and forms an *iodide of arsenic.*

The combination takes place with great facility; but, according to Ruhland, the only person who has examined it, without the evolution of any heat. This iodide has a dark purple-red colour, and possesses the properties of an acid. It is soluble in water, and when the solution is saturated with potash no precipitate appears. When nitrate of silver is dropped into the solution, a sulphur-yellow precipitate falls, well known as an arsenite of silver.* No experiments have been hitherto made to determine the proportions in which the two ingredients are combined in this iodide.

V. Nothing is known respecting the combination of arsenic with fluorine. It does not seem capable of uniting with azote.

VI. Arsenic combines with hydrogen and forms a compound, which may be called *arsenureted hydrogen gas.*

It was discovered by Scheele during his experiments on arsenic acid.† It was afterwards noticed by Proust during his experiments on tin.‡ In the year 1803, an elaborate set of experiments on it was published by Tromsdorf.§ In 1806, a very valuable set of experiments was made upon it by Professor Stromeyer.‖ It was examined in 1808 by Gay-Lussac and Thenard, during their experiments on potassium.¶

I do not believe that it has hitherto been obtained in a state of purity. Probably the mineral called *mispickel*, which is an arsenuret of iron, might be employed with advantage in the preparation of it. The easiest method of procuring it, according to Tromsdorf, 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 recommends an alloy composed of 15 parts of tin and 1 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. Gehlen, who fell a victim to his experiments on it in 1815, prepared it by heating arsenic in an alkaline ley.

Arsenured 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, according to Tromsdorf, is 0·5293, that of air being 1. Davy found it as high as 0·5552.** But all these gravities are undoubtedly greatly below the truth.

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

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* Ruhland, Schweigger's Journal, xi. 140.

† Scheele's Mem. de Chymie, i. 182.

‡ Ann. de Chim. xxviii. 215.

§ Nicholson's Journal, vi. 200.

‖ Ibid. xix. 381.

¶ Recherches Physico-chimiques, i. 229.

** Elements of Chemical Philosophy, p. 456.

a lighted taper, an explosion takes place, and water and arsenious acid are formed. Equal parts of these gases do not explode so loudly, but give a more vivid flame. 2 parts of this gas and 1 of oxygen leave a small residue. According to Stromeyer it requires for combustion 0·72 parts of its bulk of oxygen gas.

Arsenureted 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 chlorine gas 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. Tromsdorf, to whom we are indebted for all these facts, did not succeed in analysing this gas. Stromeyer analysed it by means of nitric acid, and found it composed of 106 parts arsenic and 2·19 hydrogen. Gay-Lussac and Thenard decomposed it by heating tin placed in a glass tube filled with the gas. 100 volumes of this gas, when deprived of their arsenic, expanded so as to occupy 140 volumes. So that the increase amounted to $\frac{2}{5}$ths of the original bulk. Were we to suppose this experiment and the analysis of Stromeyer to be correct, it would follow that the specific gravity of arsenureted hydrogen gas is 4·799. Farther researches are necessary before the constitution of this compound be accurately known. It appears from the experiments of Davy and of Gay-Lussac and Thenard, that arsenic and hydrogen combine also in a solid form in brown flocks, which give out arsenureted hydrogen gas when heated.

VII. We are not acquainted with any combination of arsenic with carbon, boron, or silicon.

VIII. 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.[*]

IX. Arsenic combines readily with sulphur. 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 arsenious 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

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[*] Pelletier, Ann. de Chim. xiii. 139.

[†] Proust, Jour. de Phys. liii. 94.

has a scarlet colour, and is often crystallized in transparent prisms. Its specific gravity is 3·3384.[*] 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.

If arsenious acid 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 plates, which have a considerable degree of flexibility. Its specific gravity is 3·4522.[‡] 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.[§] Haüy observed that the figure of their crystals is the same. Hence he was led to consider them as different forms of the same substance, conformably to the opinion of Proust.[‖] This induced Laugier to make a set of experiments to elucidate the subject.[¶] The result of his experiments was that sulphuret of arsenic, artificially prepared, is composed of

Arsenic	58⅓	- -	100
Sulphur	41⅔	- -	71·42

Now this approaches to a compound of 1 atom arsenic with 2 atoms sulphur.

Native orpiment and realgar he found, when heated, allowed a quantity of arsenious acid to sublime. The substance was then composed exactly as the artificial sulphuret. Hence he supposes that in these substances, when native, there is a certain quantity of arsenic or arsenious acid mixed mechanically between their particles.

SECTION VIII.

OF TELLURIUM.

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 sub-

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[*] Haüy's Mineralogie, iv. 228.

[†] Hoffman informs us, that he gave two scruples of it to a dog without any bad effects whatever. Observ. Physico-Chemico-Select. p. 236.

[‡] Haüy, iv. 235.

[§] Jour. de Phys. liii. 94.

[‖] Ann. de Chim. lxxxv. 36.

[¶] Ibid.

stance, 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 chemist to decide the point. He ascertained, however, that the metal in question is not antimony. The experiments of Muller appeared so satisfactory, that they induced Mr. Kirwan, in the second edition of his Mineralogy, published in 1796, to give this metal a separate place, under the name of *sylvanite*. Klaproth published an analysis of the ore in 1798, and completely confirmed the conclusions of Muller.[†] To the new metal, which constitutes 0·925 of the ore, he gave the name of *tellurium;* and this name has been generally adopted. Gmelin examined the ore in 1799;[‡] and his experiments coincide almost exactly with those of Muller and Klaproth. By these philosophers the following properties of tellurium have been ascertained. Some curious new combinations of tellurium were discovered by Davy in 1809;[§] and a set of important experiments were made upon it by Berzelius in 1812.[‖]

1. Tellurium has a bluish white colour, 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.

II. Tellurium combines with only one proportion of oxygen, and forms a compound possessing acid properties. It might be called *telluric acid*. But as it likewise possesses alkaline properties, it will be better to retain the common name, *oxide of tellurium*.

1. When tellurium is exposed to the action of the blow-pipe upon charcoal, it takes fire, and burns with a lively blue flame, the edges of which are green; and is completely volatilized in the form of a white smoke, which, according to Klaproth, has a smell not unlike that of radishes.[**]

This white smoke is the oxide of tellurium, which may be ob-

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[*] Born, ii. 468.

[†] Crell's Annals, 1798, i. 91.

[‡] Ibid. 1799, i. 275 and 365.

[§] Phil. Trans. 1810, p. 16.

[‖] Nicholson's Journal, xxxvi. 129. Unfortunately this paper of Berzelius is so inaccurately printed that in many places it is quite unintelligible.

[¶] Muller found it 6·343; but probably his specimen was not pure.

[**] Gmelin could not perceive this smell.

tained 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. It may be volatilized by the application of heat. When heated on a bit of charcoal before a bellows, it becomes first yellow, then orange, and lastly of a fine red.* After fusion it produces no change on litmus paper. But it combines with the different bases, and forms with them neutral salts. It dissolves also in acids, and forms neutral salts with them likewise.

According to the experiments of Klaproth,† this oxide is composed of—Metal 100—Oxygen 20.

But Berzelius found the weight of oxygen somewhat greater. According to his experiments,‡ the oxide is composed of—Metal 100—Oxygen 24·8.

If we suppose the real quantity of oxygen that unites with 100 metal to be 25, or ¼th of the weight of the metal, and that this oxide is a compound of 1 atom metal, + 1 atom oxygen, then the weight of an atom of tellurium will be 4.

III. Tellurium burns spontaneously when introduced into chlorine gas. The *chloride of tellurium* formed is white, and semitransparent. When heated it rises in vapour, and crystallizes. Water decomposes it, and separates a white powder consisting of oxide of tellurium united to water or *hydrated oxide*, as such compounds are called. According to Davy it is composed of—Tellurium 2—Chlorine 1·83. These numbers approach nearest to 1 atom tellurium and 1 atom chlorine. But they do not entirely agree with that supposition.§

IV. Iodine combines very readily with tellurium when the two substances are brought into contact. The solution in water has a dark purple red colour. It combines readily with potash, and forms a colourless solution, which yields by evaporation small white prisms.‖

V. Nothing is known respecting the combination of tellurium with fluorine or azote.

VI. Tellurium has the property of combining with hydrogen, and of forming a gaseous substance, to which the name of *telluretted hydrogen gas* has been given.

It was discovered by Sir Humphry Davy in 1809,¶ and some experiments on it by Berzelius were published in 1813.**

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* Berzelius, Nicholson's Journal, xxxvi. 130.

† Beitrage, iii. 14.

‡ Annals of Philosophy, iii. 250.

§ Davy, Elements of Chemical Philosophy, p. 409.

‖ Ruhland, Schweigger's Journal, xi. 140.

¶ Phil. Trans. 1810, p. 16, or Nicholson's Journal, xxvi. 333.

** Nicholson's Journal, xxxvi. 132.

It is formed by mixing together oxide of tellurium, potash, and charcoal; and exposing the mixture to the action of a red heat. It is then put into a retort; diluted sulphuric acid is poured on it, and the beak of the retort is plunged into a mercurial trough. A gas comes over, which may be collected in glass jars previously filled with mercury. This gas has been but imperfectly examined, owing to the difficulty of procuring tellurium in sufficient quantity for experimental purposes. The following are its properties, as far as they have been ascertained.

It is transparent and colourless, and possesses the mechanical properties of common air. It has a strong peculiar smell, bearing considerable resemblance to that of sulphureted hydrogen. It burns with a bluish flame, and oxide of tellurium is deposited. It is soluble in water, and gives that liquid a claret colour. Davy was not able to determine whether it reddens vegetable blues. But in other respects it possesses the properties of an acid, combining with alkalies, and precipitating most metallic solutions like sulphureted hydrogen. There is reason to suspect that this compound may be formed by heating tellurium in hydrogen gas. Chlorine gas immediately decomposes it. The compound of tellureted hydrogen and potash is immediately decomposed when the solution of it is exposed to the air. Berzelius has endeavoured to show by indirect experiments that the gas is a compound of

Tellurium - -	100 - -	4
Hydrogen - -	3·1 - -	0·125

Supposing these proportions correct, it is obviously a compound of 1 atom tellurium + 1 atom hydrogen. If we suppose it to be analogous to sulphureted hydrogen gas in its constitution, which is probable, its specific gravity in that case will be 2·3074.

Ritter, in 1808, discovered that when tellurium is connected with the negative pole of a galvanic battery, and the circuit completed by dipping the tellurium in water, a brown powder is formed, which appears to be a solid compound of tellurium and hydrogen.

VII. It would appear, from an experiment of Berzelius, that tellurium is capable of combining with carbon.* The compound is a black powder; but its properties have not been examined.

VIII. No experiments have been made on the combination of tellurium with boron, silicon, or phosphorus. It may be combined with sulphur by fusion. The *sulphuret* has a leaden grey colour, and a radiated texture. On red-hot coals it burns with a green flame.†

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* Nicholson's Journal, xxxvi. 133.

† Klaproth's Beitrage, iii. 12.

SECTION IX.

OF OSMIUM.

OSMIUM has been hitherto so imperfectly examined that we are not sufficiently acquainted with its characters to be able to assign it a proper place in a chemical arrangement. The great volatility of its oxide, its solubility in water, and its property of uniting with alkalies, leads to the suspicion that it is analogous to the substances placed under this genus. But future experiments must determine whether this suspicion be well or ill founded.

For the discovery of this very singular metallic substance, we are indebted to Mr. Tennant; Fourcroy and Vauquelin, indeed, observed some of its most remarkable properties, but they confounded it with iridium.

Osmium is separated from iridium by the process described when treating of iridium, 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*.

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, 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.

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.

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.

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 disolved in nitro-muriatic acid, and, by distillation, afforded the oxide of osmium with the usual properties.*

Vauquelin has lately examined the properties of osmium.† He has confirmed the experiments of Tennant; but was possessed of too small a quantity of the metal to be able to add much to the chemical description of it.

Such are the properties of the first genus of simple combustible bodies. They are remarkable for the great number of combinations into which they enter, and the important nature of many of

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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.

† Ann. de Chim. lxxxix. 241.

the substances formed either by their union with each other or with the simple supporters.

1. We have found reason to conclude that the weight of the atoms of these bodies may be represented by the following numbers, supposing the weight of an atom of oxygen to be 1.

Hydrogen	0·125	Silicon	1·	Tellurium	4
Carbon	0·75	Phosphorus	1·5	Arsenic	4·75
Boron*	0·875	Sulphur	2		

These numbers are important; because they represent the proportions according to which these bodies enter into combinations. They are all aliquot parts of 0·125, which represents the atom of hydrogen. If, therefore, we represent the weight of an atom of hydrogen by 1, the following numbers will, in that case, be the weight of the atoms of the respective bodies:

Hydrogen	1	Silicon	8	Tellurium	32
Carbon	6	Phosphorus	12	Arsenic	38
Boron	7	Sulphur	16		

This is the mode of representing these atoms, which Mr. Dalton has chosen.

Of these weights that of boron and of silicon are the least certain; because we know only one compound which they form with oxygen. In the present state of our knowledge, however, the weight of an atom of boron and silicon is of comparatively little consequence. The weights of boracic acid and silica, the substances which enter into these combinations with which we are acquainted, are much more important. They have been determined with much more precision, and are as follows:—Boracic acid 2·875 —Silica 2·00.

2. All of these bodies combine with oxygen, some of them with only one proportion; others with two, and some with three of that substance. This will be seen by the following table:

Hydrogen	unites with	1	proportion of oxygen, forming	Water.
Carbon	- -	2	- -	Carbonic oxide. Carbonic acid.
Boron	- -	2?	- -	Oxide of boron? Boracic acid.
Silicon	- -	1	- -	Silica.
Phosphorus	-	3	- -	Hypophosphorous acid. Phosphorous acid. Phosphoric acid.
Sulphur	- -	3	- -	Hyposulphurous acid. Sulphurous acid. Sulphuric acid.
Arsenic	- -	2	- -	Arsenious acid. Arsenic acid.
Tellurium	-	1	- -	Oxide of tellurium.

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* [In page 214 it is 0·66.—C.]

We see that they are all capable of forming acids with oxygen, excepting hydrogen, which forms the neutral compound, *water*.

The order of their affinities for oxygen at a red heat, which seems necessary to promote the action, is as follows:—*Oxygen*, Silicon, Hydrogen, Carbon, Boron, Phosphorus, Sulphur, Arsenic, Tellurium.

The substances placed nearest oxygen have the property of separating that principle from all those after them.

3. They are all capable of combining with chlorine; except carbon. With respect to silicon, indeed, no experiments have hitherto been made. The following table exhibits the number of such combinations at present known:

Hydrogen	unites with chlorine in	1	proportion, forming	Muriatic acid
Carbon	-	0		
Boron	-	1	-	Chloride of boron
Silicon	-	Unknown		
Phosphorus	-	2	-	Protochloride of phosphorus Perchloride of phosphorus
Sulphur	-	1	-	Chloride of sulphur
Arsenic	-	1	-	Chloride of arsenic
Tellurium	-	1	-	Chloride of tellurium

Doubtless many blanks remain in these combinations to be filled up.

With respect to the order of affinities of these bodies for chlorine we know but little. Hydrogen seems capable of depriving most of them of chlorine at a moderately high temperature. But a sufficient number of experiments has not yet been made on the subject.

4. They are all capable likewise of combining with iodine, except carbon. Upon boron and silicon no experiments have been made. The following table shows these combinations as far as known:

Hydrogen	with iodine in	1	proportion, forming	Hydriodic acid
Carbon	-	0		
Boron	-	Unknown		
Silicon	-	Unknown		
Phosphorus	-	2	-	Protiodide of phosphorus Periodide of phosphorus
Sulphur	-	1	-	Iodide of sulphur
Arsenic	-	1	-	Iodide of arsenic
Tellurium	-	1	-	Iodide of tellurium

We see from this table that the combinations of iodine and chlorine with these bodies are exactly analogous.

We have no data to determine the affinities of these different bodies for iodine. Hydrogen will probably be found to have the strongest.

5. Only three of these bodies are known at present to combine with fluorine, and they all form with it very powerful acids. These are

Hydrogen forming Fluoric acid
Boron - - - Fluoboric acid
Silicon - - - Fluosilicic acid.

No experiments have been hitherto made on the combination of the other bodies with fluorine. The affinities of these bodies for fluorine seem to follow an order, the inverse of that in which they stand in the preceding table.

6. All these bodies have the property of combining with hydrogen, and of forming with it a permanently elastic fluid. On silicon, indeed, no experiments have been hitherto made. But we have every reason from analogy to conclude that a gaseous compound of silicon and hydrogen will be hereafter discovered. None of the other simple combustibles have this remarkable property. Two of these gaseous combinations possess acid properties; namely, *sulphureted hydrogen gas* and *tellureted hydrogen gas*. The others are destitute of acidity.

7. But few experiments have been hitherto made upon the compounds which the last seven of these substances are capable of making with each other. The facts ascertained have been detailed in the preceding sections.

8. Hydrogen and carbon are capable of combining with azote, and forming ammonia and cyanogen, two gaseous bodies; the first of which possesses the properties of an alkali; the second of a supporter of combustion.

9. Thus the eight bodies described in the eight preceding sections are distinguished from all the other simple combustibles by two remarkable properties.

I. They all form acids by uniting with the supporters of combustion.

II. They are all capable of entering into gaseous combinations *with hydrogen.*[*]

Neither of the two following genera possess these properties.

GENUS II. ALKALIFIABLE COMBUSTIBLES.

All the substances belonging to this genus are solids, and are usually distinguished by the name of metals. They have the property of uniting to oxygen, and forming with it compounds capable of neutralizing *acids*, and of constituting *salts*. Now such bodies are called *alkalies*. All the salifiable bases are formed from substances belonging to this genus. The only exception is *oxide of tellurium*, which possesses both the properties of an acid and an alkali. Tellurium, therefore, constitutes an intermediate substance between this genus and the preceding, though it is more closely connected with the preceding genus.

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

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[*] If silicon be an exception, we must add, *or a simple supporter of combustion.*

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.

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.

2. They are perfectly opaque, or impervious to light, even after they have been reduced to very thin plates. Silver leaf, for instance, $\frac{1}{100000}$ of an inch thick, does not permit the smallest ray of light to pass through it. Gold, however, when very thin, is not absolutely opaque; for gold leaf $\frac{1}{280000}$ of an inch thick, when held between the eye and the light, appears of a lively green; and must therefore, as Newton first remarked, transmit the green coloured rays. It is not improbable that all other metals, as the same philosopher supposed, would also transmit light if they could be reduced to a sufficient degree of thinness. It is to this opacity that a part of the excellence of the metals, as mirrors, is owing; their brilliancy alone would not qualify them for that purpose.

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.

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 belonging to them all. But several very singular metals, discovered by Davy, are not so heavy as water, and of course much lighter than most stony bodies.* Platinum, the heaviest of the metals, is 21·5 times heavier than water; while the specific gravity of potassium is little more than 0·6, that of water being 1.

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

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* [Hence, for the purpose of ranking the substances which constitute the first family, among metals, a *new definition* of metallic substances becomes necessary.—C.]

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.

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.

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.

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.

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.

The bodies belonging to this genus are 27 in number, and they may, I think, be subdivided into five different families or groups.

FAMILY I.

The substances belonging to this family are six in number. Their names are as follows:

1. Potassium
2. Sodium
3. Calcium
4. Barium
5. Strontium
6. Magnesium

The combinations of these bodies with oxygen possess the alkaline properties in the greatest perfection. They all convert vegetable blues to green. They are all soluble in water except the oxide of magnesium.*

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* [As yet these substances would be better characterised as *metalloids* than as metals; which heretofore have been considered, 1st, as insoluble in water; 2d, as heavier than all stony bodies. Any substance may be considered as a metal, if a definition be expressly fabricated to include it.—C.]

SECTION I.

OF POTASSIUM.

If a sufficient quantity of wood be burnt to ashes, and these ashes be afterwards washed repeatedly with water till it comes off free from any taste, and if this liquid be filtrated and evaporated to dryness, the substance which remains behind is *potash*;* not, however, in a state of purity, for it is contaminated with several other substances, but sufficiently pure to exhibit many of its properties. In this state it occurs in commerce under the name of *potash*. When heated to redness, many of its impurities are burnt off: it becomes much whiter than before, and is then known in commerce by the name of *pearl-ash*. Still, however, it is contaminated with many foreign bodies, and is itself combined with carbonic acid gas, which blunts all its properties. It may be obtained perfectly pure by the following process:

1. Mix it with twice its weight of quicklime, and ten times its weight of pure water: boil the mixture for some hours in a clean iron vessel, or allow it to remain for 48 hours in a close glass vessel, shaking it occasionally. Then pass it through a filter. Boil the liquid obtained in a silver vessel very rapidly, till it is so much concentrated as to assume when cold the consistence of honey. Then pour upon it a quantity of alcohol equal in weight to one-third of the pearl-ash employed. Shake the mixture, put it on the fire, let it boil for a minute or two, then pour it into a glass vessel, and cork it up. The solution gradually separates itself into two strata: the lowest consists of the impurities, partly dissolved in water and partly in a solid state; the uppermost consists of the pure potash dissolved in alcohol, and is of a reddish-brown colour. Decant this alcohol solution into a silver basin, and evaporate it rapidly till a crust forms on the surface, and the liquid below ac-

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* [The common method of making potash in the large way in this country, is as follows. Tubs, or ash vessels in the form of the frustrum of a cone, about 2 feet 6 inches wide at the bottom, and 3 feet 6 inches at the top, and as much in height, are placed on tresles, high enough for a pail or tub to stand on the ground and receive the liquor from the cock inserted in the bottom of the ash-vessel. This last has a false bottom about 4 inches higher than the fixed bottom. The false bottom is bored full of augur holes. It is covered with a layer of clean white poplar sticks or thick twigs: then with 4 inches of clean straw: then with 4 inches of fresh-slacked lime trodden down: then with a layer of 12 inches of ashes trodden down: then with a layer of 4 inches of slacked lime: then with ashes as before. Water is gradually poured in, which filters through the ashes and lime, and percolates clear into the space between the true and the false bottom, where it is drawn off and poured into iron kettles which are heated by a furnace underneath; and this is continued until the water being evaporated, the potash is dug out by iron crows in solid lumps, and packed in barrels for sale.

A full bushel of hearth ashes from an oak wood fire, will furnish from 3 to 4 pounds of potash: a similar bushel of hickory ashes will yield near 6 pounds of ashes. When hearth ashes are at 18 cents per bushel, field ashes, from clearing new ground, are not worth more than 10 cents. In New York state, a purchaser of uncleared land expects to pay the expense of clearing by the produce of the ashes. Pearl ash is potash freed from all carbonaceous matter, by burning it in a reverberating furnace.—C.]

quires such consistence as to become solid on cooling. Then pour the solution into a porcelain vessel. When cold, it concretes into a white substance, which is pure potash. It must be broken to pieces, and put into an air-tight phial.

For this process we are indebted to Berthollet.[*] The following, which was first proposed by Lowitz of Petersburgh, is less expensive. The potash of commerce and quicklime are to be boiled together, as above described. The filtered liquor is then to be evaporated till a thick pellicle appears on its surface, and afterwards allowed to cool; and all the crystals which have formed are to be separated, for they consist of foreign salts. The evaporation is then to be continued in an iron pot; and, during the process, the pellicle which forms on the surface is to be carefully taken off with an iron skimmer. When no more pellicle appears, and when the matter ceases to boil, it is to be taken off the fire, and must be constantly agitated with an iron spatula while cooling. It is then to be dissolved in double its own weight of water. This solution is to be filtered and evaporated in a glass retort[†] till it begins to deposite regular crystals. If the mass consolidates ever so little by cooling, a small quantity of water is to be added, and it must be heated again. When a sufficient number of crystals have been formed, the liquor which swims over them, and which has assumed a very brown colour, must be decanted off, and kept in a well-closed bottle till the brown matter has subsided, and then it may be evaporated as before, and more crystals obtained.[‡]

A still simpler method is employed by Klaproth. He boils equal parts of salts of tartar (carbonate of potash prepared from tartar), and Carrara marble or oyster shells, burnt to lime, with a sufficient quantity of water, in a polished iron kettle. The ley is then strained through clean linen, and though still turbid, is reduced by boiling, till it contain about one half its weight of potash. It is then passed a second time through a linen cloth, and set by in a glass bottle. After some days, when the ley has become clear of itself, it is decanted off from the sediment into another bottle.[§]

That potash was known to the ancient Gauls and Germans cannot be doubted, as they were the inventors of soap, which, Pliny informs us, they composed of ashes and tallow. These ashes (for he mentions the ashes of the beech-tree particularly) were nothing else but potash; not, however, in a state of purity.[||] The κονια, too, mentioned by Aristophanes and Plato, appears to have been a ley made of the same kind of ashes. The alchymists were well acquainted with it; and it has been in every period very much employed in chemical researches. It may be said, however, with justice, that till Berthollet published his process in the year

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[*] Jour. de Phys. xxviii. 401.

[†] Dr. Kennedy observes, very justly, that a glass retort ought not to be employed, because potash in this state dissolves glass. Edin. Trans. v. 97.

[‡] Nicholson's Journal, i. 164.

[§] Klaproth's Beitrage, i. Preface, p. 10.

[||] Plinii, lib. xviii. c. 51.

1786, chemists had never examined potash in a state of complete purity.[*]

2. Potash is a brittle substance of a white colour, and a smell resembling that which is perceived during the slacking of quicklime. Its taste is remarkably acrid; and it is so exceedingly corrosive, that when applied to any part of the body, it destroys it almost instantaneously. On account of this property, it has been called *caustic*, and is often used by surgeons, under the name of the *potential cautery*, to open abscesses, and to destroy useless or hurtful excrescences. Its specific gravity is 1·7085.[†]

3. When potash is perfectly dry,[‡] it is a non-conductor of electricity, but it becomes a conductor when slightly moistened on the surface, a degree of moisture which it acquires by being exposed for a few seconds to the atmosphere. When pieces of potash in this state are placed upon a disc of platinum attached to the negative end of a powerful galvanic battery, and a platinum wire from the positive extremity is made to touch its upper surface, the potash is gradually decomposed, oxygen gas separating at the extremity of the positive wire, while globules of a white metal like mercury appear at the side in contact with the platinum disc. A number of accurate experiments demonstrated to Sir H. Davy that these globules were the basis of potash, and that they were converted into potash by absorbing oxygen. This brilliant discovery was made in the year 1807.[§] To the metallic basis, thus discovered, Davy gave the name of *potassium*.[‖]

Soon after Gay-Lussac and Thenard discovered that potassium could be obtained in greater quantities by passing potash through iron turnings, heated to whiteness in a gun-barrel covered on the outside with clay to protect it from the action of the fire.[¶] This difficult process was improved by Mr. Smithson Tennant in 1814.[**]

The properties of potassium were ascertained with much industry and sagacity by Sir H. Davy.[††] They were likewise examined with much care by Gay-Lussac and Thenard, who corroborated the facts determined by Davy, and added some important ones of their own.[‡‡]

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[*] Potash was long distinguished by the name of *vegetable alkali*, because it is obtained from vegetables, and because it was long thought to be peculiar to the vegetable kingdom; but this is now known to be a mistake. It was called also *salt of tartar*, because it may be obtained by burning the salt called *tartar*. Mr. Kirwan has given it the name of *tartarin;* Klaproth, *kali;* and Dr. Black, *lixiva*. By most British chemists it is called *potash;* but this term, in common language, signifies the carbonate of potash, or the potash of commerce.

[†] Hassenfratz, Ann. de Chim. xxviii. 11.

[‡] [Potash freed from carbonic acid gas, and flowing like oil in a red heat in a crucible contains near 20 per cent. of water, as appears on decomposing it by red-hot iron filings in a gun-barrel. The water is not dissipated by mere heat, but sublimes from the crucible in combination with the potash.—C.]

[§] Davy has given a detailed account of it in Phil. Trans. 1808.

[‖] The German and Swedish chemists call it *kalium*.

[¶] This process is described at length in Recherches Physico-chimiques, i. 74.

[**] Phil. Trans. 1814, p. 587.

[††] Ibid. 1808, p. 1.

[‡‡] Recherches Physico-chimiques, i. 107.

Potassium is white, and it has the metallic lustre as completely as silver or mercury. At the temperature of 50° it is a soft and malleable solid. Its fluidity becomes perfect at 136½, and at 32° it is hard and brittle, and when broken in fragments exhibits a crystalline structure. Nearly a red heat is required to convert it into vapour. Its specific gravity at 60° is 0·86507, so that it is lighter than water. It is an excellent conductor of electricity and of heat.

II. When potassium is exposed to the air, it absorbs oxygen, and is covered with a crust of potash in a few minutes. This crust absorbs water, which is rapidly decomposed, and in a short time the whole becomes a saturated solution of potash. When heated in oxygen gas to the temperature at which it begins to evaporate, it burns with a brilliant white light producing intense heat.

When thrown upon the surface of water it decomposes that liquid with rapidity, and the hydrogen gas evolved, carrying with it small particles of the metal, takes fire in the air, and communicating the combustion to the potassium, the whole burns with a kind of explosion.

Potassium combines with two proportions of oxygen, and forms two compounds, which have received the names of *potash* and *peroxide of potassium.*

1. Potassium is converted into potash when put into water. That liquid is decomposed, giving out hydrogen gas, while its oxygen unites to the potassium and converts it into potash. According to the experiments of Gay-Lussac and Thenard 34·177 grains of potassium when put into water, evolve 40·655 cubic inches of hydrogen gas at the temperature of 59°, and when the barometer stands at 29·351 inches.* Hence, under a pressure of 30 inches of mercury, the quantity of gas evolved would have been 39·776 cubic inches. According to this experiment, 100 grains of potassium, when converted into potash in water, occasions the evolution of 116·38 cubic inches of hydrogen gas. Consequently the potassium must have united with a quantity of oxygen equivalent to 58·19 cubic inches. But 58·19 cubic inches weigh 19·72 grains. According to this experiment, potash is composed of—Potassium 100—Oxygen 19·72.†

Berzelius took an amalgam of potassium, decomposed it by water, saturated the potash by muriatic acid, and then determined its quantity by weighing the salt which he had thus formed. The loss of weight of the amalgam gave him the quantity of potassium. This weight, subtracted from that of the potash, gave the quantity of oxygen with which it had combined. The result of his experiments gave him potash, composed of 100 potassium + 20·525 oxygen;‡ but which he afterwards corrected to the following numbers:§—Potassium 100—Oxygen 20·45.

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* Recherches Physico-chimiques, i. 117.

† [Before these calculations can be admitted, it is necessary to shew that when potassium decomposes water, it unites to oxygen only, and not to water. This has never been shewn to my knowledge; and therefore I consider potassium simply as potash free from moisture. —C.]

‡ Ann. de Chim. lxxx. 245.

§ Annals of Philosophy, iii. 360.

Now the mean of these two sets of experiments gives us potash composed of—Potassium 100—Oxygen 20·08. Hence, I think, we may without hesitation adopt the following as the true proportions in which the constituents of potash combine:—Potassium 100—Oxygen 20.

If we consider potash as a compound of 1 atom potassium and 1 atom oxygen, and nothing appears contrary to this supposition; then it follows that the weight of an atom of potassium is 5, and that of an atom of potash 6: 6 accordingly is the equivalent number according to which potash enters into all combinations.

2. The peroxide of potassium was discovered in 1810, by Gay-Lussac and Thenard. It is formed by heating potassium in a glass jar filled with oxygen gas. A vivid combustion takes place, and a great deal of oxygen gas is absorbed. From the experiments of Gay-Lussac and Thenard, it appears that 100 grains of potassium, when thus burnt, are capable of absorbing 177 cubic inches of oxygen gas. Hence this peroxide is composed of—Potassium 100 or 5—Oxygen 60 or 3—So that it is a compound of 1 atom potassium and 3 atoms oxygen.

This peroxide is a solid body of a yellow colour. It fuses when exposed to a temperature higher than is requisite to fuse common caustic potash. On cooling, it crystallizes in plates. When put into water it effervesces, and is reduced to the state of potash, giving out the excess of oxygen which it contained. When brought in contact with phosphorus, sulphur, and carbon, combustion takes place when the temperature is raised; these bodies are acidified, and the acids formed unite to the potash. When surrounded with hydrogen and heated, that gas is absorbed without the appearance of light, and much water is formed. In like manuer, sulphurous acid, and protoxide of azote, are acidified when it is heated in them. Ammonia is decomposed, water being formed and azotic gas disengaged.*

3. Gay-Lussac and Thenard describe a third oxide of potassium containing less oxygen than potash. But they have produced no evidence that it is any thing else than a mixture of potassium and potash.†

III. Potassium combines readily with chlorine, and forms a compound called *chloride of potassium.*

When potassium is introduced into chlorine gas, it burns with a brilliant red flame, the chlorine is absorbed, and the whole is converted into a white saline mass. This substance is *chloride of potassium.* If potash be heated in chlorine gas its oxygen is disengaged, while the chlorine is absorbed and takes its place. It appears from this experiment, which was made by Davy, that at a red heat potassium has a stronger affinity for chlorine than it has for oxygen.

1. Chloride of potassium has been long known to chemists. It

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* Recherches Physico-chimiques, i. 128.

† Ibid. p. 125.

was formerly distinguished by the names of *febrifuge* or *digestive salt of Sylvius;* and Boerhaave called it *regenerated sea salt.* The French chemists gave it the name of *muriate of potash*, which it retained till its true nature was pointed out by Sir Humphry Davy. That gentleman proposed to distinguish it by the term *potassane;* but I consider the name which I have given it as more systematic, and therefore preferable.

2. It is easily obtained by saturating potash with muriatic acid, and exposing the compound formed to a red heat. At that temperature, it seems the oxygen of the potash unites with the hydrogen of the acid, and converts it into water while the potassium and chlorine remain united.

3. This chloride is white, and seems to crystallize in cubes. Its taste is somewhat similar to that of common salt, but more inclined to bitter. Its specific gravity is 1·836. When boiled in water it dissolves in 1·7 times its weight of that liquid.[*] It requires thrice its weight of cold water.[†] But this difference is not sufficient to enable us to obtain regular crystals, by allowing a saturated boiling solution of it to cool. Regular crystals can only be obtained by abandoning the solution to spontaneous evaporation. It suffers but little alteration in the air. It is not sensibly soluble in alcohol.

Many accurate experiments have been made on the composition of this salt, on the supposition that it is a compound of muriatic acid and potash. The most accurate of these are the three following:

Acid	35[‡]	35·85[§]	36[‖]
Base	65	64·15	64
Total	100	100·	100

The last two of these analyses almost coincide. If we correct them by depriving the potash of its oxygen, and adding the amount to the acid, we shall find the composition of the chloride

	Berzelius.	Kirwan.
Chlorine	48·114	48
Potassium	53·46	53·333

Now, if we suppose it a compound of 1 atom chlorine and 1 atom potassium, its constituents will be

Chlorine	4·5	48·6	90
Potassium	5	54	100

Now these numbers coincide so nearly with the preceding analysis, that we can have no doubt about their accuracy.

IV. Potassium combines readily with iodine, and forms a compound which we shall call *iodide of potassium.*

When the vapour of iodine comes in contact with potassium the

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[*] Wenzel's Verwandtschaft, p. 310.

[†] Bergman, Opusc. i. 134.

[‡] Wenzel's Verwandtschaft, p. 100.

[§] Berzelius, Ann. de Chim. lxxvii. 84.

[‖] Kirwan, Nicholson's Quarto Journal, iii. 215.

metal takes fire and burns with a violet coloured flame, while the iodine is absorbed. The compound melts, and is volatilized at a temperature below redness. On cooling it crystallizes, and assumes a pearly lustre. It dissolves readily in water, and the solution does not alter vegetable blues. This iodide has not been analysed; but there can be little doubt that it consists of an atom of iodine combined with an atom of potassium, or of

Iodine	15·625	100
Potassium	5·000	32

V. Nothing is known respecting the combination of potassium with *fluorine*. It does not appear capable of uniting with *azote*.

VI. When potassium is heated in hydrogen gas a portion of it is volatilized, and remains mixed with the gas. The hydrogen, in consequence, acquires the power of burning spontaneously when mixed with common air or oxygen gas. But if the gas be kept it speedily deposits the potassium, and is reduced to its ordinary state. We cannot, therefore, consider this as a gaseous compound of potassium and hydrogen.

When potassium is heated in hydrogen gas, there is a particular temperature intermediate between a red heat and the common temperature of the air, at which the metal absorbs the gas and is converted into a *hydruret*. This hydruret has a grey colour, and is destitute of the metallic lustre. It is infusible, and does not burn spontaneously either in common air or oxygen gas. In water it is converted into potash, and the hydrogen which it contains is disengaged along with what proceeds from the water decomposed.* According to Gay-Lussac and Thenard, to whom we are indebted for the discovery of this hydruret, the quantity of hydrogen which potassium absorbs is rather more than ¼th of what it disengages from water when converted into potash. Now 100 grains of potassium evolve from water 116·4 cubic inches of hydrogen. The fourth part of 116·4 is 29·1. But 29·1 cubic inches of hydrogen gas weigh 0·616 grain. So that hydruret of potassium is composed of

Potassium	100	5
Hydrogen	0·616	0·0308

But 0·0308 × 4 = 0·1232, which is nearly equivalent to the weight of an atom of hydrogen. We have reason, therefore, to conclude that this hydruret is a compound of 4 atoms potassium and 1 atom hydrogen. If so, its constituents are

Potassium	5	100
Hydrogen	0·03125	0·625

According to this statement 100 grains of potassium, in order to be converted into a hydruret, must absorb 29·5 cubic inches of hydrogen. But this I consider as in reality ¼th of the hydrogen which potassium disengages from water when it is converted into potash.

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* Recherches Physico-chimiques, i. 176.

VII. We are not acquainted with any combination which potassium forms with *carbon*, *boron*, or *silicon*.

VIII. When potassium is heated in contact with phosphorus, a combination takes place with the evolution of a weak light. The phosphuret formed has a chocolate colour, and is similar in appearance to phosphuret of lime. It burns in the open air, and when thrown into water a kind of detonation takes place in consequence of the rapid evolution of phosphureted hydrogen gas. If we suppose this phosphuret a compound of one atom potassium and 1 atom phosphorus, its composition will be

Potassium	5	100
Phosphorus	1·5	30

IX.* Potassium combines with sulphur with great energy when the two substances are heated together. A violent combustion accompanies their union. This sulphuret has a dark grey colour. When thrown into water it acts upon that liquid with violence, producing sulphureted hydrogen gas. When heated in the air it burns brilliantly, and is converted into *sulphate of potash*. From this experiment it follows that this *sulphuret* is composed of 1 atom potassium and 1 atom sulphur, or of

Potassium	5	100
Sulphur	2	40

X. Arsenic combines readily with potassium by the application of a moderate heat. Light is evolved during the combination. This *arseniuret* has a brown colour, and little of the metallic lustre. When put into water much less hydrogen gas is evolved than would have appeared if the potassium had not been alloyed with the arsenic. The reason is, that a portion of it remains combined with the arsenic, forming a solid hydruret of arsenic.†

XI. The alloy of potassium and tellurium has not been examined.

Potassium has so great an affinity for oxygen that it separates that body from every one of the combustible substances belonging to the preceding genus. The order of its affinities for the supporters of combustion at a red heat are as follows:—*Potassium*—Chlorine—Iodine—Oxygen. Of the simple acidifiable combustibles it has the strongest affinity for sulphur. Phosphorus comes next, and then hydrogen.

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* [From an account of a paper of Vauquelin, in 8 Brande's Journ. 375, it appears, that the combinations of sulphur with the alkaline oxides, are proportionate to the quantities of oxygen, with which these alkalies can unite: and thus a perfect resemblance is established between the acids and sulphur, in this respect. In the dry way, in 100 parts, there are Potash 47·3; Sulphur 52·7; Soda 38; Sulphur 62; Lime 74; Sulphur 26. In the moist way, Lime 60; Sulphur 40; Barytes 65·5; Sulphur 34·5.

100 parts of Sulphat barytes contain	34 acid	100 parts of Dry sulphat lime contain	58 acid
Sulphuret barytes	34·5 sulp.	Sulphuret lime	63 sulp.
Dry sulphat soda	64 acid	Dry sulphat potash	47 acid
Sulphuret soda	62 sulp.	Sulphuret potash	52·7 sulp.

C.]

† Gay-Lussac and Thenard. Recherches Physico-chimiques, i. 224.

SECTION II.

OF SODIUM.

Soda, called also *fossil* or *mineral alkali*,* because it was thought peculiar to the mineral kingdom, was known to the ancients (though not in a state of purity) under the names of *νιτρον* and *nitrum*.†

It is found in large quantities combined with carbonic acid in different parts of the earth, especially in Egypt; and common salt is a compound of soda and muriatic acid. But the soda of commerce is obtained from the ashes of different species of the *salsola*, a genus of plants which grow upon the sea-shore, especially from the *salsola soda*, from which the alkali has obtained its name. The soda of commerce is also called *barilla*, because the plant from which it is obtained bears that name in Spain. Almost all the algæ, especially the fuci, contain also a considerable quantity of soda. The ashes of these plants are known in this country by the name of *kelp;* in France they are called *varec*.

The soda, or barilla, of commerce, is far from being pure; besides carbonic acid it contains common salt, and several other foreign ingredients; but it may be obtained perfectly pure by the processes described in the last section for purifying potash.

Soda and potash resemble each other so nearly, that they were confounded together till Du Hamel published his dissertation on common salt in the Memoirs of the French Academy for 1736. He first proved that the base of common salt is soda, and that soda is different from potash. His conclusions were objected to by Pott, but finally confirmed by Margraf in 1758.‡§

Soda is of a greyish-white colour, and agrees exactly with potash in its taste, smell, and action upon animal bodies; but its specific gravity is only 1·336.‖

Heat produces on it exactly the same effects as upon potash. When exposed to the air, it absorbs moisture and carbonic acid, and is soon reduced to the consistence of paste: but it does not liquify like potash; in a few days it becomes dry again, and crumbles into powder.

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* Klaproth calls it *natron*, and the German and Swedish chemists have followed his example.

† The *λιτρον* of the Athenians was evidently the same substance; and so was the נתר of the Hebrews.

‡ Opusc. ii. 331.

§ [To distinguish potash from soda, when contained in water: 1st. A few drops of carbonated or uncarbonated potash, let fall into a solution of tartaric acid, forms cream of tartar, which is held in solution with great difficulty, and therefore falls: too much of the alkaline liquor will re-dissolve it. 2d. The alkali of potash will readily decompose the muriat of platinum, which will not be decomposed by soda. Potash is also separable from its acids in neutral salts by the fluo-silicic acid, as Mr. J. L. Wheeler has shewn in 8 Brande's Journ. 287.—C.]

‖ Hassenfratz, Ann. de Chim. xxviii. 11.

Many contradictory opinions respecting the component parts of soda were advanced by different chemists. At last, in 1808, Sir Humphry Davy succeeded in decomposing it, by the same process which enabled him to obtain the basis of potash. Like that alkali its basis is a metal, and Davy distinguished it by the name of *sodium.*[*]

Davy published a full account of its properties soon after its discovery.[†] Gay-Lussac and Thenard succeeded in procuring it in large quantities by the process described in the last section for obtaining potassium. They likewise examined its properties in detail, and published an elaborate account of them.[‡] Berzelius made a set of very careful experiments in order to determine the proportions in which it combines with oxygen.[§]

Sodium is a white metal, having a colour intermediate between that of silver and lead. At the common temperature of the air it is solid and very malleable, and so soft that pieces of it may be welded together by strong pressure. It retains its softness and malleability at the temperature of 32°. It is an excellent conductor of electricity. Its specific gravity is 0·97223.[‖] It melts when heated to the temperature of 194°,[¶] and requires a much higher temperature to be volatilized than potash. Davy found it to remain fixed at a heat which melted plate glass.

II. Its affinity for oxygen is similar to that of potassium. When exposed to the air it speedily is converted on the surface to soda. As soda deliquesces much more slowly than potash, a globule of sodium is not so soon destroyed by exposure to the atmosphere as a globule of potassium. When put into water that liquid is rapidly decomposed; its hydrogen escapes in the state of gas while its oxygen converts the sodium into soda. Sodium, like potassium, combines with two doses of oxygen, and forms two compounds, which are called *soda* and *peroxide of sodium.*

1. Soda is formed when the metal is brought in contact with water. From the experiments of Gay-Lussac and Thenard, it appears that 38·394 grains of sodium, when converted into soda by decomposing water, occasion the evolution of a quantity of hydrogen gas, which, at the temperature of 60°, and when the barometer stands at 29·882 inches, amounts to 76·437 cubic inches.[**] Therefore, supposing the barometer at 30 inches, the amount would be 76·14 cubic inches. Consequently 100 grains of sodium would cause the evolution of 198·30 cubic inches of hydrogen gas. The quantity of oxygen which united to the sodium to convert it into soda must have been equivalent to 99.15 cubic inches, amounting

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[*] The German and Swedish chemists call it *natrium* or *natron*.

[†] Phil. Trans. 1808, p. 1.

[‡] Recherches Physico-chimiques, i. 97.

[§] Ann. de Chim. lxxx. 245.

[‖] By the experiments of Gay-Lussac and Thenard. Davy makes it 0·9348. But his experiment was on a very minute scale.

[¶] Gay-Lussac and Thenard.

[**] Recherches Physico-chimiques, i. 121.

in weight to 33·6 grains. According to these data soda is a compound of—Sodium 100—Oxygen 33·6. Berzelius found, by a set of very careful experiments, that 100 sodium, when converted into soda, combine with 34·61 parts of oxygen,[*] which he afterwards corrected into 34·52.[†] Davy says that, in a careful set of experiments which he made on the subject, he found soda a compound of from 75 to 73 sodium, and from 25 to 27 oxygen.[‡] Now the mean of the experiments of Gay-Lussac and Thenard, and of those of Berzelius, give 34·06 as the quantity of oxygen; while one of Davy's results is 33⅓. I think, therefore, we cannot hesitate to conclude that sodium, in order to be converted into soda, must combine with exactly one-third of its weight of oxygen. Hence soda is composed of—Sodium 100—Oxygen 33·3. If we consider soda as a compound of 1 atom sodium and 1 atom oxygen, the weight of an atom of sodium will be 3, and the weight of an atom of soda 4.

2. The peroxide of sodium was discovered by Gay-Lussac and Thenard. It is easily formed by heating sodium in oxygen gas. It burns with great splendour, and combines with a maximum of oxygen.

The peroxide of sodium, when pure, is of a dirty greenish yellow colour. It is fusible when heated, but requires a much higher temperature than the peroxide of potassium for its fusion. When introduced into water, it is reduced to soda, giving out the excess of oxygen which it contains. From the experiments of Gay-Lussac and Thenard, it appears, that sodium in the peroxide is united with 1½ times as much oxygen as in soda.[§] Hence it is composed of sodium 100 - - 2—oxygen 50 - - 1. But we cannot conceive it to be a compound of 1 atom sodium + 1½ atom oxygen; because atoms are considered as incapable of farther division. The only other alternative is to suppose it a compound of 2 atoms sodium and 3 atoms oxygen. On that supposition an integrant particle of it will weigh 9.

The action of the different combustible bodies and gases on the peroxide of sodium, as far as that action has been examined, bears a close resemblance to their action on peroxide of potassium.[‖]

II. Sodium combines with great energy with chlorine, and forms a compound which may be called *chloride of sodium*.

When sodium is introduced into chlorine gas, it takes fire spontaneously and burns vividly, emitting bright red sparks. The substance formed is *chloride of sodium*. It may be formed, likewise, by passing a current of chlorine gas over soda, previously heated to redness. The soda gives out its oxygen in the state of gas, and is converted into a chloride.[¶]

Chloride of sodium has been known, and in common use as a sea-

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[*] Ann. de Chim. lxxx. 251.

[†] Annals of Philosophy, iii. 360.

[‡] Ann. de Chim. lxxx. 251.

[§] Recherches Physico-chimiques, i. 152.

[‖] Recherches Physico-chimiques, i. 154.

[¶] Davy.

soner of food from the earliest ages, under the names of *common* or *sea salt*. Sometimes, also, it was called *sal gem*. Glauber knew that muriatic acid could be obtained from it. Stahl, in his *Specimen Beccherianum*, affirmed that its base is an alkali. But Duhamel was the first who showed how to obtain this base in a separate, state, and who demonstrated the difference between it and potash. The true nature of this substance was first shown by Sir Humphry Davy.

This chloride exists in great abundance native, and therefore is never formed artificially by chemists. Immense masses of it are found in different countries, which require only to be dug out and reduced to powder. In that state it is called *rock salt*. The water of the ocean also contains a great proportion of it, to which indeed it owes its state, and the power which it possesses of resisting freezing till cooled down to 28.5°. When this water is evaporated sufficiently, the chloride precipitates in crystals. It is by this process that it is obtained in this country. But the common salt of commerce is not sufficiently pure for the purposes of chemistry, as it contains usually muriate of magnesia, &c.; but it may be obtained pure either by repeated crystallizations, or by the following process: Dissolve it in four times its weight of pure water, and filter the solution. Drop into it a solution, first of muriate of barytes, then of carbonate of soda, as long as any precipitate continues to fall. Separate the precipitates by filtration, and evaporate slowly till the salt crystallizes.

Common salt usually crystallizes in cubes, which, according to Haüy,[*] is the primitive form of its crystals and of its integrant particles. Sometimes the angles of the cubes are truncated; and in urine the crystals of common salt, as Fourcroy and Vauquelin have ascertained, assume the form of octahedrons.

Its taste is universally known, and is what is strictly speaking denominated *salt*. Its specific gravity is 2·125.[†] According to Bergman, it is soluble in 2.82 times its weight of cold water, and in 2·76 times its weight of boiling water.[‡] When it is boiled for some time in water, it dissolves in 2·59 times its weight of that liquid.[§] The specific gravity of the saturated solution is 1·198, temperature 42°.[‖] Pure alcohol does not dissolve this salt, but it is somewhat soluble in alcohol of ·830.

It is not affected by exposure to dry air. The common salt of commerce, indeed, contains a quantity of muriate of magnesia, which renders it deliquescent. It contains, also, sulphate of magnesia and sulphate of lime.

When heated, it decrepitates. In a red heat it melts, and at a white heat it evaporates in a white smoke without undergoing decomposition.

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[*] Mineralogy, ii. 357.

[†] Fahrenheit; Phil. Trans. 1724, vol. xxxiii. 114. Kirwan makes it 2·120, and Dr. Watson found it 2·143. See his Essays, v. 67.

[‡] Opusc. i. 134.

[§] Wenzel's Verwandtschaft, p. 310.

[‖] Watson's Chem. Essays, v. 85.

Numerous very careful experiments have been made to determine the composition of this chloride. The three following appear to me to be entitled to the greatest confidence.

	Berzelius.[*]	Wenzel.[†]	Marcet.[‡]
Muriatic acid	45·74	46	46
Soda	54·26	54	54
	100	100	100

We shall obtain the true composition of the chloride by subtracting ¼th of its weight from the soda to reduce it to sodium, and adding the same quantity to the acid to convert it into chlorine. This will give us the constitution of the chloride as follows.

	Berzelius.	Wenzel.	Marcet.
Chlorine	59·305	59·5	59·5
Sodium	40·695	40·5	40·5
	100·000	100·0	100·0

Now if we suppose it a compound of 1 atom sodium and 1 atom chlorine, its constituents by weight will be

Chlorine	4·5	60	150
Sodium	3	40	100

These numbers almost coincide with the above analysis. There cannot, therefore, be any doubt that the true composition is as just stated.

III. No experiments have been hitherto made on the combination of *iodine* and sodium. There cannot, however, be a doubt that they are capable of combining and forming an *iodide of sodium.* Hydriodic acid readily combines with soda, and forms a salt which crystallizes in large prisms, very similar to sulphate of soda. It is very soluble in water, and deliquescent. When this salt is dried, we may consider it as an iodide of sodium.[§] It has not hitherto been analysed. But we may consider it from analogy as composed of 1 atom sodium + 1 atom iodine, or by weight of

Iodine	15·625	100
Sodium	3·	19·2

IV. Nothing is known respecting the combination of sodium with *fluorine.* It does not appear to have the property of combining with *azote.*

V. Sodium, as far as is known at present, does not combine with *hydrogen*, *carbon*, *boron*, nor *silicon.*

VI. Sodium combines readily with phosphorus, when it is brought in contact with that substance and heat applied. A feeble light appears during the combination. It has the colour and appearance of lead. Water converts it into phosphate of soda. When heated in the open air it is likewise converted into phosphate of soda. This

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[*] Ann. de Chim. lxxvii. 84.

[†] Verwandtschaft, p. 101.

[‡] Nicholson's Journal, xx. 30.

[§] Gay-Lussac, Ann. de Chim. xci. 56.

conversion shows, that the *phosphuret of sodium* is a compound of 1 atom sodium and 1 atom phosphorus; or by weight of

Sodium	3	200
Phosphorus	1·5	100

VII. Sodium combines with sulphur, when heated with it in close vessels, with great vividness, much heat and light being evolved. *Sulphuret of sodium* has a deep grey colour. When heated in the open air it takes fire, and is converted into sulphate of soda. Therefore it is a compound of 1 atom sodium + 1 atom sulphur; or by weight of

Sodium	3	150
Sulphur	2	100

VIII. It unites with arsenic when placed in contact with it, and raised to a cherry-red heat. A feeble light is emitted at the moment of combination. An alloy of 1 volume sodium and 3 volumes of arsenic has a greyish white colour, is brittle, is fine granular, and has a strong taste. It is rapidly decomposed in the open air. When put into water it is soon separated into soda and a brown powder which is a hydruret of arsenic. Some hydrogen gas, likewise, makes its escape. An alloy of 2 volumes sodium and 1 volume arsenic has a brown colour and earthy aspect without any metallic lustre. Water produces on it the same effects as upon the last-mentioned alloy.*

IX. The alloy of sodium and tellurium is still unknown.

X. Potassium and sodium readily unite together, and form a brittle crystallizable alloy, always more fusible than sodium, and often more so than potassium. Three parts of sodium, and one of potassium form an alloy which fuses at 32°, and crystallizes when plunged into a mixture of snow and salt. If we increase the quantity of sodium (while the potassium remains as before) the alloy becomes less fusible; but it is always more fusible than sodium, and always brittle and crystallizable. One thirtieth of potassium is sufficient to give these properties to sodium in a marked degree, and to communicate to it the colour of silver. If we unite less than 3 parts of sodium with 1 part of potassium, we obtain alloys becoming more and more fusible. The fusibility does not diminish till the quantity of potassium be very considerable. Ten parts of potassium and 1 of sodium form an alloy still liquid at 32°, and lighter than naphtha.†

The affinities of the simple supporters of combustion for sodium are in the following order. *Sodium*, Chlorine, Iodine, Oxygen.

Potassium has a stronger affinity for each of these bodies than sodium has. Hence one of the easiest methods of procuring sodium is to heat a mixture of potassium and common salt in close vessels. Sodium is separated from the common salt.

Sulphur has the strongest affinity for sodium of the acidifiable combustibles.

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* Recherches Physico-chimiques, i. 244.

† Gay-Lussac and Thenard, Recherches Physico-chimiques, i. 111.

SECTION III.

OF CALCIUM.

LIME has been known from the earliest ages. The ancients employed it in medicine; it was the chief ingredient in their mortar; and they used it as a manure to fertilize their fields.

Lime abounds in most parts of the world, or perhaps I should rather say, that there is no part of the world where it does not exist. It is found purest in limestones, and marbles, and chalk. None of these substances, however, is, strictly speaking, lime; but they are all capable of becoming lime by a well-known process, by keeping them for some time in a white heat: this process is called *the burning of lime*. The product which in common language is denominated *quicklime* is the substance known in chemistry by the name of *lime*.

1. Lime may be obtained perfectly pure by burning those crystallized limestones, called *calcareous spars*, which are perfectly white and traasparent, and also by burning some pure white marbles.* It may be procured also in a state of purity by dissolving oyster-shells in muriatic acid, filtering the solution, mixing it with ammonia as long as a white powder continues to fall, and filtering again. The liquid is now to be mixed with a solution of carbonate of soda: the powder which falls, being washed and dried, and heated violently in a platinum crucible, is pure lime.

2. Pure lime is of a white colour, moderately hard, but easily reduced to a powder.

It has a hot burning taste, and in some measure corrodes and destroys the texture of those animal bodies to which it is applied. Its specific gravity is 2·3.† It tinges vegetable blues green, and at last converts them to yellow.

With respect to the composition of lime nothing better than conjecture was advanced on the subject, till Davy's great discovery of the bases of potash and soda. This naturally led him to the idea that lime and the other earthy bodies possessing properties similar to lime, were likewise compounds of oxygen and particular metals.

He accordingly exposed them in various states to the action of a galvanic battery, and found reason to conclude that his opinion of their nature was correct, though he found it much more difficult to decompose them and obtain their bases, than it had been to obtain potassium and sodium by similar processes. When acted upon under naphtha they were not distinctly decomposed. When fused with an excess of potash, and acted upon in that state, the results were rather more distinct, metallic substances appeared less fusible

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* [Almost all the marbles called primitive by the geologists, contain magnesia, from their vicinity to steatite and serpentine.—C.]

† Kirwan's Miner. i. 5.

than potassium, which burnt the instant after they were formed, and produced a mixture of potash and the earth employed. When the earths were exposed to the action of electricity, mixed with the oxides of mercury, tin, lead, or silver, amalgams were produced, which exhibited properties indicating unequivocally that they were mixtures of the base of the earth employed and of the base of the metallic oxide mixed with it. But the quantity of amalgam obtained was too minute to admit of an accurate examination. While Sir H. Davy was engaged in these experiments, he received a letter from Professor Berzelius of Stockholm, informing him that he and Dr. Pontin had succeeded in decomposing barytes and lime, by negatively electrifying mercury in contact with them. Davy immediately repeated this happy experiment, and succeeded completely in obtaining amalgams of the base of the earth employed.

To procure these amalgams in sufficient quantity for distilling off the mercury, and obtaining the base of the earth pure, Davy combined his own previous method with that of Berzelius and Pontin. The earth was slightly moistened, mixed with one third of red oxide of mercury, and placed upon a plate of platinum connected with the positive end of the battery. A cavity was made in the earthy mixture, a globule of about 60 grains of mercury put into it, and this globule connected with the negative end of the battery by a platinum wire. The amalgams obtained in this way were distilled in glass tubes filled with the vapour of naphtha. The greater part of the mercury was easily driven off, but it was extremely difficult to separate the whole. The globule that remained behind was in all cases white like silver, solid, and extremely combustible. When exposed to the air it absorbed oxygen, and regenerated the earth from which it was obtained in a few minutes.

The metallic basis of lime Davy has called *calcium*. He did not succeed in investigating its properties. It is white like silver, solid, and probably 4 or 8 times heavier than water. When heated in the open air it burns brilliantly, and quicklime is produced.*

II. Calcium as far as is known at present combines with only 1 proportion of oxygen, and forms the well known and important oxide called *lime*. The attempts to determine the proportion of oxygen in lime by the loss of weight which the amalgam of calcium underwent when put into water, and by the quantity of lime formed, though made by Berzelius with very great care, were upon so small a scale that great confidence cannot be placed in their accuracy. The mean of three trials made in this way gives the composition of lime as follows:†—Calcium 100—Oxygen 38·57. But from other considerations he has fixed the proportions,—Calcium 100—Oxygen 39·21.‡ There is a method of coming to considerable certainty with respect to the accuracy of these numbers. Sulphate of lime has been analysed with great care, and is a compound of

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* Phil. Trans. 1808, p. 333.

† Ann. de Chim. lxxxi. 13.

‡ Annals of Philosophy, iii. 360.

Sulphuric acid	100	5
Lime	72·41	3·6205

Carbonate of lime has been likewise analysed with great care. It has been found composed of

Carbonic acid	43·2	2·75
Lime	56·8	3·615

From the first of these salts it appears that, if the weight of sulphuric acid be represented by 5, the equivalent number for lime will be 3·6205. From the second we see, that if the weight of carbonic acid be represented by 2·75, the equivalent number for lime will be 3·615. These two numbers very nearly agree. I conceive we may therefore without committing any sensible error consider 3·625 as the true equivalent number for lime. As calcium combines with only one proportion of oxygen, we must suppose lime a compound of 1 atom calcium + 1 atom oxygen. On that supposition its constituents will be

Calcium	2·625	100
Oxygen	1·000	38·09

So that the composition of lime agrees very nearly with the original experiments of Berzelius.

III. When lime is heated in chlorine gas it is decomposed. It gives out its* oxygen in the form of gas, and the calcium combines with the chlorine, forming a *chloride of calcium*. From the experiments of Davy, to whom we are indebted for this very curious fact, it follows that for every volume of oxygen evolved two volumes of chlorine gas are absorbed. Hence it follows that chloride of calcium is composed of 1 atom chlorine united to 1 atom calcium. Its constituents therefore are

Chlorine	4·5	100	63·16
Calcium	2·625	58·3	36·84

Chloride of calcium is the substance distinguished among chemists by the name of *muriate of lime*. It was formerly called *fixed ammoniac*, because it was commonly obtained by decomposing sal ammoniac by means of lime.

It is usually prepared from the residue of that process, but it may be obtained by dissolving carbonate of lime in muriatic acid.

Its crystals are six-sided striated prisms, terminated by very sharp pyramids. It is not easy to procure it in crystals, in consequence of its extreme tendency to deliquesce. Indeed, in summer, it is next to impossible to procure good crystals; but in winter they form spontaneously, if we dissolve four parts of the salt, in one of water, of the temperature of 70°, and expose the solution in an atmosphere of 32°.

The taste of this salt is very bitter and pungent. Its specific gravity is 1·76.†

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* [Whether the oxygen proceeds from the lime, or from the chlorine, depends upon the settlement of the long litigated question concerning the nature of chlorine.—C.]

† Hassenfratz, Ann. de Chim. xxviii. 12.

It is extremely soluble in water; water at 60° dissolving very nearly four times its weight of it. The solubility diminishes very rapidly with the temperature. Hence water at 30° does not dissolve above half that quantity, while at 100° it dissolves any quantity of it whatever. In hot weather, therefore, it cannot be obtained in crystals, but only in a hard, white, solid mass. Mr. Walker has ascertained, that when the evaporation of the solution is carried on till its specific gravity is 1·450 at the temperature of 80°, it crystallizes when exposed to an atmosphere whose temperature is 32°. When its specific gravity at 80° is 1·490, it assumes on cooling the form of a hard pearl-coloured mass.*

Alcohol dissolves this salt so copiously when concentrated, that I presume it is capable of taking up considerably more than its own weight of the salt, even though previously exposed to a red heat to dissipate the moisture. So much heat is evolved during the solution as to cause the alcohol to boil.

When this salt is exposed to the air, it attracts moisture very speedily, and deliquesces.

When exposed to the action of heat, it swells up, melts, and then loses its water of crystallization. A violent heat separates a small portion of muriatic acid. When thus altered, it has the property of shining in the dark, as Homberg first observed: Hence it has been called the *phosphorus of Homberg*.

Of the experiments hitherto made to determine the constituents of this chloride, the following are the most accurate.

	Wenzel.†	Marcet.‡	Berzelius.§
Acid	51	49·23	48·1
Lime	49	50·77	51·9
	100	100·00	100·0

When these analyses are corrected by converting the lime into calcium according to the data established above, we obtain the composition of this chloride as follows:

	Wenzel.	Marcet.	Berzelius.
Chlorine	64·52	63·23	62·41
Calcium	35·48	36·77	37·59
	100·00	100·00	100·00

If we compare these analyses with the numbers deduced from the oxygen gas evolved, which I consider as exact, it will be seen that the analysis of Dr. Marcet is nearest the truth.

IV. Iodine of calcium may be obtained by combining hydriodic acid and lime, and exposing the compound to a strong heat. The hydriodate of lime is a very soluble and deliquescent salt. This iodide has not been analysed, but there can be no doubt that it is a compound of 1 atom iodine and 1 atom calcium, or of Iodine 15·625—Calcium 3·625.

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* Nicholson's Journal, v. 226.

† Verwandtschaft, p. 103.

‡ Nicholson's Journal, xx. 29.

§ Ann. de Chim. lxxvii. 84.

When lime is heated in vapour of iodine no oxygen gas is evolved. Hence it appears that oxygen has a greater affinity for calcium than iodine has.

V. We are ignorant of all the combinations which calcium may be capable of forming with fluorine, azote, and the whole of the simple acidifiable combustibles. It combines with potassium and sodium, but we know nothing respecting the nature of these alloys.

The affinity of calcium for the supporters of combustion are in the following order: *Calcium*—Chlorine—Oxygen—Iodine.

SECTION IV.

OF BARIUM.

Barytes was discovered by Scheele in 1774; and the first account of its properties published by him in his Dissertation on Manganese.[*] There is a very heavy mineral, most frequently of a flesh colour, of a foliated texture and brittle, very common in Britain and most other countries, especially in copper mines. It was known by the name of *ponderous spar*, and was supposed to be a compound of sulphuric acid and lime. Gahn analysed this mineral in 1775, and discovered that it is composed of sulphuric acid and the new earth discovered by Scheele.[†] Scheele published an account of the method of obtaining this earth from ponderous spar.[‡] The experiments of these chemists were confirmed by Bergman,[§] who gave the earth the name of *terra ponderosa*. Morveau gave it the name of *barote*, and Kirwan of *barytes*;[‖] which last was approved of by Bergman,[¶] and is now universally adopted. Different processes for obtaining barytes were published by Scheele, Bergman, Wiegleb, and Afswelius; but little addition was made to the properties ascertained by the original discoverer, till Dr. Hope published his experiments in 1793.[**] In 1797, our knowledge of its nature was still farther extended by the experiments of Pelletier, Fourcroy, and Vauquelin.[††]

Barytes may be obtained from ponderous spar, or sulphate of barytes, as it is now called, by the following process, for which we are indebted to Scheele and Vauquelin. Reduce the mineral to a fine powder; mix it with the eighth part of its weight of charcoal powder, and keep it for some hours red hot in a crucible, and it will be converted into sulphuret of barytes. Dissolve the sulphuret in water, and pour nitric acid into the solution, and the sulphur will be precipitated. The solution, which consists of nitric acid

[*] Scheele, i. 61 and 78, French Translation.

[†] Bergman's Notes on Scheffer, § 167.

[‡] Crell's Annals, iii. 3, Eng. Trans.

[§] Opusc. iii. 291.

[‖] From Βαρυς, heavy.

[¶] Opusc. iv. 261.

[**] Edin. Trans. iv. 36.

[††] Ann. de Chim. xxi. 113 and 276.

combined with barytes, is to be filtered and evaporated slowly till it crystallizes. Put the crystals into a crucible, and expose them gradually to a strong heat; the nitric acid is driven off, and the barytes remains in a state of purity.*

Another method, attended with less expense, was pointed out long ago by Dr. Hope, and afterwards improved by Pelletier. The method is this: Decompose the sulphate of barytes by heating it strongly along with charcoal powder. The product is to be treated with water to dissolve every thing that is soluble; and the liquid, being filtered, is to be mixed with a solution of carbonate of soda. A white powder falls. Wash this powder, make it up into balls with charcoal, and heat it strongly in a crucible. When these balls are treated with boiling water, a portion of barytes is dissolved, which crystallizes as the water cools.

Barytes obtained by the first method is a greyish-white, porous body, which may be very easily reduced to powder. It has a harsh and more caustic taste than lime; and when taken into the stomach proves a most violent poison. It has no perceptible smell. It tinges vegetable blues green, and decomposes animal bodies like the fixed alkalies, though not with such energy.

Its specific gravity, according to Fourcroy,† is 4; but according to Hassenfratz only 2·374.‡ But there is reason to conclude, from the method employed by this philosopher, that the specific gravities which he assigns are all too low.

When heated it becomes harder, and acquires internally a bluish-green shade. When exposed to the blow-pipe on a piece of charcoal, it fuses, bubbles up, and runs into globules, which quickly penetrate the charcoal.§ This is probably in consequence of containing water, for Lavoisier found barytes not affected by the strongest heat which he sould produce. Gehlen and Bucholz have ascertained that when crystals of barytes are exposed to heat, they speedily melt and give out water. When the heat is raised to redness they again undergo fusion, and assume the appearance of an oil. But this experiment does not succeed with barytes, obtained from the nitrate, by Vauquelin's process. This difference, they showed, is not owing to the presence of carbonic acid, or of any earthy matter from the crucible in the barytes from the nitrate.‖ The fusibility, in the first case is owing, I conceive, to the barytes retaining a portion of water.¶

It had been suspected, by Bergman, that barytes was a metallic oxide.** But no attempts to detect its supposed metallic basis were attended with any success, till after the analysis of potash and so-

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[*] When thus prepared, it always contains about 0·08 of carbonate of barytes, and sometimes much more.

[†] Fourcroy, ii. 189.

[‡] Ann. de Chim. xxviii. 11.

[§] Fourcroy and Vauquelin, Ann. de Chim. xxi. 276.

[‖] Gehlen's Journal für die Chemie, Physik und Mineralogie, iv. 258.

[¶] This I think follows evidently from the experiments of Gay-Lussac and Thenard. See Recherches Physico-chimiques, i. 170.

[**] Opusc. iv. 212.

da, by Davy, in 1808. This immediately led to the idea that all the earths were likewise metallic oxides. Berzelius and Pontin first succeeded in decomposing barytes, by exposing a globule of mercury to the action of negative electricity, while placed upon moistened barytes on a platinum plate ; an amalgam of the metal of barytes was formed. Davy repeated these experiments, and by distilling the amalgam, succeeded in obtaining small quantities of the metal of barytes, to which he gave the name of *barium*. More lately Dr. Clarke has* decomposed barytes by exposing it to an intense heat, produced by the combustion of a stream of oxygen and hydrogen gas, mixed together in the requisite proportions to form water. He has given to the metal of barytes the name of *plutonium*.

Barium, thus obtained, is a solid metal of the colour of silver, it melts at a temperature below redness, and is not volatilized by a heat capable of melting plate glass, but at that temperature it acts violently upon the glass ; probably decomposing the alkali of the glass, and converting it into a protoxide. When exposed to the air it rapidly tarnishes, absorbs oxygen, and is converted into barytes. It sinks rapidly in water, and seems to be at least four or five times heavier than that liquid. It decomposes water with great rapidity ; hydrogen is emitted, and it is converted into barytes. When strongly pressed it becomes flat, and hence appears to be both ductile and malleable.

II. From the experiments of Gay-Lussac and Thenard, we learn that barium combines with two proportions of oxygen, forming two oxides which have been called *barytes* and *peroxide of barium*.

1. Barytes is the substance formed when barium is put into water. It has been known since the year 1774, and is found abundantly in the mineral kingdom, combined sometimes with carbonic acid, but much more frequently with sulphuric acid.

It has not been possible to make any direct experiments on the quantity of oxygen with which barium combines when it is converted into barytes. But there is another mode by which we have it in our power to determine this point with tolerable accuracy. The constituents of sulphate of barytes have been determined as follows :

Sulphuric acid	100	5
Barytes	194	9·70

And carbonate of barytes is composed of

Acid	22	100	2·75
Barytes	78	354·54	9·75

From these analyses it is obvious that the equivalent number for barytes is 9·75. Farther, it will be found that 100 parts of sulphuric acid combine with a quantity of base that contains 20 oxygen, while 100 of carbonic acid combine with a quantity of base containing 36·267 oxygen. Hence it follows that 194 parts of barytes

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* [This is not certain. See 8 Brande's Jour. 317.—C.]

contain 20 of oxygen, and that 354·54 parts contain 36·267 of oxygen. According to the first of these determinations, 100 parts of barytes contain 10·309 of oxygen; according to the second, 100 parts of barytes contain 10·23 of oxygen. The mean of these two gives 10·2695 for the quantity of oxygen in 100 parts of barytes. Therefore barytes is composed of—Barium 89·7305—Oxygen 10·2695. If we now divide the number 9·75 (the weight of an atom of barytes) in the proportion of 89·7305 : 10·2695, it will be as follows:

Barium - -	8·7538585
Oxygen - -	0·9961415
	9·75

But the number for oxygen is very nearly equal to 1. It is obvious that it would be exactly equal to it, if our preceding calculations had been founded upon experiments quite free from error. There can be no doubt then that barytes is composed of

Barium -	8·75 -	100
Oxygen -	1·00 -	11·42

Barytes then is a compound of 1 atom barium and 1 atom oxygen, and an atom of barium weighs 8·75.

2. Gay-Lussac and Thenard found that when dry barium from nitrate of barytes, or from the carbonate of barytes, decomposed by charcoal, is heated in oxygen gas; it absorbs that gas with great rapidity. The peroxide formed is grey. It gives out its excess of oxygen when put into water. When heated in hydrogen gas the hydrogen is absorbed and water formed, which remains united to the barytes.* We have no data for determining the additional quantity of oxygen which barytes absorbs when converted into peroxide.

III. Barium combines readily with chlorine, and forms a compound called *chloride of barium.* It may be formed by heating barytes in chlorine gas. The oxygen separates from the barium and the chlorine takes its place. Davy, to whom we are indebted for this experiment, ascertained that for every 2 volumes of chlorine absorbed, 1 volume of oxygen gas was given out. Hence it follows that this chloride is composed of 1 atom barium and 1 atom chlorine, or by weight of

Barium	8·75 -	100 -	66·04
Chlorine	4·5 -	51·42 -	33·96
			100·00

This chloride has been long known under the name of *muriate of barytes.* Its properties were first investigated by Scheele.† Dr. Crawford wrote a treatise on it in 1790. Since that period many

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* Recherches Physico-chimiques, i. 169.

† Crell's Annals, iii. 6. English Translation.

processes have been published for preparing it.[*] To Kirwan, Haüy, Bucholz, and Bouillon La Grange, we are indebted for most of the additions made to the description of it by Scheele.

The easiest method of preparing it would be to dissolve carbonate of barytes in muriatic acid, and crystallize the solution; but as the carbonate of this earth is rare, the salt is usually formed by calcining in a crucible a mixture of sulphate of barytes and charcoal, decomposing by means of muriatic acid the sulphuret formed, filtrating the solution, evaporating it till a pellicle begins to form on its surface, then allowing it to cool slowly. The crystals of the chloride gradually deposite. If the salt happens to be contaminated with iron, which is often the case, the crystals are to be calcined, dissolved in water, the solution filtered and crystallized again. By this process the oxide of iron is separated. The improvements proposed lately consist in promoting the fusion and decomposition of the sulphate of barytes, by adding to the mixture sulphur, chloride of calcium, or common salt.

The primitive form of this chloride is, according to Haüy, a four-sided prism, whose bases are squares. It crystallizes most commonly in tables. Sometimes it assumes the form of two eight-sided pyramids applied base to base.[†]

It has a pungent and very disagreeable taste; and, like all the other preparations of barytes, is poisonous. Its specific gravity is 2·8257.[‡] It requires 2·29 parts of water, of the temperature 190°, to dissolve one of this salt. It is scarcely less soluble in cold water. Hence it cannot be procured in crystals by cooling a saturated solution of it in hot water.[§]

From the experiments of Bucholz we learn, that pure alcohol, while cold, dissolves no sensible portion of it; but at a boiling heat it is soluble in 400 parts of that liquid.[||] Weak alcohol dissolves a little of it, and the solubility increases with the dilution. Alcohol of ·900, for instance, dissolves $\frac{1}{100}$ of its weight of this salt.[¶]

It is not altered by exposure to the open air. When heated, it decrepitates and dries, and when the temperature is very high it melts: but no heat which we can apply is capable of decomposing it.

Many analyses of it have been published by different chemists. The following are the most accurate of these:

	Kirwan.[**]	Rose.[††]	Berzelius.[‡‡]	Aiken.[§§]
Muriatic acid	23·8	24·3	25·75	28
Barytes -	76·2	75·7	74·25	72
	100	100·0	100	100

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[*] See Van Mon's Jour. de Phys. xlv. 297. Goettling, Phil. Mag. xxii. 218. Bouillon La Grange, Ann. de Chim. xlvii. 139. Resat, Ibid. lv. 51.

[†] Crawford.

[‡] Hassenfratz, Ann. de Chim. xxviii. 12.

[§] Crawford.

[||] Beitrage, iii. 24.

[¶] Kirwan on Mineral Waters, p. 274.

[**] Nicholson's Quarto Journal, iii. 25.

[††] Gehlen's Journal für die Chemie, Physik und Mineralogie, iii. 335. The analysis of Bucholz is almost the same.

[‡‡] Ann. de Chim. lxxviii. 113.

[§§] Nicholson's Journal, xxii. 301.

When we make the requisite corrections, these analyses give us the following results:

	Kirwan.	Rose.	Berzelius.	Aiken.
Chlorine -	31·6	32·06	33·36	35·38
Barium -	68·4	67·94	66·64	64·62
	100·0	100·00	100·00	100·

All of these analyses appear to be near approximations to the truth. That of Berzelius agrees very nearly with the numbers determined above.

IV. Barium combines readily with iodine, and forms an iodide of barium. When hydriodic acid is passed over barytes at the temperature of — 4°, the barytes becomes red hot and abundance of water is formed. In this case it is obvious that both the barytes and hydriodic acid are decomposed, and converted into water and iodide of barium.[*] When iodine is heated with barytes a combination takes place, but no oxygen gas is given out. Hence we see that oxygen gas has a stronger affinity for barium than iodine has. Iodide of barium is easily formed by dissolving barytes in hydriodic acid, and exposing the salt formed to a red heat. This salt consists of fine needles, similar in appearance to muriate of strontian. It is gradually decomposed by exposure to the atmosphere.[†] This iodide has not been analized. But there can be no doubt that it is a compound of 1 atom barium and 1 atom iodine, or by weight of—Barium 8·75—Iodine 15·625.

V. We are not acquainted with the compounds which barium is capable of forming with fluorine, azote, the simple acidifiable combustibles, potassium, sodium, and calcium.

The order of affinities of the simple supporters for barium is as follows:—*Barium*—Chlorine—Oxygen—Iodine.

SECTION V.

OF STRONTIUM.

About the year 1787 a mineral was brought to Edinburgh, by a dealer in fossils, from the lead mine of Strontian, in Argyleshire, where it is found imbeded in the ore, mixed with several other substances. It is sometimes transparent and colourless, but generally has a tinge of yellow or green. It is soft. Its specific gravity varies from 3·4 to 3·726. Its texture is generally fibrous; and sometimes it is found crystallized in slender prismatic columns of various lengths.[‡]

This mineral was generally considered as a carbonate of barytes; but Dr. Crawford having observed some differences between its

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[*] Gay-Lussac, Ann. de Chim. xci. 58.

[†] Ibid.

[‡] Hope, Edin. Trans. iv. 44.

solution in muriatic acid and that of barytes, mentioned in his treatise on *muriate of barytes*, published in 1790, that it probably contained a new earth, and sent a specimen to Mr. Kirwan, that he might examine its properties. Dr. Hope made a set of experiments on it in 1791, which were read to the Royal Society of Edinburgh in 1793, and published in the Transactions about the beginning of 1794. These experiments demonstrate, that the mineral is a compound of carbonic acid, and a peculiar earth, whose properties are described. To this earth Dr. Hope gave the name of *strontites*. Klaproth analysed it also in 1793, and drew the same conclusions as Dr. Hope, though he was ignorant of the experiments of the latter, which remained still unpublished. Klaproth's experiments were published in Crell's Annals for 1793[*] and 1794.[†] Kirwan also discovered the most interesting peculiarities of this new earth in 1793, as appears by his letter to Crell, though his dissertation on it, which was read to the Irish Academy in 1794, was not published till 1795. The experiments of these philosophers were repeated and confirmed in 1797 by Pelletier, Fourcroy, and Vauquelin,[‡] and several of the properties of the earth still farther investigated. To the earth thus detected Klaproth gave the name of *strontian*, from the place where it was first found; and this name is now generally adopted.

Strontian is found abundantly in different parts of the world, and always combined with carbonic acid or sulphuric acid.

The carbonic acid may be expelled from the carbonate, and the strontian obtained pure, by mixing the mineral with charcoal powder, and exposing it to a heat of 140° Wedgewood;[§] or by dissolving the mineral in nitric acid, evaporating the solution till it crystallizes, and exposing the crystals in a crucible to a red heat till the nitric acid is driven off. Strontian may be obtained from the sulphate by following exactly the process described in the last section for obtaining barytes.

Strontian, thus obtained, is in porous masses, of a greyish white colour; its taste is acrid and alkaline; and it converts vegetable blues to green.[‖] Its specific gravity, according to Hassenfratz, is 1·647.[¶] It does not act so strongly on animal bodies as barytes, nor is it poisonous.[**]

Davy, after his discovery of the metallic nature of potash and soda, was naturally led to consider strontian as a metallic oxide, as well as barytes and lime. He succeeded in decomposing it by the same processes as have been detailed in the preceding sections for decomposing lime and barytes. To the metallic basis of it he gave the name of *strontium*.

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[*] Vol. ii. 189.

[†] Vol. i. 99. See also Klaproth's Beitrage, i. 260, and Jour. de Min. No. v. p. 61.

[‡] Ann. de Chim. xxi. 113 and 276. Jour. de Min. An. vi. 3.

[§] Kirwan.

[‖] [All the salts of strontian with muriatic, nitric, and acetic acids, give a red colour to the flame, when cloth, impregnated with them, is dipt in alcohol and burnt.—C.]

[¶] Ann. de Chim. xxviii. 11.

[**] Pelletier, Ibid. xxi. 120.

This metal is white, solid, much heavier than water, and bears a close rememblance to *barium* in its properties. When exposed to the air, or when thrown into water, it rapidly absorbs oxygen, and is converted into strontian.*

II. Strontium, as far as is known at present, combines only with one proportion of oxygen, and forms the well-known compound called *strontian*. We have no direct experiments on the quantity of oxygen which it contains; but we may ascertain it in the same way as we did the quantity in barytes. The composition of sulphate of strontian, according to the experiments of Stromeyer is

Strontian	132·55	6·627
Sulphuric acid	100	5

The carbonate of strontian by my experiments is composed of

Strontian	234·44	6·447
Carbonic acid	100	2·75

The mean of these two analyses gives us the equivalent number for strontian 6·537. We may, therefore, without sensible error, consider it as 6·5. For the reasons assigned in the last section, it follows that 100 parts of strontian, by the first analysis, contain 15·08, and, by the second, 15·47 of oxygen. The mean of both is 15·275. Therefore 100 strontian are composed of—Strontium 84·725—Oxygen 15·275.

If we divide 6·5 (the weight of an atom of strontian) in the proportion of the numbers 84·725 : 15·275, we obtain for the composition of strontian

Strontium	5·507125
Oxygen	0·992875
	6·5

It is evident that the number for oxygen would have been 1, had the experiments on which our calculation is founded been quite free from error. There can be no doubt then that strontian is composed of

Strontium	5·5	100
Oxygen	1·0	18·18

It is a compound of 1 atom strontium and 1 atom oxygen, and an atom of strontium weighs 5·5

III. When strontian is heated in chlorine gas it gives out oxygen gas, and combines with the chlorine, as Davy first observed. The compound formed is *chloride of strontium*.

This substance has been long known in chemistry by the name of *muriate of strontian*. It was first described by Dr. Crawford in 1790. It was afterwards examined by Dr. Hope, by Klaproth, Pelletier, Fourcroy, and Vauquelin.

It may be prepared by dissolving carbonate of strontian in muriatic acid, or by decomposing sulphuret of strontian by means of

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* Davy's Electro-chemical Researches into the Decomposition of the Earths, &c., Phil. Trans. 1808.

that acid. The solution is then to be evaporated to a proper consistence, in order to obtain the muriate in crystals.

Its crystals, according to Haüy, are very long, slender, hexagonal prisms.[*] It has a peculiar sharp, penetrating taste. Its specific gravity is 1·4402.[†] Three parts of these crystals are soluble in two parts of water at the temperature of 60°. Boiling water dissolves any quantity of them whatever.[‡] From the experiments of Bucholz, we learn that 24 parts of pure alcohol, at the temperature of 60°, dissolve one part of this salt; and that it is soluble in 19 parts of pure boiling alcohol.[§] The alcohol solution burns with a fine purple colour.

The crystals suffer no change when exposed to the air, except they be very moist; in which case they deliquesce.

When heated, they first undergo the watery fusion, and are then reduced to a white powder.

There can be no doubt that this chloride is a compound of 1 atom chlorine and 1 atom strontium; or by weight of

Chlorine	4·5	69·23	40·9
Strontium	6·5	100	59·1
			100·0

We have several analyses of this chloride, giving the constituents as if it were a muriate. The two following are the most recent:

	Kirwan.[‖]	Rose.[¶]
Muriatic acid	31	38·33
Strontian	69	61·67
	100	100·

When we introduce into these the proper corrections we obtain the following numbers:

	Kirwan.	Rose.
Chlorine	41·6	47·81
Strontium	58·4	52·19
	100	100

Kirwan's analysis we see is by far the most accurate of the two.

IV. Little is known respecting the iodide of strontium. When strontian is heated in the vapour of iodine, it absorbs that substance without giving out any oxygen gas. The iodide may be formed by dissolving strontian in hydriodic acid, and exposing the salt formed to a strong heat without the contact of air; for when the heat is applied while the salt is exposed to the air it is decomposed.[**] No experiments have been made on the proportions in

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[*] Foureroy, iii. 262, Eng. Trans.

[†] Hassenfratz, Ann. de Chim. xxviii. 12.

[‡] According to Crawford, they dissolve in 0·825 of water of the temperature 190°; but they are much less soluble in cold water. Hence they crystallize in cooling.

[§] Bucholz Beitrage, iii. 29.

[‖] Nicholson's Quarto Journal, iii. 215.

[¶] Gehlen's Journal, vi. 33.

[**] Gay-Lussac, Ann. de Chim. xci. 60.

which the constituents of this iodide combine. But probably they unite atom to atom. Supposing this to be the case, the iodide will be a compound of Strontium 5·5—Iodine 15·625.

V. We know nothing respecting the combinations of strontium with fluorine, azote, or any of the simple combustibles.

The order of the affinities of the supporters of combustion for strontium is as follows: *Strontium*—Chlorine—Oxygen—Iodine.

SECTION VI.

OF MAGNESIUM.

About the beginning of the eighteenth century, a Roman canon exposed a white powder to sale at Rome as a cure for all diseases. This powder he called *magnesia alba.* He kept the manner of preparing it a profound secret; but in 1707 Valentini informed the public that it might be obtained by calcining the lixivium which remains after the preparation of nitre;[*] and two years after, Slevogt discovered that it might be precipitated by potash from the mother ley[†] of nitre.[‡] This powder was generally supposed to be *lime* till Frederic Hoffman observed that it formed very different combinations with other bodies.[§] But little was known concerning its nature, and it was even confounded with lime by most chemists, till Dr. Black made his celebrated experiments on it in 1755. Margraff published a dissertation on it in 1759,[‖] and Bergman another in 1775, in which he collected the observations of these two philosophers, and which he enriched also with many additions of his own.[¶] Butini, of Geneva, likewise published a valuable dissertation on it in 1779.

As magnesia has never yet been found native in a state of purity, it may be prepared in the following manner: *Sulphate of magnesia*, a salt composed of this earth and sulphuric acid, exists in seawater, and in many springs particularly in some about Epsom; from which circumstance it was formerly called *Epsom salt.* This salt is to be dissolved in water, and half its weight of potash added. The magnesia is immediately precipitated, because potash has a stronger affinity for sulphuric acid. It is then to be washed with a sufficient quantity of water, and dried.

Magnesia, thus obtained, is a very soft white powder, which has very little taste, and is totally destitute of smell. Its specific gra-

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[*] De Magnesia Alba.

[†] The mother ley is the liquid that remains after as much as possible of any salt has been obtained from it. Common salt, for instance, is obtained by evaporating sea-water. After as much salt has been extracted from a quantity of sea-water as will crystallize, there is still a portion of liquid remaining. This portion is the mother ley.

[‡] Diss. de Magnesia Alba.

[§] Obs. Phys. Chim. 1722, p. 105 and 177.

[‖] Opusc. ii. 20.

[¶] Opusc. i. 365.

vity is about 2·3.* It converts delicate vegetable blues (paper, for instance, stained with the petals of the mallow) to green.

Davy, after his decomposition of potash and soda, was naturally led to consider magnesia also to be a metallic oxide. He succeeded in decomposing it by the same process by which he decomposed the other alkaline earths. When moistened magnesia is exposed to the action of galvanism in contact with mercury, the earth is reduced, and its base amalgamated with mercury much more slowly than the other alkaline earths; owing probably to its insolubility in water. The process succeeds much more rapidly when moistened sulphate of magnesia is substituted for the pure earth. To the base of magnesia thus obtained, Davy gave the name of *magnesium.*

Magnesium is a white solid metal having the appearance of silver; sinks rapidly in water, and of course is considerably heavier than that liquid. When the amalgam of magnesium is distilled in a glass tube filled with the vapour of naphtha, the metal appears to act upon the glass before the whole of the mercury is separated from it. Of course it is difficult to obtain it in a state of purity. When exposed to the air it rapidly absorbs oxygen, and is converted into magnesia. It decomposes water, separating the hydrogen, and combining with the oxygen; but not nearly so rapidly as the other metals obtained from the alkaline earths; owing doubtless to the insolubility of the magnesia in water. But when the water is acidulated with sulphuric acid, the decomposition of water and the formation of magnesia goes on with great rapidity.†

II. We are acquainted with only one compound of magnesium and oxygen; namely, *magnesia.* Though it has not been possible to determine the proportion of its constituents by direct experiments, we can settle the point in the same way as we ascertained the composition of barytes and strontian.

Sulphate of magnesia, according to the experiments of Berzelius, is composed of

Sulphuric acid	100	5
Magnesia	50·06	2·51

Hence it is obvious that the equivalent number for magnesia is 2·5. Further it follows, from what has been stated in the preceding sections, that 50 parts of magnesia contain 20 of oxygen. So that it is composed of—Magnesium 60—Oxygen 40.

If we divide 2·5 in the ratio of 60 : 40, we obtain magnesia composed of

Magnesium	1·5	100	3
Oxygen	1·0	66·6	2

III. When magnesia is heated in chlorine gas, it gives out oxygen gas, and combines with the chlorine. It is thus converted into

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* Kirwan's Miner. i. 8.

† Davy's Electro-chemical Researches on the Decomposition of the Earths, &c. Phil. Trans. 1808.

a *chloride of magnesium.* Davy, to whom we are indebted for this experiment, ascertained, that for every volume of oxygen gas evolved, 2 volumes of chlorine gas were absorbed. Hence it follows, that this chloride is a compound of 1 atom chlorine and 1 atom magnesium; or by weight of

Chlorine	4·5	75	100
Magnesium	1.5	25	33·3

The substance formerly known by the name of *muriate of magnesia* is nothing else than a combination of this chloride with water.

It exists in sea water and in several mineral springs, particularly that at Lymington in Hampshire. It was first described by Mr. Brown in the Philosophical Transactions for 1723;[*] but its nature was not understood till long after, when the experiments of Black and Margraff had established the peculiar nature of its base. Bergman afterwards published a description of it.[†] As it is found native in abundance, it is seldom formed artificially; but it may be prepared by dissolving carbonate of magnesia in muriatic acid, and evaporating the solution to a proper consistency.

It is not easily crystallized. Bergman's method was to evaporate it by a considerable heat to the proper degree of concentration, and then to expose it to a sudden cold. By this method he obtained it in small needles.[‡] Its specific gravity is 1·601.[§]

Its taste is extremely bitter, hot, and biting. It requires rather more than half its weight of water to dissolve it; for when exposed to the air it runs into a liquid, and attracts $\frac{66}{100}$ parts of its weight of water.[‖] The solubility in alcohol increases with the strength of that liquid. Alcohol of ·817 dissolves half its weight of it, but alcohol of ·900 only $\frac{1}{5}$th of its weight.[¶] A saturated solution of it quickly forms a jelly; on which, if hot water be poured, spongy masses are formed, not even soluble in muriatic acid.[**] It deliquesces very speedily when exposed to the air.

When strongly heated, the water which it contains is decomposed; the hydrogen combines with the chlorine and flies off in the state of muriatic acid, while the oxygen converts the magnesium into magnesia.

Of the analyses made of this salt, under the supposition that it is a compound of muriatic acid and magnesia, by far the most accurate is that of Wenzel. According to him[††] its constituents are, in the hundred parts,—Muriatic acid 57—Magnesia 43.

When we make the requisite corrections, these numbers give us the composition of the chloride as follows:

Chlorine	74·2
Magnesium	25·8
	100·0

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[*] Phil. Trans. xxxii. 348.

[†] Opusc. i. 382.

[‡] Bergman, i. 382.

[§] Hassenfratz, Ann. de Chim. xxviii. 12.

[‖] Bergman, Opusc. i. 136.

[¶] Kirwan on Mineral Waters, p. 274.

[**] Bergman, i. 382.

[††] Verwandtschaft, p. 104.

Now these numbers do not differ much from those which we have given above, founded on the real constitution of the chloride.

IV. The iodide of magnesium is at present unknown. When iodine, magnesia, and water are heated together, a brown-coloured insoluble matter is formed, which Gay-Lussac, to whom we are indebted for the experiment, considers as an *iodide of magnesia.*[*] When magnesia is dissolved in hydriodic acid, a deliquescent salt is obtained which is probably a compound of iodide of magnesium and water. But if this be the case, the water is decomposed by the application of heat; hydriodic acid flies off and magnesia remains behind.

V. Nothing is known respecting the combination of magnesium with fluorine, azote, and the simple combustibles.

FAMILY II.

The substances belonging to this family are four in number; namely,

1. Yttrium, 2. Glucinum, 3. Aluminum, 4. Zirconium.

The compounds which they form with oxygen are white, and these oxides form colourless solutions in acids. It has hitherto been impossible to reduce them in any quantity to the metallic state. They are insoluble in water, and produce no alteration in the colour of vegetable blues. On that account they were formerly distinguished in chemistry by the name of *earths proper*.

SECTION I.

OF YTTRIUM.

Some time before 1788, Captain Arhenius discovered, in the quarry of Ytterby in Sweden, a peculiar mineral different from all those described by mineralogists. Its colour is greenish-black, and its fracture like that of glass. It is magnetic, and generally too hard to be scratched by a knife. It is opaque, except in small pieces, when it transmits some yellow rays. Its specific gravity is 4·237.[†] A description of it was published by Geyer in 1788, in Crell's Annals, and by Rinman in his Miner's Lexicon. Professor Gadolin analysed this mineral in 1794, and found it to contain a new earth: but though his analysis was published in the Stockholm Transactions for 1794, and in Crell's Annals for 1796, it was some time before it drew the attention of chemical mineralogists. The conclusions of Gadolin were confirmed by Ekeberg in 1797,

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[*] Ann. de Chim. xci. 64.

[†] Gadolin, Crell's Annals, 1796, i. 313.—Vauquelin, Ann. de Chim. xxxvi. 146.—Klaproth's Beitrage, iii. 58.

who gave to the new earth the name of *yttria*.[*] They were still farther confirmed and extended by Vauquelin in 1800,[†] and likewise by Klaproth about the same time;[‡] and Ekeberg published a new dissertation on the subject in the Swedish Transactions for 1802.[§] Since that time it has been repeatedly examined by Berzelius, who has shown that the yttria, as examined by Gadolin and Ekeberg, was not pure. He has himself succeeded in separating it from most of the cerium with which it was contaminated, and has described its properties.[‖]

Hitherto yttria has been found only in the black mineral first analysed by Gadolin, and hence called *Gadolinite*, in which it is combined with black oxide of iron and the earth called silica; and in yttrotantalite, which from the description of Ekeberg is a compound of tantalum and yttria. Both of these minerals have been found only in Sweden. From the first, which is the most common, the yttria may be procured by treating the mineral reduced to powder with a mixture of nitric and muriatic acids, till it is completely decomposed; then filtering the solution, previously evaporated nearly to dryness, and diluting it with water. By this process the silica is left behind. The liquid which passes through the filter is to be evaporated to dryness, and the residue heated to redness for a considerable time in a close vessel, and then redissolved in water and filtered. What passes through the filter is colourless; when treated with ammonia a mixture of yttria and oxide of cerium falls. Heat this powder to redness, dissolve it in nitric acid, and evaporate to dryness to get rid of the excess of acid. Dilute with 150 parts of water, and put into the liquid crystals of sulphate of potash. The crystals gradually dissolve, and after some hours a white precipitate will appear. This precipitate contains the oxide of cerium. Repeat the process to be sure of getting rid of the oxide of cerium. Filter the liquid, precipitate the yttria with pure ammonia; wash it well, and then heat it to redness.[¶]

Yttria, thus procured, has the appearance of a fine white powder, and has neither taste nor smell. It has no action on vegetable blues. It is much heavier than any of the other earths; its specific gravity, according to Ekeberg, being no less than 4·842.

It is insoluble in water; yet it is capable of retaining a great proportion of that liquid, as is the case with alumina. Klaproth ascertained, that 100 parts of yttria, precipitated from muriatic acid by ammonia, and dried in a low temperature, lose 31 parts, or almost a third of their weight, when heated to redness in a crucible. Now this loss consists of pure water alone.

It is not soluble in pure alkalies; but it dissolves readily in car-

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[*] Crell's Annals, 1799, ii. 63.

[†] Ann. de Chim. xxxvi. 143.

[‡] Ann. de Chim. xxxvii. 86, and Beitrage, iii. 52.

[§] Kongl. Vetenskaps Acad. nya Handlingar. 1802, p. 68, and Jour. de Chim. iii. 78.

[‖] Annals of Philosophy, iii. 359. Afhandlingar i Fysik, Kemi och Mineralogi, iv. 217, 236.

[¶] Berzelius, Afhandlingar, iv. 223.

bonate of ammonia, and in all the other alkaline carbonates. It combines with acids, and forms with them salts which have a sweet taste, and at the same time a certain degree of austerity.

Yttria is not altered by light, nor is it likely that it combines with oxygen. From the experiments of Klaproth, it does not appear to combine readily with sulphur; nor is it likely that it unites with any of the other simple combustibles.

Davy found that when potassium is passed through red hot yttria it is converted into potash, while grey metallic particles are perceived mixed with the alkali. These it is probable are yttrium reduced to the metallic state.

Though yttrium in the metallic state has never been examined, and of course no direct experiments have been made upon the proportion of oxygen with which it combines in order to be converted into yttria, we may however succeed in ascertaining the composition of this oxide by the same method that we employed in the three last sections to determine the composition of barytes, strontian, and magnesia.

From the experiments of Berzelius it appears that sulphate of yttria is composed of equal weights of acid and base.* So that the equivalent number for yttria is the same as for sulphuric acid; namely 5. It follows from this experiment that 100 parts of yttria must contain 20 of oxygen. So that yttria is composed of

Yttrium	80	4	100
Oxygen	20	1	25

Yttria then is composed of 1 atom yttrium + 1 atom oxygen; and the weight of an atom of yttrium is 4.

SECTION II.

OF GLUCINUM.

The beryl is a transparent stone, of a green colour, and a considerable degree of hardness, which is found crystallized in the mountains of Siberia, and in many other parts. Vauquelin analysed this mineral in 1798, at the request of Haüy, to determine whether it was formed of the same ingredients with the emerald, as Haüy had conjectured from mineralogical considerations. The result of the analysis was a confirmation of the suspicions of Haüy, and the discovery of a new earth, to which Vauquelin and his associates gave the name of *glucina*.† The experiments of Vauquelin have been repeated by Klaproth‡ and other eminent chemists.

To obtain glucina pure, the beryl or the emerald, reduced to powder, is to be fused with thrice its weight of potash. The mass

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* Afhandlingar, iv. 236.

† Ann. de Chim. xxvi. 155.

‡ Beitrage, iii. 215.

is to be diluted with water, dissolved in muriatic acid, and the solution evaporated to dryness. The residuum is to be mixed with a great quantity of water, and the whole thrown on a filter. The silica, which constitutes more than half the weight of the stone, remains behind; but the glucina and the other earths, being combined with muriatic acid, remain in solution. Precipitate them by means of carbonate of potash. Wash the precipitate, and then dissolve it in sulphuric acid. Add to the solution sulphate of potash; evaporate it to the proper consistency, and set it by to crystallize. Alum crystals gradually form. When as many of these as possible have been obtained, pour into the liquid carbonate of ammonia in excess, then filter, and boil the liquid for some time. A white powder gradually appears, which is *glucina.*

Glucina, thus obtained, is a soft light white powder, without either taste or smell; which has the property of adhering strongly to the tongue. It has no action on vegetable colours. Its specific gravity is 2·976.*

It is insoluble in water, but forms with a small quantity of that liquid a paste which has a certain degree of ductility. It does not combine with oxygen nor with any of the simple combustibles; but sulphureted hydrogen dissolves it, and forms with it a hydrosulphuret, similar to other hydrosulphurets in its properties.†

Glucina is soluble in the liquid fixed alkalies, in which it agrees with alumina. It is insoluble in ammonia, but soluble in carbonate of ammonia, in which respect it agrees with yttria; but it is about five times more soluble in carbonate of ammonia than that earth.

It combines with all the acids and forms with them sweet-tasted salts,‡ as is the case also with yttria.

II. From the experiments of Sir H. Davy there is reason to conclude that glucina like yttria is a metallic oxide. When heated with potassium that metal is converted into potash, and grey metallic-looking particles are observed mixed with the potash, which when put into water slowly evolve hydrogen gas and are converted into glucina.

According to the experiments of Berzelius,§ sulphate of glucina is composed as follows,

Acid	100	5
Glucina	64·1	3·205

Hence the equivalent number for glucina is 3·25. Farther, 64 glucina must contain 20 parts of oxygen, therefore it is composed of

Glucinum	44	100
Oxygen	20	45·45

If we divide the number 3.25 in the proportion of 100 : 45 we obtain glucina composed of

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[*] Ekeberg, Ann. de Chim. xliii. 277.

[†] Fourcroy, ii. 159.

[‡] Hence the name *glucina*, from γλυκυς, *sweet.*

[§] Attempt to establish a pure scientific system of Mineralogy, p. 134.

Glucinum	2·25	100
Oxygen	1·00	44·4

Hence we see that glucina is composed of 1 atom glucinum and 1 atom oxygen, and that the weight of an atom of glucinum is 2·25.

SECTION III.

OF ALUMINUM.

Alum is a salt which was well known to the ancients, and employed by them in dyeing, but they were ignorant of its component parts. The alchymists discovered that it is composed of sulphuric acid and an earth; but the nature of this earth was long unknown. Stahl and Neuman supposed it to be lime; but in 1728 Geoffroy junior proved this to be a mistake, and demonstrated, that the earth of alum constitutes a part of clay.[*] In 1754, Margraff showed that the basis of alum is an earth of a peculiar nature, different from every other; an earth which is an essential ingredient in clays, and gives them their peculiar properties.[†] Hence this earth was called *argil;* but Morveau afterwards gave it the name of *alumina*, because it is obtained in the state of greatest purity from alum. The properties of alumina were still farther examined by Macquer in 1758 and 1762,[‡] by Bergman in 1767 and 1771,[§] and by Scheele in 1776;[||] not to mention several other chemists who have contributed to the complete investigation of this substance. A very ingenious treatise on it was published by Saussure junior in 1801.[¶]

Alumina may be obtained by the following process: Dissolve alum in water. and add to the solution ammonia as long as any precipitate is formed. Decant off the fluid part, and wash the precipitate in a large quantity of water, and then allow it to dry. The substance thus obtained is *alumina;* not however in a state of absolute purity, for it still retains a portion of the sulphuric acid with which it was combined in the alum. But it may be rendered tolerably pure, provided it has been deprived of all the potash by careful washing, if we expose it to a strong heat in a platinum crucible. For at a high temperature the sulphuric acid may be driven off almost completely.

The earth thus obtained assumes two very different appearances according to the way in which the precipitation has been conducted. If the earthy salt be dissolved in as little water as possible, the alumina has the appearance of a white earth, light, friable, very

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[*] Mem. Par. 1728, p. 303.

[†] Mem. Berlin, 1754 and 1759. Margraff, ii. 1.

[‡] Mem. Paris.

[§] Bergman, i. 287, and v. 71.

[||] Scheele, i. 191, French Transl.

[¶] Jour. de Phys. lii. 280.

spongy, and attaching itself strongly to the tongue. In this state Saussure distinguishes it by the name of *spongy alumina.*

But if the salt has been dissolved in a great quantity of water, the alumina is obtained in a brittle transparent yellow-coloured mass, splitting in pieces like roll sulphur when held in the hand. Its fracture is smooth and conchoidal; it does not adhere to the tongue, and has not the common appearance of an earthy body. In this state Saussure gives it the name of *gelatinous alumina.**

Alumina has little tase: when pure, it has no smell; but if it contains oxide of iron, which it often does, it emits a peculiar smell when breathed upon, known by the name of *earthy smell.*† This smell is very perceptible in common clays. The specific gravity of alumina is 2·00.‡

When heat is applied to alumina it gradually loses weight, in consequence of the evaporation of a quantity of water with which, in its usual state, it is combined; at the same time its bulk is considerably diminished. The spongy alumina parts with its moisture very readily, but the gelatinous retains it very strongly. Spongy alumina, when exposed to a red heat, loses 0.58 parts of its weight; gelatinous, only 0·43: Spongy alumina loses no more than 0·58 when exposed to a heat of 130° Wedgewood; gelatinous in the same temperature loses but 0·4825. Yet Saussure has shown that both species, after being dried in the temperature of 60°, contain equal proportions of water.§

Davy was naturally led by his previous discoveries to consider alumina as a metallic oxide. His experiments leave little doubt on the subject, though he did not succeed in obtaining the metal in a separate state. When potassium is passed through alumina heated to whiteness, a considerable proportion of it is converted into potash, and grey metallic particles are perceived in the mass, which effervesce in water and are converted into alumina. When a globule of iron is fused by galvanism in contact with moist alumina it forms an alloy with aluminum. It effervesces slowly in water, being covered with a white powder.‖ To this metallic basis Davy gave the name of *aluminum.*

II. According to the experiments of Berzelius¶ sulphate of alumina is composed of

Sulphuric acid	100	5
Alumina	42·722	2·115

From this experiment it follows that the equivalent number for alumina is 2·115. We shall consider it as 2·125. Farther, 42·722 parts of alumina must contain 20 parts of oxygen. Hence alumina is composed of—Aluminum 22·722—Oxygen 20. Or, dividing 2·125 in the proportion of these numbers, its constituents are,

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* Jour. de Phys. lii. 290.

† Saussure, Jour. de Phys. lii. 287.

‡ Kirwan's Miner. i. 1.

§ Jour. de Phys. lii. 287.

‖ Elements of Chemical Philosophy, p. 355.

¶ Ann. de Chim. lxxxii. 14.

Aluminum	1·125	100
Oxygen	1	28·8

Hence it appears that alumina is a compound of 1 atom aluminum and 1 atom oxygen, and that an atom of aluminum weighs 1·125.

SECTION IV.

OF ZIRCONIUM.

Among the precious stones which come from the island of Ceylon, there is one called *jargon*,[*] or *zircon*, which is possessed of the following properties:

Its colour is various; grey, greenish-white, yellowish, reddish-brown, and violet. It is often crystallized, either in right-angular quadrangular prisms surmounted with pyramids, or octahedrons consisting of double quadrangular pyramids. It has generally a good deal of lustre, at least internally. It is mostly semitransparent. Its hardness is from 10 to 16: its specific gravity from 4·416 to 4·7.[†]

It loses scarcely any of its weight in a melting heat; for Klaproth, who analysed it in 1789, found that 300 grains, after remaining in it for an hour and a half, were only ¼th of a grain lighter than at first.[‡] Neither was it attacked either by muriatic or sulphuric acid, even when assisted by heat. At last, by calcining it with a large quantity of soda, he dissolved it in muriatic acid, and found that 100 parts of it contained 31·5 of silica, 0·5 of a mixture of nickel and iron, and 68 of a new earth, possessed of peculiar properties, which has received the name of *zirconia*, from the mineral in which it was detected. Owing probably to the scarcity of the zircon, nobody attempted to repeat the analysis of Klaproth, or to verify his discovery. In 1795 he published his analysis of the *hyacinth*, another mineral from the same island, in which he also detected a large proportion of zirconia, expressing his hopes that it would induce chemists to turn their attention to the subject.[§] This analysis induced Guyton Morveau, in 1796, to examine the hyacinths of Expailly in France. They proved similar to the hyacinths of Ceylon, and contained the proportion of zirconia indicated by Klaproth.[‖] These experiments were soon after repeated, and the nature of the new earth still further examined by Vauquelin.[¶]

Zirconia has hitherto been found only in the zircon and hya-

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[*] [The silversmiths and jewellers call the transparent stones with which French and Genevan watches are frequently ornamented, *jargoons:* they are white hyacinths.—C.]

[†] Kirwan's Miner. i. 333.

[‡] Jour. de Phys. xxxvi. 180.

[§] Beitrage, i. 231.

[‖] Ann. de Chim. xxi. 72.

[¶] Ann. de Chim. xxii. 158, and Jour. de Min. An. v. 97.

cinth. It may be obtained pure by the following process: reduce the mineral to powder, mix it with thrice its weight of potash, and fuse it in a crucible. Wash the mass in pure water till the whole of the potash is extracted; then dissolve the residuum as far as possible in diluted muriatic acid. Boil the solution to precipitate any silica which may have been dissolved; then filter, and add a quantity of potash. The zirconia precipitates in the state of a fine powder.

Zirconia, thus prepared, has the form of a fine white powder, which feels somewhat harsh when rubbed between the fingers. It has neither taste nor odour. It is infusible before the blowpipe; but when heated violently in a charcoal crucible, it undergoes a kind of imperfect fusion, acquires a grey colour, and something of the appearance of porcelain. In this state it is very hard, its specific gravity is 4·3, and it is no longer soluble in acids.

Zirconia is insoluble in water: but it has a considerable affinity for that liquid. When dried slowly, after being precipitated from a solution, it retains about the third of its weight of water, and assumes a yellow colour, and a certain degree of transparency, which gives it a great resemblance to gum arabic.*

It does not combine with oxygen, azote, or the simple combustibles; but it has a strong affinity for several metallic oxides, especially for oxide of iron, from which it is very difficult to separate it.

It is insoluble in liquid alkalies, neither can it be fused along with them by means of heat; but it is soluble in alkaline carbonates.

Davy subjected zirconia to the same experiments as the other earths described in the three preceding sections, and obtained the same evidence for its metallic nature. To the metallic basis he gave the name of *zirconium*.

As no very accurate analyses of the salts, containing a basis of zirconia, have been hitherto made, we have no good data for determining its *equivalent* number, and for deducing from it its composition. The analyses published by Klaproth and Vauquelin lead us to consider its equivalent number as 5·625. And to suppose it composed of

Zirconium	4·625	100
Oxygen	1	23·78

These numbers may be employed as approximations till better data enable us to determine the point with more precision.

FAMILY III.

This family includes under it six substances, all of which are of a metallic nature; namely:

1. Iron
2. Nickel
3. Cobalt
4. Manganese
5. Cerium
6. Uranium.

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* Vauquelin, Ann. de Chim. xxii. 158.

They are distinguished from the other metals comprehended under this genus by two properties. 1. Their oxides cannot be reduced to the metallic state by the most violent heat which can be applied. 2. When dissolved in an acid they cannot be precipitated in the metallic state by plunging into the solution a rod composed of any other metal.

SECTION I.

OF IRON.

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

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 exceeds most of the metals; and it may be rendered harder than most bodies when converted into steel. Its specific gravity varies from 7·6 to 7·8.[††]

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

[††] Kirwan's Min. ii. 155. Dr. Shaw states the specific gravity of iron at 7·645. Shaw's Boyle, ii. 345. Brisson 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 Muschenbroek, hammered

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.

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.

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.

Iron has a strong affinity for oxygen. It decomposes water at the common temperature of the air slowly, and almost imperceptibly. But at a red heat the decomposition goes on with rapidity; pure hydrogen gas being evolved in abundance. It is even capable of decomposing potassium when assisted by a sufficiently high temperature. When iron wire,[‡] having a little cotton tied to its extremity, is plunged into oxygen gas while the cotton is in flames, it takes fire and burns with great brilliancy.

As far as is known at present, iron combines with only two proportions of oxygen, and forms two oxides, the *protoxide* and the *peroxide*. The protoxide is *black*, but the peroxide is *red*.

1. The *black* oxide of iron may be obtained by three 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 burn-

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iron softened by heat is of the specific gravity 7·600; the same hammered hot, becomes 7·7633; and the same hammered cold, becomes 7 875. Wasserberg, i. 168.

[*] Sickingen, Ann de Chim. xxv. 9. English iron only supports a weight 348·38 lbs. See Annals of Philosophy, vii. 320.

[†] Nicholson's 4to Jour. iv. 109.

[‡] [Fine harpsichord wire.—C.]

[§] 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 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.

ing 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. 3. 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, when pure, is a black tasteless powder, insoluble in water; but soluble in acids, forming solutions of a pale green colour and a sweetish astringent taste. It is capable of combining with water,[†] and the compound has a dirty greenish colour; but the water is very easily driven off. Many experiments have been made to determine the proportion of oxygen which this oxide contains. The following table exhibits the results obtained by the different experimenters.

Proust[‡] - - - -	100 iron	+ 28 oxygen
Hassenfratz[§] - - -	100	+ 29
Bucholz[‖] - - -	100	+ 29·87
Berzelius[¶] - - -	100	+ 29·57
Thomson[**] - - -	100	+ 28
Gay-Lussac[††] - - -	100	+ 28·3
Mean of the whole	100	+ 28·78

In order to be able to judge of the accuracy of these numbers, let us examine some of the salts into which this oxide enters.

According to the experiments of Berzelius, sulphate of iron is composed of

Sulphuric acid - -	100 - -	5
Protoxide of iron - -	88 - -	4·4

From this we see that the equivalent number for protoxide of iron is 4·4. Let us take it at 4·5, which would suppose the salt a compound of 100 acid + 90 oxide. Farther, 90 protoxide of iron must contain 20 of oxygen. Hence it is a compound of

Iron - -	79 - - -	100
Oxygen - -	20 - - -	28·57

Thus we obtain 28·57 for the quantity of oxygen which unites with 100 of iron in order to constitute protoxide of iron. If we divide the number 4·5 in the proportion of 79 : 20 we obtain the protoxide composed of

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

[†] [Distilled water does not appear to act on a polished needle.—C.]

[‡] Ann. de Chim. xxiii. 85.

[§] Ibid. lxix. 152.

[‖] Gehlen's Journal fur die Chimie und Physik, iii. 711. His experiments gave only 29·09. But he considers the number in the text as the true one.

[¶] Annals of Philosophy, iii. 356. Ann. de Chim. lxxviii. 240.

[**] Annals of Philosophy.

[††] Ann. de Chim. lxxx. 163.

Iron	3·5	100
Oxygen	1·0	28·57

We see from this that the protoxide is a compound of 1 atom iron and 1 atom oxygen, and that an atom of iron weighs 3·5.

2. The *peroxide* of iron may by formed by keeping iron filings red hot in an open vessel, and agitating them constantly till they are converted into a dark red powder. This oxide was formerly called *saffron of Mars*. Common rust of iron is 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, when pure, has a fine red colour, bordering on crimson. It has frequently a shade of yellow or brown, owing to causes not well understood; but probably from the presence of some foreign body. It is tasteless, and insoluble in water; but it dissolves in acids, though not so readily as the protoxide, and forms brownish or yellowish solutions having a sweetish and astringent taste.

From the experiments recently made on the constitution of this oxide, there can be no doubt that it is a compound of 100 iron + $28·57 \times 1\frac{1}{2}$ oxygen $= 42·955$. From the experiments of Berzelius it appears that the persulphate of iron is composed of—Sulphuric acid 100—Peroxide of iron 65·5.

This approaches very nearly to

Acid	100	5
Oxide	66·6	3·3

The equivalent number we perceive is $3\frac{1}{3}$. This appears at first sight absurd. The peroxide contains more oxygen than the protoxide, and yet its equivalent is less. But let us suppose it a compound of 2 atoms iron 3 atoms oxygen.—Then the weight will be $3·5 + 3·5 + 3 = 10$. Let us suppose the persulphate a compound of 3 atoms sulphuric acid and 1 atom peroxide. Then we have its composition

Acid	100	$5 \times 3 = 15$
Oxide	66·6	10

Now this is what I consider to be the true constitution of this salt, and the true nature of the peroxide. We thus get rid of the anomaly of the red oxide being a compound of 1 atom iron + $1\frac{1}{2}$ atom oxygen. If we get rid of this anomaly, by supposing the black oxide of iron to contain 2 atoms and the red oxide 3 atoms of oxygen, we represent these oxides by numbers which do not correspond with their equivalents, and which cannot, therefore, be correct.

3. I do not notice here the new oxides of iron announced by Thenard* and Gay-Lussac;† because I do not think that these chemists have succeeded in establishing their existence.

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* Ann. de Chim. lvi. 59.

† Ibid. lxxx. 164.

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 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.[†] That these different shades of colour are owing to the oxidizement of the surface becomes evident from a mode of ornamenting sword-blades, knives, &c. long practised in Sheffield. Flowers, and various other ornaments, are painted on the blade with an oily composition. It is then subjected to the requisite heat for tempering it. The colour of the blade is altered in every part except where it is covered with the paint. When the paint is taken off the ornaments appear of the natural colour of polished steel, and of course are easily distinguishable. Sir H. Davy, in consequence of a letter from Mr. Stoddart, found that when steel is heated in hydrogen gas it does not change its colour as it does when tempered in the usual way.[‡] From these facts it is obvious that the changes of colour are owing to the oxidizement of the surface of the iron. Whether the changes be owing to alterations in the thickness of the coat of oxide or to the formation of various proportions of the two oxides we have no data to determine.

III. Iron combines readily with chlorine, and forms two compounds, which we shall call *protochloride* and *perchloride of iron.*

1. The protochloride may be formed by dissolving iron in muriatic acid, evaporating the solution to dryness, and exposing the dry mass to a red heat in such a manner as to exclude the action of air on it. It was first described by Dr. John Davy,[§]

Protochloride of iron has a grey but variegated colour and a metallic splendour. Its texture is lamellated. When heated to redness it melts, but is not volatilized. It is imperfectly soluble in water, and the solution yields crystals of green muriate of iron. According to the analysis of Dr. John Davy,[‖] it is composed of

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[*] See the curious experiments of Mr. Stoddart, as related by Mr. Nicholson. Nicholson's Quarto Jour. iv. 129.

[†] Lewis, Newman's Chem. p. 79.

[‡] Annals of Philosophy, i. 131.

[§] Phil. Trans. 1812, p. 181.

[‖] Phil. Trans. 1812, p. 182.

Chlorine	53·43	100	4·5
Iron	46.57	87·16	3·9
	100·00		

From this analysis we see that the protochloride is a compound of 1 atom chlorine + 1 atom iron. The accurate proportions, according to the numbers formerly ascertained for the atoms of these bodies, are as follows:

Chlorine	4·5	100
Iron	3·5	77·7

2. The perchloride of iron was first described by Sir H. Davy,* and afterwards more particularly examined by Dr. John Davy.† It may be obtained by burning iron wire in chlorine gas, or by evaporating the red muriate of iron to dryness, and heating it in a tube with a narrow orifice. It is a substance of a bright brown colour, with a lustre approaching that of iron ore from the isle of Elba. It is volatilized by a moderate heat, and forms minute brilliant crystals, the shape of which has not been determined. It dissolves completely in water, and the solution constitutes red muriate of iron. According to the analysis of Dr. Davy, it is composed of

Chlorine	64·9	100	4·5 × 2
Iron	35·1	54·08	4·86

If it be a compound of 2 atoms chlorine and 1 atom iron, of which there seems no doubt, then its composition should be

Chlorine	9	100
Iron	3·5	38·8

These numbers do not agree with the results obtained by Dr. John Davy: but if we consider that his analysis was the first, and that it was upon a minute scale, we shall not be surprised at this want of coincidence.

IV. Iron combines readily with iodine. We know at present only one *iodide* of this metal. It was first mentioned by Sir H. Davy and afterwards was more minutely described by Gay-Lussac. It may be formed by heating iron in contact with vapour of iodine. It is a brown substance which fuses at a red heat. It dissolves in water and forms a light green solution consisting without doubt of hydriodate of iron. It has not been analysed. But it is probably composed of 1 atom iodine united to 1 atom iron, or by weight of

Iodine	15·625	100
Iron	3·5	22·4

Analogy leads to the opinion that there exists likewise a periodide of iron, though it has not hitherto been observed.

V. We know nothing respecting the action of fluorine on iron.

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* Phil. Trans. 1811, p. 23.

† Ibid. 1812, p. 181.

Azote does not seem capable of uniting with iron. Neither does it appear to form any permanent combination with hydrogen.

VI. Iron has the property of combining with *carbon* and the compound constitutes the very important modifications of iron known by the names of *cast iron* and *steel.*

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, or Pig Iron, is the name of this 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.

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:

1st, *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.

2d, *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 lathe. Artillery is made of it.

3d, *Black* cast iron, is the most unequal in its texture, the most fusible, and least cohesive of the three.*

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.*

2. This was usually done in this country by keeping the iron

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* Black's Lectures, ii. 495.

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 25 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 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. This constitutes the foundation of the *puddling* process now universally practised in our manufactories.

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, silicon, or phosphorus.

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

It is so hard as to be unmalleable while cold, or at least it acquires that 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 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*.‡

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* Beddoes, Phil. Trans. 1791.

† This process is called *cementation*.

‡ Dr. Pearson on Wootz, Phil. Trans.

4. 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 obtained 48 ounce measures; and from 100 parts of wrought iron, 50 ounce measures. From 100 parts of cast iron he obtained, at an average, 2·2 of plumbago, or $\frac{1}{45}$; from 100 parts of steel, 0·5, or $\frac{1}{200}$; and from 100 parts of wrought iron, 0·12, or $\frac{1}{900}$.‡ From this analysis he concluded, that cast iron contains the least phlogiston, steel more, and wrought iron most of all; for the hydrogen gas was at that time considered as an indication of 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 applause; and his candour and love of truth procured him the confidence and the esteem of the world.—But all these qualities were united in Bergman, and conspired to form one of the noblest characters that ever adorned human nature.

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* Pliny, lib. xxxiv. 14.

† Opusc. iii. 1.

‡ 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.

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.*

That steel is composed of iron combined with carbon, 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. 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 silicon.§

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* Ann. de Chim. xxii. 1. † Ibid. xxxi. 328. ‡ Nicholson's Journal, iv. 103.

§ A specimen of very pure cast iron analysed by Berzelius, yielded

Iron (with silicon and magnesium)	91·53
Manganese	4·57
Carbon	3·90
	100·00

The silicon was $\frac{1}{2}$ a per cent. the magnesium $\frac{1}{5}$th of a per cent. Afhandlingar, iii. 152.

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

The conversion of cast iron into wrought iron is effected by burning away the 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 ¼th 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 ⅓d) is scorified or converted into black oxide of iron, known when melted by the name of *finery cinder*.‡ 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.

6. 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 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 is made by stratifying bars of pure iron and charcoal powder alternately in large earthen troughs or crucibles, the mouths of which are carefully closed up with clay. These troughs are put into a furnace, and kept sufficiently hot till the bars of iron are converted into steel, which usually requires eight or ten days.‖ This process was invented, or at least first practised to any extent, in Britain. The bars of steel thus formed, are known

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[*] 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. An. vii. p. 8.

[‡] The French name for this is *laitier*.

[§] A detailed account of this process, as performed in different iron works, may be seen in the Jour. de Min. No. iv. p. 3.

[‖] The process is described at large by Mr. Collier in the Manchester Memoirs, v. 117.

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 is the most valuable of all, as its texture is most compact, and it admits of the finest polish. It is used for razors, surgeons' instruments, and other similar purposes. It is more fusible than common steel, and for that reason cannot be welded with iron: it melts before it can be heated high enough. The method of making it was discovered about 1750 by Mr. Huntsman of Sheffield. The process was for some time kept secret; but it is now well known in this country, and other manufacturers succeed in it equally well with the original discoverer. It consists in fusing blistered steel in a close crucible, mixed with a certain proportion of pounded glass and charcoal powder. It may be formed also, according to the experiments of Clouet, by melting together 30 parts of iron, 1 part of charcoal, and 1 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.

7. 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 exceeds, 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

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

[†] Jour. de Min. An. vii. 3.

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

[§] Phil. Mag. xii. 27.

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.†

$\frac{1}{120}$	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.

8. The substance described in a preceding section under the name of plumbago, has been usually considered as a carburet of iron. But this opinion cannot be maintained by any plausible arguments. According to the analysis of Allen and Pepys, it is composed of—Carbon 95—Iron 5.

Now if an atom of carbon weigh 0·75 and an atom of iron 3·5, it must follow that it consists of about 100 atoms of carbon, united to only 1 atom of iron. But such a combination cannot be conceived. It is much more probable that the small proportion of iron is only mechanically mixed.

VII. From the experiments of Descotils‡ and Gmelin§ we learn, that iron is capable of combining with *boron*. The *boruret* was formed by fusing a mixture of iron filings and boracic acid in a covered crucible. It constituted a ductile mass of a silver white colour.

VIII. From the experiments, of Berzelius and Stromeyer, it appears that silicon may be combined with iron. It is even probable, from Berzelius' observations, that some kinds of iron may owe their peculiar qualities to the silicon which they contain. *Silicuret* of iron is of a silver white colour and ductile. It requires heat before it dissolves in sulphuric acid. When dissolved in acids it leaves a quantity of silica, constituting a porous mass of the size of the silicuret dissolved. Nothing is known respecting the proportions of iron and silicon, capable of uniting.

IX. Iron readily unites with phosphorus, and forms a *phosphuret of iron*.

1. *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 phos-

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* Phil. Mag. xiii. 138.

† Ibid. xiii. p. 142.

‡ Recherches Physico-chimiques, i. 306.

§ Schweigger's Journal, xv. 246.

phorus 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*.

2. 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 Upsala in examining the cause of this property, while Meyer[§] was occupied at Stetin with the same investigation; and both of them discovered, nearly at the same time, that by means of sulphuric acid, a white powder could be separated from this kind of iron, which by the usual process they converted into a metal of a dark steel grey exceedingly brittle, and not very soluble in acids. Its specific gravity was 6.700; it was not so fusible as copper; and when combined with iron rendered it *cold short*. Both of them concluded that this substance was a *new metal*. Bergman gave it the 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 phosphuret of iron; the phosphoric acid being deprived of its oxygen during the *reduction*.[‡‡]

X. Iron combines with two proportions of sulphur, and forms *protosulphuret* and *persulphuret of iron*, compounds which are usually distinguished among mineralogists by the names of *magnetic pyrites* and *cubic pyrites*.

1. Protosulphuret of iron or magnetic pyrites, is found native in considerable quantity. Its colour is that of bronze. It has a me-

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[*] Pelletier, Ann. de Chim. i. 105.

[†] Ibid. xiii. 113.

[‡] Opusc. iii. 109.

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

[||] This process in chemistry is called *reduction*.

[¶] Crell's Annals, 1784, i. 390.

[**] Ibid. i. 195.

[††] Crell, i. 112, Eng. Trans.

[‡‡] 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.

tallic lustre; but its powder is blackish grey. Its specific gravity is 4·518. It strikes fire with steel, and easily melts when heated. Mr. Hatchett found it composed of 63 iron and 37 sulphur, which agrees almost exactly with the analysis of Proust. He is of opinion 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.†

If we suppose it a compound of 1 atom iron + 1 atom sulphur, its constituents will be,

Iron	3·5	100
Sulphur	2	57·1

Now the result of Hatchett's analysis is,—Iron 100—Sulphur 58·73. Here we see the coincidence is very close.

2. *Persulphuret of iron*, or *cubic pyrites*, 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 crystallizes 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 protosulphuret 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 protosulphuret of iron—20 sulphur.

But this method is not susceptible of great accuracy. Mr. Hatchett 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:§

	Pyrites.	Specific gravity.	Constituents.		
			Iron.	Sulphur.	Total.
1st	In dodecahedrons	4·830	47·85	52·15	100
2d	Striated cubes		47·50	42·50	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
	Mean		46·94	53·06	100

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* Hatchett's Analysis of Magnetical Pyrites, Phil. Trans. 1804.

† Hatchett, ibid.

‡ Jour. de Phys. liii. 89.

§ Hatchett, Phil. Trans. 1804.

If we suppose the persulphuret of iron to be a compound of 1 atom iron with 2 atoms sulphur, then its constituents will be

Iron	3·5	100
Sulphur	4	114·2

Now the mean of Mr. Hatchett's analyses, just stated, gives us,—Iron 100—Sulphur 113.

Here the coincidence between the experimental and theoretical result is still greater than is the case with protosulphuret of iron. As the deviations in the two cases are on opposite sides, the mean of both would come still nearer the truth. This is sufficient to convince us that on the supposition of perfect precision the differences would vanish altogether.

Protosulphuret of iron is not only attracted by the magnet, but may be itself converted into a magnet by the usual methods; but persulphuret is not in the least obedient to the magnet, neither is it susceptible of the magnetic virtues.*

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 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 phosphorous; but whether the magnetism disappears when the proportion of phosphorus is increased, has not been ascertained.

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,"

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* Hatchett, Phil. Trans. 1804.

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 phospurets, 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."

XI. 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.*

XII. We are not acquainted with the combination of iron and tellurium. It combines with potassium and sodium; but its alloys with these metals have not been particularly observed. We know nothing of its combinations with the metals of the alakaline earths and earths proper.

At present it would be difficult to determine the order of the affinities of the simple combustibles for oxygen. Iron has the property, when assisted by heat, of depriving potassium and sodium of their oxygen. But potassium and sodium are equally capable of reducing the oxides of iron to the metallic state. Again, iron at a red heat rapidly decomposes water and separates the hydrogen gas. Here it would seem that iron has a stronger affinity for oxygen than hydrogen gas. But, on the other hand, when oxide of iron is surrounded with hydrogen gas, and heated, it is rapidly converted

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* Bergman, ii. 281.

into the metallic state while abundance of water is formed. Here the affinities of the different bases for oxygen seem to have alternately the preponderance Various other examples might easily be given. They show sufficiently that our present opinions respecting affinity are by no means accurate. The order of the affinities of the simple supporters for iron is as follows: *Iron*—Chlorine—Oxygen*—Iodine.

SECTION II.

OF NICKEL.

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 give it the name of *Kupfernickel*, or "false copper." Hierne, who may be considered as the father of the Swedish chemists, is the first person who mentions this mineral. He gives a description of it in a book published by him in 1694, on the art of detecting metals. It was generally considered by mineralogists as an ore of copper, till it was examined by the celebrated Cronstedt. He concluded from his experiments, which were published in the Stockholm Transactions for 1751 and 1754, that it contained a new metal, to which he gave the name of *nickel*.

This opinion was embraced by all the Swedes, and indeed by the greater number of chemical philosophers. Some, however, particularly Sage and Monnet, affirmed that it contained no new metal, but merely a compound of various known metals, which could be separated from each other by the usual processes. These assertions induced Bergman to undertake a very laborious course of experiments, in order, if possible, to obtain *nickel* in a state of purity; for Cronstedt had not been able to separate a quantity of arsenic, cobalt, and iron, which adhered to it with much obstinacy. These experiments, which were published in 1775,† fully confirmed the conclusions of Cronstedt. Bergman has 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

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* It would appear from Davy's experiments that the peroxide of iron retains oxygen more obstinately than the protoxide. For the red oxide was not decomposed by chlorine, though the black oxide was. See Phil. Trans. 1811, p. 25.

† Bergman, ii. 231.

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, 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 eight other processes have been proposed by chemists, all of them ingenious, and attended each with peculiar advantages and inconveniences.[†]

In the year 1804 an elaborate paper on nickel was published by Richter,[‡] and in the year 1811 an excellent set of experiments on this metal and its combinations was published by Tupputi.[§] About the same time an elaborate analysis of its oxides was made by Rothoff.[||]

Tupputi's mode of obtaining pure nickel is as follows. The impure metallic substance to be met with in commerce called *speiss*, is to be reduced to powder and digested in 2½ times its weight of nitric acid diluted with an equal weight of water. When the action is at an end, filter the solution in order to get rid of a quantity of arsenious acid which exists in it in the state of a powder. Evaporate the liquid to ¼th of its bulk; more crystals of arsenious acid will fall; let them be separated by a filter. Then into the liquid, still hot, drop by degrees a solution of carbonate of soda till the precipitate which falls begins to assume a green colour.[¶] Then filter the liquid, dilute it with a good deal of water, and add an excess of acid, and pass through it a current of sulphureted hydrogen gas in order to precipitate the whole of the arsenic. It falls in the state of yellow flocks. When it has been all thrown down, filter again and add a sufficient quantity of potash to precipitate

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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.

[‡] Gehlen's Journal, iii. 244.

[§] Ann. de Chim. lxxviii. 133.

[||] Berzelius's Lärbok i kemien, ii. 311.

[¶] There first falls arseniate of iron in yellowish-white flocks, then arseniate of cobalt in rose-red flocks mixed with arseniate of copper and some arseniate of manganese.

the oxide of nickel which now remains combined with nitric acid. Mix this oxide with 3 per cent. of resin, make it into a paste with oil, and expose it to the most violent heat of a forge in a charcoal crucible. A metallic button of pure nickel will be obtained.

But a much shorter process may be employed to procure nickel in a state of very considerable purity. Dissolve speiss in sulphuric acid by adding the quantity of nitric acid necessary to produce the solution. Concentrate this solution and set it aside. Fine green crystals of sulphate of nickel make their appearance. Proceed in this manner till you have obtained a sufficient quantity of crystals of sulphate of nickel. Dissolve these crystals in water and crystallize them a second time. If they be now dissolved in water, and decomposed by an alkali, pure oxide of nickel will fall. It may be reduced as above to the metallic state.

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

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.[†] But Tourte found the specific gravity of Richter's nickel 8·402, and when strongly hammered it was as high as 8·932.[‡] According to Tuputi, when fused it is 8·380, and after being hammered it is as high as 8·820.[§]

It is malleable both cold and hot; and may without difficulty be hammered out into plates not exceeding the $\frac{1}{100}$ part of an inch in thickness.[||]

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

According to Lampadius, its magnetic energy is to that of iron as 35 to 55.[**]

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.[‡‡]

From the experiments of Tuputi, it appears that preparations of nickel possess poisonous qualities.[§§]

II. Nickel, when moderately heated, is soon tarnished; and from the observations of Tourte, it appears that it runs through nearly the same changes of colour that steel does when tempered. It becomes first light-yellow, then deep-yellow, light violet-blue,

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

[†] Gehlen's Jour. iii. 352.

[‡] Gehlen's Journal, für die Chemie, Physick und Mineralogie, vii. 444. From Lampadius' experiments it appears that this nickel contained cobalt and arsenic. Tromsdorf's Journal, xvi. 49, as quoted by Tuputi.

[§] Ann. de Chim. lxxviii. 140.

[||] Richter, Gehlen's Jour. iii. 252.

[¶] Bergman, Klaproth, Fourcroy, Richter, &c.—Mr. Chenevix had announced a method of procuring nickel which was not magnetic; but he afterwards ascertained, that it owed this peculiarity to the presence of arsenic.

[**] Annals of Philosophy, v. 62.

[††] Bergman, ii. 269. According to Richter, its melting point is as high as that of manganese. Tuputi thinks it rather lower.

[‡‡] Richter, Ibid.

[§§] Ann. de Chim. lxxx. 188.

and last of all greyish-blue.[*] It is capable of combining with two proportions of oxygen, and of forming two oxides. The protoxide is *blackish ash grey*, the peroxide *black*.

1. By exposure to heat, however long continued, Tuputi was not able to oxidize this metal completely. The protoxide is easily procured by dissolving nickel in nitric acid, throwing it down by potash, and after washing the precipitate, drying it and heating it to redness. We have four sets of experiments to determine the quantity of oxgen in this oxide. The following table exhibits the results.

Proust[†]	-	100 nickel		+ 26 oxygen
Richter[‡]	-	100	-	+ 28·2
Tuputi[§]	-	100	-	+ 27
Rothoff[‖]	-	100	-	+ 27·255
Klaproth[¶]		100	-	+ 32·5

To determine which of these numbers is most correct, let us examine the composition of sulphate of nickel. This salt, according to the experiments of Tuputi, is composed of

Sulphuric acid	-	100	-	5
Protoxide of nickel		87·26	-	4·362

We see that according to this analysis the equivalent number for protoxide of nickel is 4·362. We may consider it without sensible error as 4·375. On this supposition (considering it as a compound of 1 atom metal + 1 atom oxygen) it will consist of—Nickel 100—Oxygen 29·63.

This agrees best with the determination of Richter, which therefore appears to be nearest the truth. The weight of an atom of nickel is 3·375.

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.

2. The peroxide of nickel was first examined by Thenard. It may be formed by causing a current of chlorine gas 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.[**] From the experiments of Rothoff, it appears that this oxide contains 1½ times as much oxygen as the protoxide. Hence it is a compound of—Nickel 100—Oxygen 44·445.

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[*] Gehlen's Journal, für die Chemie, Physik, &c. vii. 443.

[†] Ann. de Chim. lx. 272.

[‡] Gehlen's Journal, iii. 258.

[§] Ann de Chim. lxxviii. 144.

[‖] Berzelius Lärbok i Kemien ii. 311,

[¶] Ann. de Chim. lxxxv. 68.

[**] Thenard, Ann. de Chim. l. 125.

To get rid of the anomaly of the half atom we must consider it as a compound of 2 atoms of nickel and 3 atoms of oxygen. Hence its weight will be 9·75. From Thenard's experiments it does not appear to be capable of combining with acids without giving out its excess of oxygen, and being reduced to the state of a protoxide.

III. Nickel does not burn when introduced into chlorine gas. Its oxide is not altered though heated to redness in that gas.* But the chloride of nickel may be formed by leaving nickel in contact with chlorine gas, or by subliming dry muriate of nickel. It is an olive-coloured substance, the properties of which have not been examined.

IV. The iodide of nickel is still unknown.

V. We are not acquainted with the compound of nickel and fluorine. It does not appear to unite with azote or hydrogen.

VI. According to Tuputi nickel always contains a portion of carbon when prepared by the process described at the commencement of this section. When dissolved in acids it leaves this carbon in the state of charcoal.

VII. We are not acquainted with any combination of nickel with boron or silicon.

VIII. 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.

According to Lampadius it is composed of 100 nickel + 15 phosphorus, or 3 atoms nickel + 1 atom phosphorus. It is tin-white, according to him, and has the metallic lustre. It is moderately hard and very brittle. Its fracture is foliated, and it is not attracted by the magnet.‡

IX. 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.

Lampadius describes it as yellowish-white, or similar in appearance to copper nickel. It is not attracted by the magnet. It was composed of 100 nickel + 10 sulphur.§ This would be a compound of 6 atoms nickel and 1 atom sulphur. But no doubt it was incomplete.

X. 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. Arse-

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* Davy, Phil. Trans. 1811, p. 25.

† Pelletier, Ann. de Chim. xiii. 135.

‡ Annals of Philosophy, iv. 63.

§ Ibid.

nic possesses the curious property of destroying the magnetic virtue of iron, and all other metals susceptible of that virtue.

XI. We are ignorant of the alloys which nickel is capable of forming with tellurium, the metallic bases of the fixed alkalies, alkaline earths and earths proper. It combines readily with iron; but the properties of the alloy have not been examined. According to Lampadius an alloy of 5 parts nickel and 2 parts iron is moderately hard, quite malleable, and has the colour of steel.[*]

SECTION III.

OF COBALT.

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 celebrated 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 com-

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[*] Annals of Philosophy, v. 62.

[†] 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.

[‡] Acta Upsal. 1733 and 1742.

[§] Cadmialogia, oder Geschichte des Farben-Kobolds.

[‖] Opusc. ii. 444, 501, and iv. 371.

[¶] Ann. de Chim. xxviii. 101.

[**] Fourcroy, Discours Preliminaire, p. 114.

binations 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.[‡]

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.

2. It is rather soft. Its specific gravity according to Tassaert, is 8·5384.[‖] According to Lampadius it is 8·7.[¶]

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.

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.

Cobalt combines with two proportions of oxygen and forms two oxides. The protoxide has a *blue* colour, but the peroxide is *black*.

1. The protoxide of cobalt 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 con-

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[*] 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.

[‖] Ann. de Chim. xxviii. 99.

[¶] As quoted by Berzelius; Lärbok i Kemien, ii. 295. Bergman and the French chemists, and Hatchett, state the specific gravity as 7·7; but their specimens were obviously impure.

[**] Fourcroy, v. 137.

verts it into a fine blue colour. This oxide dissolves in acids without effervesence. 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.[*] This oxide has been analysed by Proust and Rothoff. The following are the results which they obtained:

Proust[†]	-	100 cobalt + 19·8 oxygen
Rothoff[‡]	-	100 - + 27·3

From the experiments of Rothoff it appears that when the peroxide of cobalt is converted into the protoxide it gives out 9·7 of oxygen. Hence we see that the oxygen in the two oxides are as the numbers 2 to 3. This last analysis, which seems susceptible of considerable precision, would make the protoxide of cobalt a compound of Cobalt 100—Oxygen 27·36.

From this it would appear that the weight of an atom of cobalt is 3·625; on this supposition (which must be very near the truth) the protoxide of cobalt is composed of

Cobalt	3·625	100
Oxygen	1	27·58

2. When the protoxide of cobalt, newly precipitated from an acid, is dried by heating it in the 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 chlorine gas is exhaled. From the experiments of Rothoff, combined with the preceding determination of the composition of the protoxide, it follows, that the peroxide is composed of—Cobalt 100—Oxygen 36·77.

To reconcile this proportion with the atomic theory, we must consider this oxide as a compound of 2 atoms cobalt and 3 atoms oxygen. On this supposition its weight will be 10·250.

III. Cobalt burns when gently heated in chlorine gas. The compound formed is a chloride which has not been examined.

IV. The *iodide* of cobalt has not been examined. Neither are we acquainted with its action on fluorine. It does not appear capable of combining with azote or hydrogen. We know no compound which it forms with carbon, boron, or silicon.

V. Phosphuret of cobalt may be formed by heating the metal red hot, and then gradually dropping in small bits of phosphorus. It contains about $\frac{1}{13}$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.[§]

VI. Cobalt 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

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[*] Ann. de Chim. xlii. 215. [†] Ibid. lx. 267. [‡] Annals of Philosophy, iii. 356.

[§] Pelletier, Ann. de Chim. xiii. 134.

white colour, displays the rudiments of crystals, and can scarcely be decomposed by heat.

The sulphuret of cobalt, according to Proust, may be formed by heating together the oxide of cobalt and sulphur. According to his experiments* it is composed of—Cobalt 100—Sulphur 39·86.—But he does not place much confidence in the accuracy of his experiments. If the sulphuret of cobalt be a compound of 1 atom cobalt + 1 atom sulphur, its constituents will be

Cobalt	3·625	100
Sulphur	2·	55·16

VII. We are not acquainted with the alloys which cobalt forms with arsenic, tellurium, the metallic bases of the fixed alkalies, of the alkaline earths, and earths proper.

VIII. 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.

SECTION IV.

OF MANGANESE.

The dark grey or brown mineral called *manganese*, in Latin *magnesia* (according to Boyle from its resemblance to the *magnet*,) has been long known and used in the manufacture of glass. A mine of it was discovered in England by Boyle. A few experiments were made upon this mineral by Glauber in 1656,† and by 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

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[*] Ann. de Chim. lx. 272.

[†] Prosperitas Germania.

[‡] Weigleb's Geschichte, i. 127.

[§] Mem. Stockholm, 1765, p. 235.

[‖] De Metallis dubiis, p. 48.

[¶] Opusc. ii. 201.

attempts to reduce it, but without success; the whole mass either assuming the form of scoriæ, or yielding only small separate globules attracted by the magnet. This difficulty of fusion led him to suspect, that the metal he was in quest of bore a strong analogy to platinum. In the mean time, Dr. Gahn, who was making experiments on the same mineral, actually succeeded in reducing it by the following process: He lined a crucible with charcoal powder moistened with water, put into it some of the mineral formed into a ball by means of oil, then filled up the crucible with charcoal powder, luted another crucible over it, and exposed the whole for about an hour to a very intense heat. At the bottom of the crucible was found a metallic button, or rather a number of small metallic globules, equal in weight to one-third of the mineral employed.* It is easy to see by what means this reduction was accomplished. The charcoal attracted the oxygen from the oxide, and the metal remained behind. The metal obtained, which is called *manganese*, was farther examined by Ilseman in 1782, Hielm in 1785, and Bindheim in 1789. An elaborate and extensive set of experiments on this metal and its combinations was published by Dr. John in 1807.†

1. Manganese, when pure, is of a greyish-white colour, like cast iron, and has a good deal of brilliancy. Its texture is granular. It has neither taste nor smell. It is softer than cast iron and may be filed. Its specific gravity is 8·013.‡

2. It is very brittle; of course it can neither be hammered nor drawn out into wire. Its tenacity is unknown. Its fracture is uneven and its texture fine granular.

3. It requires, according to Morveau, the temperature of 160° Wedgewood to melt it; it is therefore somewhat less fusible than iron.

4. When pure it is not attracted by the magnet, even when in powder; but a very small quantity of iron gives it the magnetic property.

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. When thrown into water it decomposes that liquid with considerable rapidity. The hydrogen extricated has a smell of assafœtida, owing it is supposed to a small portion of the metal which it carries up with it.

Three sets of experiments have been made to determine the oxides which this metal forms. According to John it forms three oxides, the *green*, the *brown*, and the *black*. The green is obtained by dissolving the metal in acids and precipitating it by an alkali, or by leaving it a sufficient time in water. The black or *peroxide*

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* Bergman, ii. 211.

† Gehlen's Journal für die Chemie und Physik, iii. 452.

‡ John, Gehlen's Journal, iii. 460.

is found native in abundance. The brown is obtained by exposing the black for some time to a red heat. According to him these oxides are composed as follows:

Green	- -	100 manganese	+	15 oxygen
Brown	- -	100	-	+ 25
Black	- -	100	-	+ 40

Berzelius, partly from his own experiments and partly from those of John, reckons five oxides. The first is *grey* and is obtained by keeping metallic manganese for some time in a phial with a cork stopper. The second is *green* and is obtained by keeping manganese in water. The third by dissolving manganese in acids; the fourth by calcining the nitrate of manganese; while the fifth or peroxide exists in nature.* According to him these oxides are composed as follows:

1 -	100 metal +	7·0266	4 -	100 metal +	42·16
2 -	100 -	+ 14·0533	5 -	100 -	+ 56·213
3 -	100 -	+ 28·1070			

Sir H. Davy obtained two oxides of manganese,† the *olive* and the *brown*, which he found composed as follows:

Olive	- -	100 metal	+ 26·58
Brown	- -	100 -	+ 39·82

Dr. John acknowledges that his analyses of these oxides is by no means to be depended on. Berzelius's statements are rather theoretical than experimental. He even doubts of the existence of his first oxide, the only one he examined; and he has advanced no proof that there exists any difference between his second and third oxide. The existence of the green oxide of John cannot be doubted. It constitutes the bases of the different salts of manganese. The existence of the black oxide is equally certain, as it occurs native in such abundance. When the black oxide is heated to redness a brown powder remains, which constitutes the intermediate oxide of John. But when we attempt to dissolve this powder in acids it is immediately separated into the green and the black oxides of manganese. Hence it would seem to be merely a mixture or combination of these two oxides. At present therefore we have evidence of the existence of only two oxides of manganese; the *protoxide* which combines with acids and forms the common salts of manganese, and the *peroxide* which exists native.

1. To determine the composition of the protoxide the best way seems to be to have recourse to the salts into which it enters. According to Dr. John, sulphate of manganese is composed of

Sulphuric acid	- -	100 -	5
Protoxide	- - -	92·06	4·6

Carbonate of manganese according to the same chemist is composed of

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* Ann. de Chim. lxxxiii. 169.

† Elements of Chemical Philosophy, p. 367.

Carbonic acid	100	2·75
Protoxide	163·46	4·495

By the first of these salts we see that the equivalent number for protoxide of manganese is 4·6; by the second it is 4·495. We may therefore take 4·5 as the true equivalent without falling into any great error. Hence it is evident that protoxide of manganese is composed of

Manganese	3·5	100
Oxygen	1	28·75

This very nearly coincides with Berzelius' third oxide. And in reality his third oxide is the *protoxide* of manganese.

The protoxide of manganese is an olive green powder, which when exposed to the air speedily attracts oxygen and becomes black. When combined with carbonic acid it constitutes a white powder.

2. The peroxide of manganese is found native in abundance particularly in Devonshire near Exeter. When pure it has a radiated texture and a dark steel-grey colour, with considerable lustre and beauty. It is brittle and very soft, soiling the fingers. Its specific gravity is about 4·7563. When heated to redness it gives out rather more than the tenth part of its weight of oxygen gas, and is converted into a brown powder destitute of metallic lustre. This oxide has never been accurately analysed. Berzelius states its composition from theoretical considerations to be—Manganese 100—Oxygen 56·213. If we suppose the quantity of oxygen which it contains to be exactly double the oxygen in the protoxide, which from the facts respecting it already known there is every reason to consider as its composition, then it must be a compound of—Manganese 100—Oxygen 57·5. And the weight of an atom of it will be 5·5.

III. As far as is known at present manganese combines with chlorine in only one proportion. The chloride of manganese was first described by Dr. John Davy. He obtained it by dissolving the black oxide of manganese in muriatic acid, evaporating the solution to dryness and exposing the white salt that remains to a red heat in a glass tube with a very narrow orifice. It is a substance of a pure delicate light pink colour and of a lamellar texture, consisting of broad thin plates. It melts at a red heat without alteration in close vessels; but in the open air it is decomposed, muriatic acid being given out and oxide of manganese remaining. When left in an open vessel it deliquesces and is converted into muriate of manganese. According to Dr. John Davy's experiments it is composed of

Chlorine	54	100	4·5
Manganese	46	85·18	3·83

This does not correspond exactly with the weight of an atom of manganese as determined from Dr. John's analyses of the sulphate and carbonate of manganese. I should not be surprised if the real weight of an atom of manganese were 3·75. But this must be left for the decision of future experiments.

IV. No experiments have been hitherto made on the combinations of manganese and iodine.

V. We are ignorant of the action of fluorine on manganese. It does not combine with azote nor hydrogen.

VI. It appears capable of combining with carbon. This compound is formed occasionally in iron founderies. And in this country it is known by the name of *Keesh*. It occurs occasionally in small cavities in the mass of cast iron, and seems to be the result of crystallizing during the cooling of the mass. It is composed of thin scales having the lustre and appearance of steel; but very brittle. It was considered as plumbago; but Dr. Wollaston examined it and found that acids have the property of separating from it a little iron. The residuum he found a compound of carbon and manganese. It is therefore a carburet of that metal.

VII. We do not know any compound of manganese with boron or silicon.

VIII. Phosphorus may be combined with manganese by melting together equal parts of the metal and of phosphoric glass; or by dropping phosphorus upon red hot manganese. The phosphuret of manganese is of a white colour, brittle, granulated, disposed to crystallize, not altered by exposure to the air, and more fusible than manganese. When heated the phosphorus burns, and the metal is oxidized.*

IX. 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.‡

Vauquelin likewise succeeded in combining sulphur with manganese, by heating them together. According to his experiments, the sulphuret of manganese is composed of

Manganese -	74·5 -	100
Sulphur -	25·5 -	34·22
		100·0§

From this analysis it is reasonable to conclude, that sulphuret of manganese is composed of 2 atoms manganese and 1 atom sulphur. On this supposition its constituents are

Manganese -	7 -	100
Sulphur -	2 -	28·57

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* Pelletier, Ann. de Chim. xiii. 137.

† Bergman, ii. 221.

‡ Jour. de Phys. lvi. 1.

§ Ann. des Mus. d'Hist. Nat. 159.

X. We are not acquainted with the alloys which manganese is capable of forming with arsenic, tellurium, the metallic bases of the fixed alkalies, alkaline earths, and earths proper.

XI. 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.

From Berzelius' experiments we learn, that manganese enters as a constituent into cast iron.

XII. We do not know the alloys of manganese with nickel and cobalt.

SECTION V.

OF CERIUM.

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 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 re-examined

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[*] Gehlen's Jour. ii. 305.

[†] Ibid.

[‡] Ibid. ii. 398.

[§] Opusc. vi. 108.

[‖] Gehlen's Jour. ii. 203.

[¶] Ann. de Chim. l. 140.

[**] Gehlen's Jour. ii. 297.

[††] Gehlen's Jour. iii. 217.

it more 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.

In 1814 a new set of experiments on it were published by Laugier.† He appears to have reduced it to the metallic state, but, instead of the pure metal, obtained only a carburet. Hisinger had previously endeavoured to determine the composition of its oxides.‡

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 fiftieth 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 of it was dissipated, small globules only remaining, which proved as before a mixture of cerium and iron.§

Laugier has shown that oxalic acid precipitates the whole of the oxide of cerium, and thus separates it from iron. He employed the oxide from the oxalate and exposed it to a strong heat made up into a paste with oil. He affirms that it is not volatile. But an experiment made in Mr. Children's laboratory demonstrates the contrary. Oxalate of cerium, which I had prepared, was exposed to the heat of a furnace, urged by bellows in a crucible of charcoal: it was completely volatilized.‖

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 re-dissolved 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.

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, disen-

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[*] Ann. de Chim. iv. 28.

[†] Ann. de Chim. lxxxix. 317.

[‡] Memoirs of the Stockholm Academy for 1813, and Annals of Philosophy, iv. 355.

[§] Ann. de Chim. liv. 59.

[‖] Annals of Philosophy, ii. 147.

[¶] A salt to be described hereafter.

[**] Gehlen's Jour. ii. 401.

gaging at first sulphureted hydrogen, and afterwards pure hydrogen gas.*

II. According to the experiments of Vauquelin and Hisinger, this metal combines with 2 portions of oxygen. The protoxide is white, the peroxide reddish brown. Hisinger endeavoured to determine the proportion of oxygen which these oxides contain by a careful analysis of some of the salts which they form. The peroxide contains 1½ times as much oxygen as the protoxide. The protoxide, according to him, is composed of—Cerium 100—Oxygen 17·41. The peroxide of—Cerium 100—Oxygen 26·115.

From Hisinger's experiments it appears, that the equivalent number for protoxide of cerium is 6·75, and that it is a compound of 1 atom cerium + 1 atom oxygen. On this supposition it is composed of

Cerium	5·75	100
Oxygen	1	17·39

We must suppose peroxide of cerium a compound of 2 atoms cerium + 3 atoms oxygen. According to this supposition the weight of an atom of it will be 14·5.

III. We are not acquainted with any combination of cerium with chlorine, fluorine, azote, or hydrogen.

IV. From the experiments of Laugier, it appears capable of combining with carbon. He obtained the carburet by heating protoxide of cerium, made into a paste with oil, surrounded with charcoal in a retort. The carburet was a black matter which took fire spontaneously when exposed to the air.†

V. 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.‡

VI. Hydro-sulphuret of ammonia throws down cerium at first of a brown colour, but it becomes deep green as we continue to add the re-agent. 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.§

VII. 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.

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* Hisinger and Berzelius, Gehlen's Jour. ii. 401.

† Ann de Chim. lxxxix. 317.

‡ Hisinger and Berzelius, Ann. de Chim. liv. 46.

§ Hisinger and Berzelius, ibid. With Vauquelin the result was different. The precipitate which he obtained was white, and contained no sulphureted hydrogen.

SECTION VI.

OF URANIUM.

I. THERE is a mineral found in the George Wagsfort mine at Johan-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) 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 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 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.[§]

To obtain uranium from its ore, the mineral is to be treated with nitric acid, which dissolves the metallic 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 pre-

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[*] Klaproth, Crell's Jour. Engl. Transl. i. 126.

[†] *Blende* is the name given to ores of zinc.

[‡] 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 Journal, iv. 17.

sent, 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.*

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 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.

II. From the experiments of Bucholz, together with those of Schoübert† we learn, that uranium combines with 2 doses of oxygen. The protoxide is *greyish-black;* but the peroxide is *yellow*.

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. According to the experiments of Bucholz, this oxide is composed of—Uranium 100—Oxygen 5·17.‡

But Schoübert, from the muriate of uranium, has calculated the composition of the protoxide as follows :—Uranium 100—Oxygen 6·373.§

As the experiments of Schoübert were made with care, and his method is susceptible of greater precision than that of Bucholz, we shall take his estimate as the most correct. If the protoxide be a compound of 1 atom metal + 1 atom oxygen, then the weight of an atom of uranium will be 15·691. We shall consider 15·625 as the correct number. We have in that case protoxide of uranium composed of

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[*] See Klaproth's Beitrage, ii. 476, Eng. Trans. and Bucholz, Gehlen's Jour. iv. 19.

[†] Berzelius' Attempt to establish a pure scientific system of Mineralogy, p. 118.

[‡] Gehlen's Journal, iv. 35.

[§] Berzelius' Attempt to establish a pure scientific system of Mineralogy, p. 118.

Uranium	15·625	100
Oxygen	1	6·4

2. When uranium or its protoxide 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, chlorine acid gas being disengaged. According to the experiments of Schoübert it follows, that this oxide contains 1½ times as much oxygen as the protoxide. It is composed therefore of—Uranium 100—Oxygen 9·6.

If we consider it as a compound of 2 atoms uranium and 3 atoms oxygen, an atom of it will weigh 34·25.

III. We are unacquainted with the compounds which uranium makes with chlorine, iodine, and fluorine. It does not appear capable of uniting with azote nor hydrogen. We are acquainted with no compounds which it forms with carbon, boron, silicon, and phosphorus.

IV. 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.†

V. Nothing is known respecting the combinations of uranium with the other metals; Bulcholz having been hitherto prevented from making any experiments on that part of the subject, by the want of a sufficient quantity of uranium.

FAMILY IV.

The substances belonging to this family are the following seven:

1. Zinc
2. Lead
3. Tin
4. Copper
5. Bismuth
6. Mercury.
7. Silver.

They are all metals, and have been long known, and are in common use for the purposes to which metals are applied. They are precipitated from their solutions in acids in the metallic state in

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* Beitrage, ii. 213.

† Gehlen's Jour. iv. 47.

the order according to which they are placed in the preceding table. Zinc precipitates all the others, but is not itself precipitated by any of them. Lead precipitates all except zinc. Tin all except zinc and lead. Copper precipitates only bismuth, mercury, and silver; and mercury precipitates only silver. Silver is precipitated by all the rest, but does not itself precipitate any of the others.

SECTION I.

OF ZINC.

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 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*.

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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 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 subtantiæ 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 silicet 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.

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 Margraff 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 Swansey. 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.[‡]

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. It is rather soft; 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 copper, lead, or tin; yet it is not brittle, like antimony or arsenic. When struck with a hammer, it does not break, but yields, and becomes somewhat flatter; and by a cautious and equal pressure, it may be reduced to pretty thin plates, which are supple and elastic, but cannot be folded without breaking. This 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 lathe. 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.[††]

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[*] 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.

[‡] 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.

[¶] 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.

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.[†]

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 rapidly; 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.[§]

Zinc combines with only one proportion of oxygen. The oxide of zinc is a tasteless, white powder, rather light and insoluble in water. It is used as a paint and answers very well as a water colour. It combines readily with acids and forms neutral salts. Many careful experiments have been made to determine the composition of this oxide. The following table exhibits the results obtained by the different experimenters:

Proust[‖]	100 metal + 25	Gay-Lussac[**]	100 metal + 24·4
Berzelius[¶]	100 . . . + 24·4	Thomson[††]	100 . . . + 24·16

We perceive a great coincidence in all these experiments. If the oxide of zinc be a compound of 1 atom metal + 1 atom oxygen, then according to Proust's determination an atom of zinc will weigh 4. According to the determination of Berzelius and Gay-Lussac its weight will be 4·098. According to mine it will be 4·139. We may take 4·125 as sufficiently near the truth.

The reduction of the oxides of zinc is an operation of difficulty,

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[*] Black's Lectures, ii. 583.

[†] Mongez.

[‡] Lavoisier, Mem. Par. 1781, p. 274.

[§] Εριον τολυπαι αφομοιονται, V. 85, p. 352.

[‖] Ann. de Chim. xxxv. 51.

[¶] Ibid. lxxvii. 84.

[**] Ibid. lxxx, 170.

[††] Annals of Philosophy, ii. 410.

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.

III. Zinc combines readily with chlorine and forms a *chloride of zinc*. This metal takes fire in chlorine gas and the chloride is formed. It may be obtained by dissolving zinc in muriatic acid, evaporating the solution to dryness, and exposing it to a red heat in a glass tube with a narrow orifice. When obtained by distilling a mixture of zinc filings and corrosive sublimate it was formerly distinguished by the name of *butter of zinc*. When obtained in this way it sublimes readily when heated, and crystallizes in needles. But Dr. John Davy assures us that when the chloride is formed by heating the muriate in a glass tube it does not sublime even at a red heat; but remains in a state of fusion. When exposed to the air it very speedily deliquesces. According to the analysis of Dr. John Davy* it is composed of

Chlorine	50	100
Zinc	50	100

If we suppose it composed of an atom of chlorine and an atom of zinc, its constituents should be

Chlorine	4·5	100
Zinc	4·125	91·6

IV. Zinc readily combines with iodine by heat. The iodide has a white colour. It is easily volatilized and crystallizes in fine quadrangular prisms. It deliquesces in the air and is very soluble in water. The solution is colourless and does not crystallize. This solution contains a combination of hydriodic acid and oxide of zinc. Hence the iodide must decompose water. Gay-Lussac has shown that this iodide is a compound of 1 atom iodine + 1 atom zinc; or by weight of

Iodine	15·625	100
Zinc	4·125	26·52

V. We are not acquainted with any combination of zinc and fluorine. It does not combine with azote, nor hydrogen.

VI. 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.‡

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* Phil. Trans. 1812, p. 125.

† 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 mix-

VII. We are not acquainted with any compound of zinc and boron, or silicon.

VIII. 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.[*]

Phosphorus combines also with the oxide of zinc; a compound which Margraff had obtained during his experiments on phosphorus. When 12 parts of oxide of zinc, 12 parts of phosphoric glass, and 2 parts of charcoal powder, are distilled in an earthenware 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 2 parts of zinc and 1 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.[‡]

IX. 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 dropped 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. Mr. Edmond Davy found that when the vapour of sulphur was passed over zinc in fusion, a yellowish compound was obtained similar in appearance to blende.

One of the most common ores of zinc is a foliated mineral, usually of a brown colour, called *blende;* 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 analy-

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ture 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.

[†] Pelletier, Ann. de Chim. xiii. 128.

[‡] Ann. de Chim. xiii. 125.

[§] Chem. Jour. p. 46, and Crell's Annals, 1786, i. 7.

[||] Mem. de l'Acad. de Dijon, 1783.

ses 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.[*] This opinion is now universally admitted to be the true one. By a careful analysis of yellow blende, I found it (abstracting some iron) a compound of—Zinc 100—Sulphur 48·84.[†]

Hence we see that it is a compound of 1 atom zinc + 1 atom sulphur.

X. Zinc may be combined with arsenic by distilling a mixture of it and of arsenious acid.[‡] This alloy, according to Bergman, is composed of four parts of zinc and one of arsenic.

XI. We are not acquainted with the alloy of zinc and tellurium.

XII. Zinc may be alloyed with potassium by heat; but the alloy is difficult to form on account of the volatility of the potassium. It has the colour of pounded zinc. It is gradually destroyed in the air, effervesces in water, and still more violently in acids.[§]

With sodium it is easily alloyed in a cherry-red heat. The colour of the alloy is bluish-grey. It is brittle, and of a foliated texture. It is destroyed in the air, and effervesces in water and in acids.[‖]

XIII. We are not acquainted with the alloys which zinc forms with the metals of the alkaline earths and earths proper.

XIV. 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.[**]

XV. Zinc does not appear capable of combining with nickel by fusion.[††] Neither does it combine with cobalt by fusion.

We are not acquainted with the alloys which zinc may be capable of forming with manganese, cerium, and uranium.

SECTION II.

OF LEAD.

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

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[*] Jour. de Phys. lvi. 79.

[†] Annals of Philosophy, iv. 92.

[‡] Malouin.

[§] Gay-Lussac and Thenard, Recherches Physico-chimiques, i. 221.

[‖] Ibid. i. 243.

[¶] Neuman's Chem. p. 69.

[**] Mem. Par. 1742.

[††] 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.

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

2. It is one of the softest of the metals, 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;† Guyton Morveau on repeating this experiment found the result as stated. But he found likewise that he could increase the specific gravity of lead, by hammering it, confined in a mould so that it had not liberty to expand.

3. It is very malleable, and may be reduced to 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 $\frac{1}{12\cdot6}$ inch diameter is capable of supporting only 18·4 pounds without breaking.

4. From the experiments 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.§

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 oxide. 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.

Lead unites with oxygen in three portions, and forms the *protoxide* of lead, which is *yellow;* the *peroxide*, which is *brown;* and the *red oxide*, which seems to be a compound of the yellow and the brown.

1. The *protoxide* or *yellow oxide* of lead, which has been longest

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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.

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.

Various careful experiments have been made in order to determine with accuracy the composition of this oxide. I consider the results obtained by Bucholz and Berzelius, especially the last, as very near the truth. These are as follows:

Bucholz* - - -	100 lead	+ 8 oxygen
Berzelius† - - -	100	+ 7·7

Let us consider the yellow oxide of lead as a compound of 100 lead + 7·692 oxygen, which does not differ materially from the determination of Berzelius. In that case, if it be a combination of 1 atom metal with 1 atom oxygen, its constitution will be

Lead - -	13 - -	100
Oxygen - -	1 - -	7·692

The weight of an atom of lead will be 13, and of an atom of protoxide 14.

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 absorbs more oxygen, assumes a yellow colour, and is then known in commerce by the name of *massicot*. The reason of this change is obvious: the metallic portion of the powder gradually absorbs oxygen, and the whole of course is converted into yellow oxide.

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.

2. If nitric acid, of the specific gravity 1·260, be poured upon the red lead, 185 parts of the oxide are dissolved; but 15 parts re-

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* Gehlen's Journal, v. 259.

† Ann. de Chim. lxxviii. 11, and lxxix. 121.

main 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 chlorine 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. From muriatic acid it absorbs hydrogen, and converts it into chlorine. When heated it gives out the half of its oxygen and is converted into yellow oxide.[‡] Hence it is obvious that the peroxide of lead is a compound of 1 atom lead + 2 atoms oxygen, or by weight of

Lead	13	100
Oxygen	2	15·384

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 *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 state of yellow oxide.

It appears from the analysis of Berzelius that the red lead of commerce is mixed with yellow oxide, with sulphate of lead, muriate of lead, and silica. When separated from all these foreign bodies he found it a compound of—Lead 100—Oxygen 11·08.[||]

It is obvious then that it contains 1½ times as much oxygen as the protoxide. We have two ways of viewing this substance. It may be considered as a compound of 2 atoms of lead and 3 atoms of oxygen, or as a compound of 1 atom of protoxide and 1 atom of peroxide. Which ever of these views we take, it is evident that

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

[†] Fourcroy, iv. 91.

[‡] Berzelius, Ann. de Chim. lxxviii. 16.

[§] See an account of the method of manufacturing *red lead* in Watson's Chemical Essays, iii. 338.

[||] Berzelius, Ann. de Chim. lxxviii. 14.

its weight will be the same. It must be twice the weight of an atom of lead + 3 atoms of oxygen; or 29. As *red lead* does not combine with any other substance without undergoing decomposition, its nature is not of much importance in a chemical point of view. But every person may convince himself by an examination of the salts into which yellow oxide of lead enters that its equivalent number is 14. It must therefore be a protoxide. Now I am not aware of any other means of reconciling the composition of the oxides of lead with this number but the two suppositions just made, one or other of them therefore must be admitted.

4. 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 in the cupel in a state of purity. This process is called *cupellation*.

5. 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 expense, 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 heating 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*. 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.*

III. When lead is introduced into chlorine gas it does not burn; but it absorbs the gas, and is converted into *chloride of lead*. This substance is easily obtained by mixing a solution of nitrate of lead with a solution of common salt. A precipitate falls, consisting of small, white, silky crystals. When these crystals are heated they melt, and are converted into pure chloride of lead. This com-

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* Some improvements in the method of separating silver from lead by cupellation may be seen in a disseration by Duhamel, published in the 3d Vol. of the Memoirs de l'Institute, p. 406. They had been previously practised in this country.

pound was formerly distinguished by the name of *plumbum corneum*, or *horn lead.* It is a semi-transparent greyish-white mass, having some resemblance to horn in appearance. When heated in the open air it partly evaporates in a white smoke; but when the access of air is excluded, it remains fixed at a red heat. According to the analysis of Dr. John Davy,* it is composed of

Chlorine	25·78	100	4·5
Lead	74.22	287·88	12·955
	100·00		

From this analysis (which is very nearly accurate) it is obvious that the chloride of lead is a compound of 1 atom chlorine and 1 atom lead.

IV. Lead combines readily with iodine when the two substances are heated together. The iodide of lead has a fine yellow colour. It is precipitated whenever a hydriodate is dropped into a solution containing lead. It is insoluble in water. It has not been analysed; but there can be no doubt that it is a compound of 1 atom iodine + 1 atom lead. Of course it must be composed of—Iodine 15·625—Lead 13·.

V. We are ignorant of the action of fluorine upon lead. Lead does not combine with azote, hydrogen, or carbon. No combination of it with boron, or silicon, is known.

VI. 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.† If we suppose it a compound of 1 atom lead + 1 atom phosphorus, it would consist of 88 lead + 10 phosphorus, which agrees sufficiently well with Pelletier's analysis.

VII. Sulphuret of lead may be formed, either by stratifying its two component parts and melting them in a crucible, or by dropping sulphur at intervals on melted lead. The sulphuret of lead is brittle, brilliant, of a deep blue-grey colour, and much less fusible than lead. These two substances are often found naturally combined; the compound is then called *galena*, and is usually crystallized in cubes. 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. There can be no doubt, from the experiments of Berzelius and others, that it is a compound of 1 atom lead + 1 atom sulphur, or by weight of

Lead	13	100
Sulphur	2	15·384

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* Phil. Trans. 1812, p. 185.

† Pelletier, Ann. de Chim. xiii. 114.

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, emitting a blue flame. It contains, at least, 25 per cent. or $\frac{1}{4}$th of its weight of sulphur. It is, therefore, a *bisulphuret* of lead. This variety has not hitherto been noticed by mineralogists, neither has it been made artificially by chemists.

VIII. 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.*

IX. Lead may be easily alloyed with potassium. The two metals unite when the heat is raised sufficiently high to fuse the lead. The alloy is very fusible and brittle. Its texture is fine granular. When exposed to the air it is speedily destroyed. It effervesces in water. The potassium is converted into potash, and the lead remains unaltered.†

The alloy of lead and sodium may be formed in the same manner. This alloy has some ductility. It is fine granular, and has a bluish-grey colour, and is nearly as fusible as lead. When exposed to the air, or placed under water, the sodium is speedily converted into soda, and the lead separates unaltered.‡

X. We do not know the alloys which lead forms with the metallic bases of the alkaline earths and earths proper.

XI. 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 $\frac{1}{2}$ of that of pure 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.‖

XII. Lead cannot readily be combined with nickel by fusion.

XIII. It was supposed formerly that cobalt does not combine with lead by fusion; for upon melting equal parts of lead and cobalt together, both metals are found separate, the lead at the bottom and the cobalt above. Indeed, when this cobalt is melted with iron, it appears that it had combined with a little lead: for the iron combines with the cobalt, and the lead is separated.¶ But Gmelin has shown that the alloy may be formed. He put cobalt in powder within plates of lead, and covered them with charcoal to exclude the air. He then applied heat to the crucibles containing the mixtures. Equal parts of lead and cobalt produced an alloy, in which the metals appeared pretty uniformly distributed, though in some

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* Bergman. † Gay-Lussac and Thenard, Recherches Physico-chimiques, i. 218.

‡ Ibid. i. 241. § Wasserberg, i. 212. ‖ Ann. de Chim. lvii. 47. ¶ Gellert, p. 137.

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.*

XIV. We do not know the alloys which lead forms with manganese, cerium, and uranium.

XV. The alloy of lead and zinc has been examined by Wallerius, Gellert, Muschenbroeck, and Gmelin. This last chemist succeeded in forming the alloy by fusion. He put some suet into the mixture, and covered the crucible, in order to prevent the evaporation of the zinc. When the zinc exceeded the lead very much, the alloy was malleable, and much harder than lead. A mixture of two parts of zinc and one of lead formed an alloy more ductile and harder than the last. A mixture of equal parts of zinc and lead formed an alloy differing little in ductility and colour from lead; but it was harder, and more susceptible of polish, and much more sonorous. When the mixture contained a smaller quantity of zinc, it still approached nearer the ductility and colour of lead, but it continued harder, more sonorous, and susceptible of polish, till the proportions approached to 1 of zinc and 16 of lead, when the alloy differed from the last metal only in being somewhat harder.†

XVI. The alloy of bismuth and lead 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.‡

SECTION III.

OF TIN.

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.‖

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* Ann. de Chim. xix. 357.

† Ibid. ix. 95.

‡ Wasserberg, i. 160.

§ Pliny, lib. iv. cap. 34, and lib. xxxiv. cap. 47.

‖ Numbers xxxi. 22.

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 between that of gold and lead. Its specific gravity is 7·291; after hammering, 7·299.[*]

3. It is very malleable: tin leaf, or *tinfoil* as it is called, is about $\frac{1}{1000}$ part of an inch thick, and it might be beat out into leaves as thin again if such were wanted for the purposes of art. Its ductility and tenacity are much inferior to that of most of the metals known to the ancients. A tin wire 0·078 inch in diameter is capable of supporting a weight of 34·7 pounds only without breaking.[†] Tin is very flexible, and produces a remarkable crackling noise when bended.

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.[§]

II. When exposed to the air it very soon loses its lustre, and assumes a greyish-black 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 white oxide, which may be obtained in crystals.

The first correct experiments on the oxides of tin were made by Proust.[¶] The subject was afterwards investigated by Dr. John Davy,[**] Berzelius,[††] and Gay-Lussac.[‡‡] It forms two oxides. The *protoxide* has a *grey* or *black* colour; but when combined with water is *white*. The protoxide is *yellow*, and in certain circumstances *transparent*, and nearly *white*.

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, be 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.[§§] The white powder, first precipitated, is the hydrate

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[*] Brisson.

[†] Morveau, Ann. de Chim. lxxi. 223.

[‡] Crichton, Phil. Mag. xv. 147.

[§] Pagot, Jour. de Phys. xxxviii. 52.

[‖] Bouillon La Grange, Ann. de Chim. xxxv. 208. Gay-Lussac, Ibid. lxxx. 170.

[¶] Ann. de Chim. xxviii. 213.

[**] Phil. Trans. 1812, p. 194.

[††] Nicholson's Journal, xxxv. 122.

[‡‡] Ann. de Chim. lxxx. 170.

[§§] See Proust, *ubi supra*, and Berthollet, junior, Statique Chimique, ii. 457.

of the protoxide. When heated, it gives out its water, and becomes dark-grey, or nearly black. This protoxide is a tasteless powder, soluble in both acids and alkalies. When heated it takes fire, and burns like tinder, and is converted into peroxide. When in a state of solution, it absorbs oxygen with avidity, and is converted into peroxide. The following table exhibits the composition of this oxide, according to the most accurate experiments hitherto made:

	Tin.	Oxygen.
Gay-Lussac	100	+ 13·5
John Davy	100	13·55
Berzelius	100	13·6

These experiments almost coincide. Supposing the protoxide of tin to be a compound of 1 atom tin + 1 atom oxygen; it follows that an atom of tin weighs 7·375. For on that supposition we have protoxide of tin composed of

Tin	7·375	100
Oxygen	1	13·55

which is the mean of the preceding experiments.

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. When heated so as to drive off all the acid and water, it assumes a yellow colour. When tin filings and red oxide of mercury are heated together, the peroxide of tin is obtained of a white colour; but in every other respect it possesses the properties of common peroxide of tin.*

This oxide does not dissolve in muriatic acid, but it forms a combination with it which is soluble in water. In the same way when digested with potash it combines with that alkali, and the compound dissolves in water. When this solution is evaporated it leaves a yellow jelly, again soluble in water. It appears also to combine with sulphuric acid though the compound does not dissolve in water, because that liquid unites in preference with the acid. When this oxide is exposed to a red heat it is no longer dissolved by acids or water. The same property is observable in most metallic oxides. Thus the peroxide of tin is capable both of acting the part of an acid and of a salifiable base. But the union which it forms both with acids and bases is very weak, since heat alone is sufficient to separate it again. The following table exhibits the composition of the peroxide of tin according to the most accurate experiments hitherto made:

	Tin.		Tin.
Berzelius	100 + 27·2	Klaproth	100 + 27·64
Gay-Lussac	100 + 27·2	John Davy	100 + 27·64

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* Berzelius, Nicholson's Journal, xxxv. 130.

These experiments very nearly coincide, though not quite so nearly as those on the protoxide. There cannot be a doubt from them that the peroxide of tin contains twice as much oxygen as the protoxide, or that it is a compound of 1 atom tin + 2 atoms oxygen. Hence it contains

Tin - -	7·375 - -	100
Oxygen - -	2 - -	27·1

Numbers which almost agree with the analyses of Berzelius and Gay-Lussac.

3. Both Proust and Berzelius have endeavoured to prove the existence of a third oxide of tin. The opinion of Proust has been refuted by the experiments of Dr. John Davy. Berzelius' evidences are quite unsatisfactory. He conceives that an intermediate oxide exists in the *Liquor of Libavius*, yet when he separated this oxide he found it possessed of precisely the same properties as the peroxide.*

III. Dr. John Davy has shown that tin combines with two proportions of chlorine, and forms 2 *chlorides*, which he has examined and analysed.

1. Protochloride of tin may be formed by heating together an amalgam of tin and calomel, or by evaporating to dryness the protomuriate of tin and fusing the residue in a close vessel. It has a grey colour, a resinous lustre and fracture, and takes fire when heated in chlorine gas, and is converted into perchloride of tin. In close vessels it may be fused at a heat rather below redness without decomposition; but when strongly heated it seems to be partially decomposed. Water converts it into muriate of tin. It is composed, according to Dr. John Davy's experiments, of—Tin 100—Chlorine 60·71†

2. The perchloride of tin has been long known under the name of *fuming liquor of Libavius*, because it was discovered by Libavius, a chemist of the 16th century. It is usually prepared by mixing together an amalgam of tin and corrosive sublimate, and distilling with a very moderate heat. The proportions that answer best according to Sulze, are 6 parts of tin, 1 part of mercury, and 33 parts of corrosive sublimate.‡ The distillation is to be conducted with a very moderate heat. At first a colourless liquid passes into the receiver, consisting chiefly of water: then the fuming liquor rushes all at once into the receiver in the state of a white vapour. John Davy found that the perchloride of tin may be prepared, likewise, by mixing a concentrated permuriate of tin with sulphuric acid, and distilling with a gentle heat. It is formed, likewise, when tin is introduced into chlorine gas. The metal catches fire and perchloride sublimes.

Fuming liquor of Libavius is a colourless liquid like water and very fluid. When exposed to the air it smokes with great vio-

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[*] See Nicholson's Journal, xxxv. 124.

[†] Phil. Trans. 1812, 177.

[‡] Gehlen's Journal, iv. 438.

lence, owing, as Adet first showed, to its avidity for moisture. When 1 part of water and 3 parts of fuming muriate are mixed together, the mixture condenses into a solid mass. Hence the reason that crystals appear on the surface of this liquor, when kept in a phial, with a common cork stopper. It gradually imbibes moisture from the air and crystallizes in consequence. These crystals fall to the bottom of the liquor and remain unaltered. Dr. Davy found that this liquor acts with great violence on oil of turpentine. In one case, indeed, it set the oil on fire. According to his experiments perchloride of tin is composed of—Tin 100—Chlorine 140·44.[*]

If we suppose the chloride of tin to be a compound of 1 atom metal + 1 atom chlorine, and the bichloride a compound of 1 atom metal + 2 atoms chlorine, as must undoubtedly be the case, their composition will be as follows:

Chloride.		Bichloride.	
Tin	100	Tin	100
Chlorine	61·01	Chlorine	122·02

The chloride agrees very well with the analysis of John Davy, but the bichloride not so well. The difference is probably owing to the difficulty of obtaining the bichloride in a state of purity. It has the property of dissolving tin, and the bichloride which he analysed, might have contained a little of that metal in solution.

IV. Iodine combines readily with tin when the melted metal is brought in contact with the vapour of this supporter. The iodide has a dirty orange colour, and is very fusible. Water decomposes it completely, converting it into hydriodic acid and oxide of tin. When tin and iodine are heated together under water, they act upon each other, and are converted respectively into hydriodic acid and oxide of tin.[†] This iodide has not been analysed, but it is probably composed of 1 atom metal + 1 atom iodine, or of—Tin 7·375—Iodine 15·625.

Analogy would lead us to suppose that 2 iodides of tin exist.

V. The action of fluorine on tin is unknown. Probably tin does not combine with azote nor with hydrogen. We do not know any compound which tin is capable of forming with carbon, boron, or silicon.

VI. 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

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[*] Phil. Trans. 1812, p. 177.

[†] Gay-Lussac, Ann. de Chim. xci. 26.

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.[*] Margraff also formed this phosphuret, but he was ignorant of its composition.

VII. Tin combines with 2 proportions of sulphur, and forms 2 sulphurets, both of which have been long known.

1. Sulphuret of tin may be formed by fusing tin and sulphur together, reducing the compound formed to powder, mixing it with sulphur, fusing it a second time, and keeping the temperature sufficiently high to volatilize the superfluous sulphur. It has the colour of lead, the metallic lustre, and is capable of crystallizing. When dissolved in concentrated muriatic acid it is totally converted into oxide of tin and sulphureted hydrogen gas. Its constituents according to the most accurate experiments hitherto made, are as follows:

	Tin.			Tin.	
Bergman[†]	100 - - - -	+ 25	John Davy[§]	100 - - -	+ 27·3
Proust[‡]	100 - - - -	+ 25	Berzelius[‖]	100 - - -	+ 27·234

There can be no doubt that this sulphuret is a compound of 1 atom tin + 1 atom sulphur, and that it is composed by weight of

Tin	7·375	100
Sulphur	2	27·1

Numbers which coincide very nearly with the analyses of John Davy and Berzelius.

2. Persulphuret of tin has been long known in chemistry under the name of *aurum mosaicum* or *musivum*, *mosaic gold*. I do not know when it was discovered, but Kunkel gives a formula for preparing it. In the year 1771 Mr. Woulfe rectified the old process and proposed the following method of making this substance, which is much cheaper than the old one. Mix together 12 parts tin, 7 parts sulphur, 3 parts mercury, and 3 parts sal ammoniac. Expose the mixture to a strong heat for eight hours in a black lead crucible, to the top of which an aludel is luted. The mosaic gold sublimes.[¶] In the year 1792 Pelletier published a set of experiments on this compound, and showed that it might be prepared by heating together in a retort a mixture of equal parts of sulphur and oxide of tin. Sulphurous acid and sulphur are disengaged, and mosaic gold remains.[**] Before the appearance of this dissertation it had been the general opinion of chemists that mosaic gold is a compound of tin and sulphur. But Pelletier endeavoured to show that the tin was in the state of an oxide. Proust published a valuable set of experiments on it in 1805 in his paper on tin.[††] According to him it is a combination of sulphur and an oxide of tin, containing less oxygen than the protoxide above described. This

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[*] Ann. de Chim. xiii. 116.

[†] Opusc. iii. 157.

[‡] Nicholson's Journal, xiv. 41.

[§] Phil. Trans. 181 , p. 199.

[‖] Nicholson's Journal, xxxv. 162.

[¶] Phil. Trans. 1771, p. 114.

[**] Ann. de Chim. xiii. 280.

[††] Nicholson's Journal, xiv. 42.

opinion was rectified in 1812 by Dr. John Davy, who demonstrated that this substance is a compound of tin and sulphur,* and thus restored the old chemical theory. Berzelius has also examined this compound, and has come to a similar conclusion.† Hence there can be no doubt that it is really a sulphuret of tin.

Mosaic gold when pure is in the form of light scales which readily adhere to other bodies and which have the colour of gold. When heated it gives out a portion of sulphur and is converted into common sulphuret of tin. It is insoluble in water and alcohol, and is not acted upon either by muriatic or nitric acids. But when nitromuriatic acid is boiled on it we gradually decompose and dissolve it. Potash ley dissolves it when assisted by heat. The solution has a green colour. When an acid is poured into the solution a yellow powder is precipitated, which according to Proust is a hydrosulphuret of tin. Mosaic gold according to the analysis of John Davy and Berzelius is composed as follows:

	Tin.
John Davy	100 + 56·25 sulphur.
Berzelius	100 + 52·3

If we suppose it a compound of 1 atom tin + 2 atoms sulphur, its composition will be

Tin	100	7·375
Sulphur	54·2	4

Now this is exactly the mean of the two preceding analyses.

3. Berzelius believes in the existence of another sulphuret of tin containing 1½ times the quantity of sulphur in the protosulphuret. But I have no doubt that the compound described by him, which I have myself obtained many years ago while engaged in preparing mosaic gold, is merely a mixture of protosulphuret and persulphuret, or in other words a persulphuret partially decomposed.

VIII. 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.‡

IX. Tin and potassium are easily alloyed by heating them together. A weak light is emitted at the instant of combination. The alloy is brittle, not so white as tin, and pretty fusible. It is speedily destroyed either in the air or under water by the conversion of the potassium into potash.§

During the combination of sodium and tin no light is disengaged. This alloy possesses similar properties as the alloy of tin and potassium, but it is less fusible than tin.‖

X. We are unacquainted with the alloys which tin forms with the metallic bases of the alkaline earths and earths proper.

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* Phil. Trans. 1812, p. 199.

† Nicholson's Journal, xxxv. 165.

‡ Bayen.

§ Gay-Lussac and Thenard, Recherches Physico-chimiques, i. 229.

‖ Ibid. p. 240.

XI. Tin does not combine readily with iron. An alloy, however, may be formed, by fusing them in a close crucible, completely covered from the external air. We are indebted to Bergman for the most precise experiments on this alloy. When the two metals were fused together, he always obtained two distinct alloys: the first, composed of 21 parts of tin and 1 part of iron; the second, of 2 parts of iron and 1 part of tin. The first was very malleable, harder than tin, and not so brilliant; the second but moderately malleable, and too hard to yield to the knife.*

The formation of *tin plate* 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 $\frac{1}{16}$th of copper to the tin, to prevent it from forming too thick a coat upon the iron.†

XII. The alloy of tin and cobalt is of a light violet colour, and formed of small grains.

XIII. 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*.

XIV. 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°.‡

XV. 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.

XVI. 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

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* Bergman, iii. 471.

† See Watson's Chem. Essays, iv. 191.

‡ Dr. Lewis, Neuman's Chem. p. 111.

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 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

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.

SECTION IV.

OF COPPER.

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

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. It is harder than silver. Its specific gravity varies according to its state. Lewis found the specific gravity of the finest copper

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* Ann. de Chim. lvii. 73.

† 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 is said to consist of 100 tin and 17 antimony. See Watson's Chemical Essays, iv. 167.

he could procure 8·830.[*] Mr. Hatchett found the finest granulated Swedish copper 8·895.[†] It is probable that the specimens which have been found of inferior gravity were not quite pure.[‡] Cronstedt 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 surface of the metal becomes oxidized. Every one must have remarked, that when water is kept in a copper vessel, a green crust of *verdigris*, as it is called, is formed on that part of the vessel which is in contact with the surface of the water.

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

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

[†] 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

[§] I have had an opportunity of taking the specific gravity of Chinese copper, and found it the same as European. Hence I am inclined to suspect that Cronstedt's number is inaccurate.

[||] Sickengen, Ann. de Chim. xxv. 9.

[¶] Phil. Trans. xliv. 672.

[**] Dr. Lewis, Neuman's Chemistry, p. 61.

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.

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 dropped 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. According to the experiments of Chenevix this oxide is composed of 100 copper + 13 oxygen.* But Berzelius who examined it more lately with scrupulous accuracy obtained as a result,†—Copper 100—Oxygen 12·5. If we suppose it a compound of 1 atom copper + 1 atom oxygen, then an atom of copper will weigh 8, and protoxide of copper is composed of—Copper 8—Oxygen 1.

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. This oxide is a tasteless black powder without any lustre. It dissolves in acids without efferves-

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* Phil. Trans. 1806, p. 227.

† Ann. de Chim. lxxviii. 107.

cence, and forms green or blue coloured solutions according to the acid. This oxide according to the analyses of Proust[*] is composed of—Copper 100—Oxygen 25. The analysis of Berzelius[†] agrees precisely with this. It is obvious therefore that it is a compound of 1 atom copper and 2 atoms oxygen, or it consists of—

Copper	8	100
Oxygen	2	25

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.

III. When copper filings are introduced into chlorine gas they take fire, a fixed yellowish substance is formed, while a portion sublimes in the state of a yellowish brown powder. The first of these compounds is a *protochloride of copper;* the second a *perchloride.*

1. The protochloride may be formed by heating a mixture of two parts of corrosive sublimate and one part of copper. Boyle obtained it in this way and published an account of it in 1666 in his treatise on the *origin of forms and qualities*,[‡] under the name of *rosin of copper*. Proust obtained it by mixing protomuriate of tin with a solution of copper in muriatic acid. He procured a white salt to which he gave the name of *muriate of copper*.[§] Chenevix found afterwards that this salt is formed when equal weights of black oxide of copper, and copper in powder, are mixed together and then acted upon by muriatic acid in a close vessel.[‖] Proust obtained it likewise by distilling green muriate of copper. A greyish mass remained in the retort, which was *protochloride of copper*. It is obtained also when a plate of copper is plunged into a bottle filled with green muriate of copper. The green colour gradually disappears and small white crystals are deposited, which consist of protochloride of copper.[¶]

Protochloride of copper when pure has an amber colour and a certain degree of translucency. It melts at a heat just below redness. In close vessels it is not decomposed nor sublimed by a strong red heat, but in the open air it is dissipated in white fumes. It is insoluble in water. But dissolves in nitric acid without effervescence. In muriatic acid it dissolves without effervescence, and is precipitated again unaltered by water. Potash throws down protoxide of copper. According to the analysis of Dr. John Davy,[**] it is composed of

Copper	64	100	8
Chlorine	36	56·25	4·5

Thus we see that it is a compound of 1 atom chlorine + 1 atom copper.

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[*] Ann. de Chim. xxxii. 26.

[†] Ibid. lxxviii. 107.

[‡] Shaw's Boyle, i. 252, 255.

[§] Ann. de Chim. xxviii. 218.

[‖] Phil. Trans. 1801, p. 237.

[¶] Jour. de Phys. li. 181.

[**] Phil. Trans. 1812, p. 170.

2. The *perchloride of copper* may be obtained by evaporating the green muriate to dryness in a temperature not exceeding 400°. It has a brownish yellow colour and is pulverulent. When exposed to the air it absorbs moisture, and becomes first white and then green. Heat decomposes it driving off a portion of the chlorine and converting it into protochloride. According to the analysis of Dr. John Davy* it is composed of

Copper	47	100	8
Chlorine	53	112·76	9·02

Thus we see that the perchloride of copper is a compound of 1 atom copper and 2 atoms chlorine.

IV. Copper may be combined with iodine by heating the two substances together. Analogy would lead us to suppose that two *iodides* of this metal exist. But no experiments have hitherto been made on the subject. The only iodide known is of a dark brown colour. It may be obtained by dropping a hydriodate of potash into a solution of copper in an acid. This iodide is insoluble in water. It is probably a compound of 1 atom copper + 1 atom iodine, or of—Copper 8—Iodine 15·625.

V. We do not know the action of *fluorine* on copper. Copper does not combine, so far as is known, with azote, hydrogen, carbon, boron, or silicon.

VI. Mr. Pelletier formed *phosphuret of copper* by melting together 16 parts of copper, 16 parts of phosphoric glass, and 1 part of charcoal.† Margraff 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 phosporus 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 phosporus, 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, and the colour of steel, and admits of an equally fine polish.¶

VII. 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

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[*] Phil. Trans. 1812, p. 170.

[†] Ann. de Chim. i. 74.

[‡] Ann. de Chim. xiii. 3.

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

[||] Fourcroy, vi. 252.

[¶] Nicholson's Jour. ix. 268.

very deep blue-grey colour, and much more fusible than copper. 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 8 parts by weight of copper filings, mixed with 3 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, Niewland, 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. It is not easy to determine the composition of this sulphuret by directly combining copper and sulphur. It would seem that the copper unites with a portion of oxygen as well as sulphur, which makes the increase of weight greater than it ought to be. The following are the most accurate experiments hitherto made on this compound:

	Copper.	Sulphur.		Copper.	Sulphur.
Proust†	78	+ 22	or	8	+ 2·25
Vauquelin‡	78·69	+ 21·31		8	+ 2·166
Berzelius§	10	+ 2·56		8	+ 2·048

We see that the sulphuret of copper is a compound of 1 atom metal + 1 atom sulphur. Berzelius' experiment comes the nearest to the truth; though the augmentation of weight is about 2½ per cent. greater than it ought to have been.

VIII. 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.‖

IX. Davy ascertained the fact that copper may be alloyed with potassium and sodium, and that the alloys formed decompose water. But their properties have not been particularly investigated.

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* Jour. de Min. No. ii. 85.

† Ann. de Chim. xxxviii. 872.

‡ Ann. du Mus. d'Hist. Nat. xvii. 16.

§ Ann. de Chim. lxxviii. 105.

‖ Neuman's Chem. p. 144.

We are not acquainted with the alloys which copper forms with the metallic bases of the alkaline earths and earths proper.

X. 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 stopped till it becomes of an obscure cherry-red, and then it may be continued till the iron is quite cold.†

XI. With nickel copper forms a white hard brittle alloy, easily oxidized when exposed to the air.

XII. The alloy of copper and cobalt is unknown.

XIII. 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.‡

XIV. The alloys of copper with cerium and uranium are unknown.

XV. 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

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* Ann. de Chim. l. 181.

† Ann. de Chim. xlii. 183.

‡ Gottingen Comment. 1787, vol. ix. p. 75.

§ Neuman's Chem. p. 65.

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.*

It is obvious that the most intimate and complete alloy will consist of 2 parts of copper by weight, and $1\frac{1}{8}$ part of zinc, which is equivalent to 1 atom of each metal. This is British brass. Dutch brass, which answers so much better for the purposes of watch-makers, &c. appears to be a compound of 2 atoms copper and 1 atom zinc.

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 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 lathe, 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.§

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

XVII. 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

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* Wasserberg, i. 267. † 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. 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*.

‖ Gellert. ¶ Lewis, Neuman's Chem. p. 57.

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.[§]

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

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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[*] Wasserberg, i. 263.

[†] Lewis, Neuman's Chemistry, p. 57. This curious mode of separation is called in Chemistry *eliquation*.

[‡] Lewis, Neuman's Chemistry, p. 57.

[§] 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.

[||] Jour. de Min. An. v. 881.

[¶] See Dize's Analyses, 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 is usually composed of 3 parts of copper and 1 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.§

The alloy used for the mirrors of telescopes was employed by the ancients for the composition of their mirrors. It consists of about 2 parts of copper, united to 1 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, and 8 lead, in the hundred.

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.¶

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.

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* See Watson's Chem. Essays, iv. 127

† Wasserberg, i. 262.

‡ Watson's Essays, iv. 132.

§ Wasserberg, i. 261.

‖ Phil. Mag. xvii. 294.

¶ See Wasserberg, i. 262, and Watson's Chem. Essays, iv. 139.

SECTION V.

OF BISMUTH.

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. Beccher 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 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. Dr. John Davy, in 1812, published a set of careful experiments on the compounds which bismuth forms with oxygen, chlorine, and sulphur.[†] In 1813, Mr. Lagerhjelm published a set of experiments on its combinations with oxygen and sulphur.[‡]

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 Haüy, is an octahedron, or two four-sided pyramids, applied base to base.[§]

2. It is rather softer than copper. 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 29 lbs.

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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.

[†] Phil. Trans. 1812, p. 169.

[‡] Annals of Philosophy, iv. 357.

[§] Jour. de Min. An. v. p. 582.

[||] Brisson and Hatchett. According to Berzelius 9·8827.

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, but scarcely undergoes any other change. It is not altered when kept under water.

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.*

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.

The oxide of bismuth is a yellow powder, tasteless, and insoluble in water. When strongly heated, it melts and becomes darker coloured. According to Bucholz, it may be sublimed at a heat below that which is necessary to fuse it. Various careful experiments have been made to determine the composition of this oxide. The following table exhibits the results obtained:

Bucholz and Klaproth†	-	100 metal + 12 oxygen
John Davy‡ - - -		100 - - + 11·111
Lagerhjelm§ - - -		100 - - + 11·275
Thomson - - -		100 - - + 11·3

These experiments all approach very near each other. I am disposed to consider Lagerhjelm's results as nearest the truth, because he was at the pains to free the bismuth on which he operated from a small quantity of iron with which it is usually contaminated. Let us then consider 100 bismuth as oxidized by uniting with 11·267 oxygen, which agrees very nearly with the determination of Lagerhjelm. On that supposition the weight of an atom of bismuth will be 8·875. Its oxide will be composed of

Bismuth	-	8·875	-	100
Oxygen	-	1	-	11·2672

The weight of an atom of it will be 9·875.

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. This

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* Irvine, Nicholson's Jour. ix. 46. According to Berzelius its fusing point is $451\frac{1}{2}$°.

† Klaproth's Beitrage, ii. 294; Bucholz's Beitrage, iii. 3.

‡ Phil. Trans. 1812, p. 201.

§ Annals of Philosophy, iv. 357.

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

III. Bismuth takes fire when introduced into chlorine gas, and forms a *chloride of bismuth.* This compound has been long known under the name of butter of bismuth. It is obtained by heating bismuth with corrosive sublimate. By keeping it in fusion for an hour or two, at a temperature below the boiling point of mercury, that metal gradually subsides, and leaves the chloride of bismuth pure. The chloride thus prepared has a greyish-white colour, is opaque, and of a granular texture, though not crystallized. It does not sublime when heated to redness in a glass tube with a narrow orifice. According to the analysis of Dr. John Davy,[*] to whom we are indebted for the preceding facts, this chloride is a compound of

Chlorine	33·6	4·5
Bismuth	66·4	8·89

This agrees very nearly with the weight of an atom of bismuth, as deduced from the oxide.

IV. Iodine readily combines with bismuth by the assistance of heat. The iodide has an orange-yellow colour; it is insoluble in water; but may be dissolved in a solution of caustic potash without occasioning any precipitation. This iodide has not been analysed, but there can be no doubt that it is a compound of—Iodine 15·625—Bismuth 8·875, or of an atom of iodine and an atom of bismuth.

V. We are ignorant of the action of fluorine on bismuth. It does not combine with azote nor with hydrogen. No compound of bismuth with carbon, boron, or silicon, is known. 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.

VI. 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. According to the experiments of Vauquelin,[‡] bismuth combines with sulphur in the following proportion:

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[*] Phil. Trans. 1812, p. 190.

[†] Ann. de Chim. xiii. 30.

[‡] Ann. du Mus. d'Hist. Nat. xv. 9.

Bismuth	68·25	100
Sulphur	31·75	46·52
	100·00	

According to Dr. John Davy,* sulphuret of bismuth is composed of

Bismuth	67·5	100
Sulphur	15·08	22·34

According to Lagerhjelm,† its constituents are—Bismuth 100—Sulphur 22·52.

We see from these experiments that bismuth combines with two proportions of sulphur. The sulphuret of John Davy and Lagerhjelm is a compound of 1 atom bismuth and 1 atom sulphur. The sulphuret of Vauquelin is a bisulphuret, containing 1 atom bismuth and 2 atoms sulphur.

SECTION VI.

OF MERCURY.

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

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, being 14·391,§ according to the experiments of Mr. Biddle 14·465.‖

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

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[*] Phil. Trans. 1812, p. 201.

[†] Annals of Philosophy, iv. 357.

[‡] 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). I have found it 13·4228.

[§] Gehlen's Jour. iv. 434.

[‖] Phil. Mag. xxx. 134.

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

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 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 however malleable; but neither the degree of its malleability, nor its ductility, nor its tenacity, have been ascertained.

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.†

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 the metal is converted into an oxide: by the last, into a black-coloured oxide; and by the first, into a red-coloured oxide.

The oxides of mercury are two in number.

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. When calomel is digested in an alkaline ley, a

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* Crichton, Phil. Mag. xiv. 49. According to Heinrich the boiling point is 658¼°. Schweigger's Journal, i. 214.

† Macquer's Chemistry.

‡ 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.

black powder is likewise obtained. This black powder has been hitherto considered as protoxide of mercury; but M. Guibourt affirms that it contains globules of running mercury, visible by means of a glass, and even to the naked eye when the metal is subjected to a strong pressure.* Various experiments have been made to determine the composition of this oxide. The most accurate appear to be those of Seftstrom;† according to whom it is a compound of—Mercury 100—Oxygen 3·99.

We may, without any sensible error, consider it as a compound 100 mercury + 4 oxygen. Supposing it to consist of 1 atom mercury and 1 atom oxygen, an atom of mercury will weigh 25, and an atom of protoxide of mercury 26.

2. 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 a peroxide. This oxide may be formed two different ways: 1. By putting a little mercury into a flat-bottomed glass bottle or matrass, the neck of which is drawn out into a very narrow tube, putting the matrass into a sand bath, and keeping it constantly at the boiling point. The height of the matrass, and the smallness of its mouth, prevents the mercury from making its escape, while it affords free access to the air. The surface of the mercury becomes gradually black, and then red, by combining with the oxygen of the air: and at the end of several 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 filing, it sets these metals on fire. According to the experiments of Seftstrom,§ which I consider as the most accurate, this oxide is composed of—Mercury 100—Oxygen 7·99.

It contains, therefore, exactly twice as much oxygen as the protoxide. Of course it is a compound of 1 atom mercury and 2 atoms oxygen.

III. Mercury takes fire when introduced into chlorine gas and heated. It is capable of combining in two proportions with chlorine, and of forming two chlorides which have been long known.

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* Ann. de Chim. et Phys. i. 422.

† Annals of Philosophy, iii. 355.

‡ See a description of the method of manufacturing this oxide, by Paysse, Ann. de Chim. li. 202.

§ Annals of Philosophy, iii. 355.

The protochloride is usually called *calomel*, and the perchloride corrosive *sublimate*.

It would occupy too much room to give a detail of the very numerous experiments that have been made upon these chlorides. Their composition was first established by Sir Humphry Davy.

1. Perchloride of mercury is usually denominated *corrosive sublimate*, or *corrosive muriate of mercury*. The original discoverer of it is unknown. It is mentioned by Avicenna, who died before the middle of the eleventh century; and was even known to Rhases, who lived in the century before him. The Chinese have been acquainted with it also for a long time.* The alchymists appear all to have been acquainted with it, and to have reckoned it among their secrets; and some of them, Albertus Magnus for instance, describe it with a good deal of precision. Bergman has enumerated no less than 14 different processes recommended by chemists for preparing it; and since that time several new methods have been proposed.

The process most commonly followed is to mix together equal parts of dry pernitrate of mercury, decrepitated common salt, and calcined sulphate of iron. One-third of a matrass is filled with this mixture; the vessel is placed in a sand-bath, and gradually heated to redness. When the apparatus is cold, corrosive sublimate is found sublimed in the upper part of the matrass. Another process, first proposed by Kunkel, is to expose, in a similar vessel, a mixture of equal parts of persulphate of mercury and dry common salt to a strong heat: corrosive sublimate is equally sublimed. It may be formed likewise by passing chlorine gas into a solution of nitrate of mercury, and evaporating the solution till the salt crystallizes.† But it would be tiresome and useless to enumerate all the different processes. By far the most simple, and certainly the best for chemical purposes, is to dissolve the red oxide of mercury in muriatic acid. The solution takes place readily, and without the disengagement of any gas; and the salt crystallizes spontaneously.‡

Perchloride of mercury, when obtained by sublimation, is in the form of a beautiful white semi-transparent mass, composed of very small prismatic needles. By evaporation, it yields cubes or rhomboidal prisms, or more commonly quadrangular prisms with their sides alternately narrower, and terminated by dihedral summits.§ Its specific gravity is 5·1398.‖ Its taste is excessively acrid and caustic, and it leaves for a long time a very disagreeable styptic metallic impression on the tongue. When swallowed, it is one of the most virulent poisons known, producing violent pain, nausea, and vomiting, and corroding in a very short time the stomach and intestines.¶ It is soluble in about 20 parts of cold water. Boiling

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* Bergman, iv. 281.

† Fourcroy, v. 337.

‡ Berthollet, Mem. de l'Instit. iii. 136.

§ Bergman, iv. 295.

‖ Hassenfratz, Ann. de Chim. xxviii. 12.

¶ Hence it was called by the alchymist the *dragon*.

water, according to Macquer, dissolves half its weight of it. According to Wenzel, water when boiled over this salt, dissolves very nearly ⅓d of its weight of it.[*] Alcohol, according to Macquer, at the temperature of 70°, dissolves ⅜ths of its weight, and 100 parts of boiling alcohol dissolve 88 parts of it. It is not altered by exposure to the air. When heated, it sublimes very readily; and while in the state of vapour, it is exceedingly dangerous to those who are obliged to breathe it.

It is soluble in sulphuric, nitric, and muriatic acids; and may be obtained again by evaporation unaltered. It is decomposed by the fixed alkalies, and oxide of mercury precipitated of a yellow colour, which soon becomes a brick-red. This decomposition renders corrosive sublimate a useful test for ascertaining the presence of alkalies in solution. If liquid sublimate be dropped into a solution containing the smallest portion of alkali, the brick-red precipitate appears. The alkaline earths also decompose this salt, and ammonia forms with it a triple compound.[†] Several of the metals, or their sulphurets, decompose it also by the assistance of heat. This is the case in particular with arsenic, bismuth, antimony, and tin. These metals unite with the chlorine, and separate the mercury which combines with sulphur if it be present.

Many experiments have been made to determine the composition of this salt on the supposition that it is a compound of muriatic acid and red oxide of mercury. The following table exhibits the most accurate of these results.

	Chenevix.	Rose.[‡]	Braamcamp and Siquiera-Oliva.[§]	Zaboada.[‖]
Muriatic acid	18	18·5	18·8	19·5
Peroxide	82	81·5	81·2	80·5
	100	100·0	100·0	100·0

If we correct these so as to make them correspond with the real composition of the perchloride, we obtain the following numbers:

	Chenevix.	Rose.	Braamcamp and Siquiera-Oliva.	Zaboada.
Chlorine	24·07	24·53	24·81	25·46
Mercury	75·93	75·47	75·19	74·54
	100·00	100·00	100·00	100·00

If we consider corrosive sublimate as a compound of 1 atom mercury + 2 atoms chlorine, its constituents will be

Chlorine	9	26·47
Mercury	25	73·53
		100·00

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[*] Verwandtschaft, p. 310.

[†] [To distinguish corrosive sublimate from calomel: pour a drop of liquid ammonia on a few grains of each salt: the sublimate remains white, the calomel turns black.—C.]

[‡] Gehlen's Journal, vi. 28. [§] Ann. de Chim. liv. 124. [‖] Jour. de Phys. lx. 383.

We see from this that the analysis of Zaboada is nearest the truth, though even he reckons the proportion of mercury rather too high.

2. Chloride of mercury is usually distinguished by the names of *calomel* and *mercurius dulcis*. I am ignorant who the original discoverer of it was. It seems to have been prepared by the alchymists; yet Crollius, so late as the beginning of the 17th century, speaks of it as a grand secret and mystery: but Beguin made the process public in 1608 in his *Tirocinium Chemicum*, in which he describes the salt under the name of *draco mitigatus*.*

The processes for preparing it, which are numerous, have been described by Bergman. The most usual is to triturate four parts of perchloride of mercury with three parts of running mercury in a glass mortar, till the mercury is *killed*, as the apothecaries term it; that is to say, till no globules of the metal can be perceived; and the whole is converted into a homogeneous mass. This mixture is put into a matrass, and exposed to a sufficient heat in a sand bath. The chloride is sublimed; mixed, however, usually with a little perchloride, which is either removed by repeated sublimations and triturations, or by washing the salt well with water.

It may be prepared also in the humid way, by a process first suggested by Scheele, but corrected by Mr. Chenevix.

Scheele's method is to form a nitrate of mercury by dissolving as much mercury as possible in a given quantity of boiling nitric acid. A quantity of common salt, equal to half the weight of the mercury used, is then dissolved in boiling water, and the boiling nitrate is cautiously poured into it. A white precipitate falls, which is to be edulcorated with water till the liquid comes off without any taste, and then dried upon a filter.† Chenevix has shown that in order to obtain the chloride by this process quite free from all mixture of subnitrate, it is necessary to mix the solution of common salt with some muriatic acid.

Chloride of mercury is usually in the state of a dull white mass; but when slowly sublimed, it crystallizes in four-sided prisms, terminated by pyramids. It has very little taste, is not poisonous, but only slightly purgative. Its specific gravity is 7·1758.‡ It is scarcely soluble, requiring, according to Rouelle, 1152 parts of boiling water to dissolve it.

When exposed to the air, it gradually becomes deeper coloured. When rubbed in the dark, it phosphoresces, as Scheele discovered. A stronger heat is required to sublime it than is necessary for the sublimation of perchloride. Chlorine gas converts it into perchloride; and the same change is produced by subliming it with one part of common salt and two parts of sulphate of iron. Nitric acid

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* It has been known also by a variety of other names; such as, *sublimatum dulce, aquila alba, aquila mitigata, manna metallorum, panchymogogum minerale, panchymogogus quercetanus*.

† Scheele, i. 221.

‡ Hassenfratz, Ann. de Chim. xxviii. 12.

dissolves it readily, and much nitrous gas is evolved, as Berthollet has shown, and the salt is converted into a perchloride.*

Mr. Chenevix employed the following method to ascertain the composition of this salt. He dissolved 100 parts of it in nitric acid, and precipitated the acid by nitrate of silver. The precipitate obtained indicated 11·5 muriatic acid. The oxide obtained was 88·5. Zaboada followed nearly the same plan. The precipitate, by means of nitrate of silver indicated 10·6 of muriatic acid. Muriate of tin threw down 85 grains of pure mercury. The following is the result of the analysis of these two chemists:

	Zaboada.	Chenevix.
Acid	10·6	11·5
Protoxide	89·4	88·5
Total	100	100

When we correct these results according to the true constitution of this chloride, we obtain

	Zaboada.	Chenevix.
Chloride	14·04	14·9
Mercury	85·96	85·1
	100·00	100·0

If we suppose it a compound of 1 atom mercury + 1 atom chlorine, its composition will be

Chlorine	4·5	15·25
Mercury	25	84·75
		100·00

Now Chenevix's analysis corresponds with these numbers very nearly. There can be no doubt then that the composition of these two chlorides is as follows:†

Protochloride.		Perchloride.	
Mercury 1 atom	100	Mercury 1 atom	100
Chlorine 1 atom	18	Chlorine 2 atoms	36

IV. Iodine combines readily with mercury. Nothing more is necessary than to place the two bodies in contact. They speedily unite. Iodide of mercury is formed likewise when a hydriodate is dropped into a solution of mercury in an acid. According to Gay-Lussac there are two iodides of mercury. The *protiodide* has a yellow colour, the *periodide* is a beautiful red, which may be employed as a paint. They are both insoluble in water. They are decomposed by nitric acid. The first, as Gay-Lussac ascertained, is a compound of 1 atom mercury + 1 atom iodine; the second of 1 atom mercury + 2 atoms iodine. Hence their composition is as follows:

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* [Because the nitric acid being decomposed oxygenates the muriatic acid of the calomel; the salt then becomes an oxymuriat of mercury: that is, corrosive sublimate.—C.]

† See Davy's observations and experiments, Phil. Trans. 1811, p. 26.

Protiodide of mercury.			Periodide of mercury.		
Mercury	25	100	Mercury	25	100
Iodine	15·625	62·5	Iodine	31·25	125

V. We do not know the action of fluorine on mercury. This metal does not unite with azote, hydrogen, carbon, boron, or silicon.

VI. 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. Phosphuret of mercury 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.*

VII. Mercury combines with two proportions of sulphur and forms two sulphurets. The *protosulphuret* is *black* but the *persulphuret* is *red.*

1. When two parts of sulphur and one of mercury are triturated together in a mortar, the mercury gradually disappears, and the whole assumes the form of a black powder, formerly called *ethiops mineral.* It is scarcely possible by this process to combine the sulphur and mercury so completely, that small globules of the metal may not be detected by a microscope. When mercury is added slowly to its own weight of melted sulphur, and the mixture is constantly stirred, the same black compound is formed. It may be obtained very readily likewise by passing a current of sulphureted hydrogen gas through an acid solution of mercury. The black sulphuret is precipitated abundantly. According to Guibourt running mercury may be pressed out of the sulphuret prepared in this way.† This sulphuret according to him is composed of

Mercury	100	25
Sulphur	8·2	2·05

Hence it is obviously a compound of 1 atom mercury + 1 atom sulphur.

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 *vermilion.*‡

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

[†] Ann. de Chim. et Phys. i. 424.

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

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 stoneware 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.*

Cinnabar 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 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.†

The persulphuret according to the experiments of Proust‡ is composed of—Mercury 100—Sulphur 17·64.

According to Guibourt§ it is a compound of

Mercury	100	25
Sulphur	16	4

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

† Nicholson's Journal, ii. 1.

‡ Jour. de Phys. liii. 92.

§ Ann. de Chim. et Phys. i. 425.

This last analysis is accurate. We see from it that the persulphuret of mercury is a compound of 1 atom mercury + 2 atoms sulphur.

VII. 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 5 parts of mercury and 1 of arsenic.[*]

IX. Mercury may be amalgamated with tellurium by trituration.

X. Mercury may be readily amalgamated with potassium and sodium, either by heat or by simply placing the two bodies in contact. Considerable heat is evolved during the combination. The amalgam is solid, unless the proportion of potassium or sodium be very small. It crystallizes and has a white colour like that of mercury. The potassium or sodium is speedily converted into alkali in the open air or under water.[†]

XI. Mercury has been amalgamated with the metallic bases of the alkaline earths, by Seebeck, Berzelius, and Davy. But these amalgams have not been examined.

We are unacquainted with the compounds which mercury is capable of forming with the bases of the earths proper.

XII. Iron is not acted on by mercury: accordingly this last metal is usually kept in vessels of iron. Mr. Arthur Aiken, however, has 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 mixture 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.[‡]

XIII. Mercury does not combine with nickel, or cobalt, or manganese. We are ignorant of the action of this metal on cerium and uranium.

XIV. 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 1 mercury, form a white very brittle compound. One zinc and 2½ mercury form an alloy, which, when melted and cooled slowly, crystallizes. This amalgam is used to promote the excitement of electric machines.[§]

XV. Mercury combines readily with bismuth, either by triturating the metals together, or by pouring 2 parts of hot mercury into 1 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 considera-

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[*] Bergman, ii. 281.

[†] Gay-Lussac and Thenard, Recherches physico-chimiques, i. 222.

[‡] Phil. Mag. xiii. 416.

[§] It was first recommended for that purpose by Dr. Higgins. See Phil. Trans. 1778, p. 861.

bly, 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 3 parts mercury, 1 lead, and 1 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 spherical, but part of it adheres to the surface, as if it were not completely fluid, or as if it were inclosed in a thin pellicle. This amalgam is used hot for silvering glass balls.

XV. 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 crystallizing. The crystals are composed of 1 part of lead and 1½ of mercury.*

XVII. 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 3 parts of mercury and 1 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.†

XVIII. 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 2 parts of mercury, 2½ parts of verdigris, and 1 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 mercury in nitric acid.

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* Dijon Academicians.

† 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.

‡ Lewis, Neuman's Chem. p. 65.

§ Shaw's Boyle, i. 343.

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.

SECTION VII.

OF SILVER.

I. Silver seems to have been known almost as early as gold, which was probably the first metal employed by man.

1. It is a metal of a fine white colour with a shade of yellow, without either taste or smell; and in point of brilliancy is inferior to none of the metallic bodies, if we except polished steel.

2. It is softer than copper, but harder than gold. 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 187·13 lbs. 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 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 $\frac{1}{12}$th of its weight.[‖] Vauquelin however found that when placed upon charcoal, urged by a current of oxygen gas, the silver was volatilized in a visible smoke.[¶]

When cooled slowly, its surface exhibits the appearance of crystals; and if the liquid part of the metal be poured out as soon as

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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.

[‖] Theatrum Chem. ii. 17.

[¶] Ann. de Chim. lxxxix. 239.

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.

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 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 an 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. This oxide is tasteless. It is insoluble in water, but readily soluble in nitric acid. When heated to redness it is reduced to the metallic state. The following table exhibits the composition of this oxide, according to the experiments of different chemists

	Klaproth.[§]	Proust.[‖]	Berzelius.[¶]	Davy.[**]	Thomson.[††]
Silver	100	100	100	100	100
Oxygen	12·36	9·5	7·44	7·3	7·291

We may, I conceive, without deviating from the truth, consider this oxide as a compound of—Silver 100—Oxygen 7·272.

In that case, if we suppose it a compound of 1 atom silver + 1 atom oxygen, an atom of silver will weigh 13·75 and an atom of oxide of silver 14·75.

III. Silver does not burn when heated in chlorine gas; but it gradually absorbs the gas, and is converted into the well known compound called formerly *horn silver*, and more lately distinguished by the name of *muriate of silver*. Sir H. Davy first showed that it is a *chloride of silver*.

This chloride is easily obtained by dissolving silver in nitric acid, and mixing the solution with a solution of common salt. A

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[*] 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' Dictionary, ii. 571.

[§] Beitrage, iii. 199.

[‖] Nicholson's Journal, xv. 375.

[¶] Ann. de Chim. lxxix. 132. An inference from the analysis of sulphuret of silver.

[**] Elements of Chemical Philosophy, p. 444.

[††] Annals of Philosophy, iv. 15.

copious curdy precipitate falls. When this precipitate is washed and dried it constitutes pure chloride of silver.

This chloride is one of the most insoluble substances known: According to Monnet it requires no less than 3072 parts of water to dissolve it. When exposed to the air, it gradually acquires a purple colour. When exposed to a heat of about 500°, it melts, and assumes, on cooling, the form of a grey-coloured semitransparent mass, having some resemblance to horn, and for that reason called *luna cornea*. A strong heat sublimes it, as Margraff ascertained.[*] When heated strongly in an earthen crucible, it passes through altogether, and is lost in the fire; but when mixed with about four times its weight of fixed alkali, formed into a ball with a little water, and melted rapidly in a crucible well lined with alkali, the silver is reduced, and obtained in a state of purity. Considerable caution is necessary in conducting this experiment. The easiest way of obtaining the silver is, by boiling the chloride in an iron pot with water and pieces of iron.

The chloride of silver is soluble in ammonia. The alkaline carbonates decompose it, but not the pure alkalies; neither is it decomposed by any of the acids. Several of the metals, when fused along with it, separate the silver in its metallic state; but it is always alloyed with a little of the metal employed. Copper, iron, lead, tin, zinc, antimony, and bismuth, have been used for that purpose.[†] If the solution of this salt in ammonia be mixed with running mercury, the silver gradually separates, combines with the mercury, and forms the crystals usually distinguished by the name of *arbor Dianæ*. Margraff recommends this amalgamation as the best method of procuring pure silver. This salt dissolves in muriatic acid, and by that means may be obtained in octahedral crystals. When the ammoniacal solution of this salt is heated, fulminating silver is precipitated.[‡] All substances containing hydrogen have the property of removing the chlorine, but no other bodies.

Considerable pains have been taken to ascertain the constituents of this chloride correctly, because it is by means of it that the different muriates are analysed. The following table exhibits the result of the most accurate trials hitherto made, on the supposition that the chloride is a compound of muriatic acid and oxide of silver:

	Proust.[§]	Rose.[‖]	Berzelius.[¶]	Marcet.[**]	Gay-Lussac.[††]
Muriatic acid	18	18·28	18·7	19·05	19·28
Oxide of silver	82	81·72	81·3	80·95	80·72
	100	100·00	100·0	100·00	100·00

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[*] Opusc. i. 265. Proust affirms that this sublimation stops after the salt is in complete fusion.

[†] Margraff, Ibid.

[‡] Proust, Nicholson's Jour. xv. 369.

[§] Jour. de Phys, xlix. 221.

[‖] Gehlen's Journal, vi. 29.

[¶] Ann. de Chim. lxxviii. 114.

[**] Nicholson's Journal, xx. 30.

[††] As quoted by Dr. Henry, Chemistry, vol. ii. p. 77. I do not know where Gay-Lussac's experiments were published. In Ann. de Chim. xci. 100, he adopts the analysis of Berzelius.

When these results are corrected according to the true composition of the chloride, we obtain the following numbers.

	Proust.	Rose.	Berzelius.	Marcet.	Gay-Lussac.	J.Davy.*
Chlorine	23·55	23·82	24·21	24·53	24·75	24·5
Silver	76·45	76·18	75·79	75·47	75·25	75·5
	100·00	100·00	100·00	100·00	100·00	100·0

If we consider this chloride as a compound of 1 atom silver and 1 atom chlorine, its constituents will be

Chlorine	4·5	24·66
Silver	13·75	75·34
		100·00

This is almost the exact mean of the analyses of Gay-Lussac and Marcet, which in consequence we must consider as the most accurate.

IV. The iodide of silver is easily obtained by dropping a hydriodate into nitrate of silver. A greenish yellow curdy precipitate falls having a good deal of resemblance to chloride of silver. It melts at a low red heat and assumes a reddish colour. When exposed to light its colour is altered more rapidly than even that of chloride of silver. It is insoluble in water and easily decomposed when heated with potash. It has not been analysed; but there can be no doubt that it is a compound of 1 atom silver + 1 atom iodine, or by weight of—Silver 13·75—Iodine 15·625.

V. We are unacquainted with the action of fluorine on silver. This metal does not combine with azote, hydrogen, carbon, boron, or silicon.

VI. Silver was first combined with phosphorus by Mr. Pelletier. If one ounce of silver, one ounce of phosphoric glass, and two drachms 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 4 parts of silver and 1 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.‡

VII. 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

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* Phil. Trans. 1812, p. 172.

† Pelletier, Ann. de Chim. i. 73.

‡ Ann. de Chim. xiii. 110.

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. The following table exhibits the most correct experiments on the composition of this sulphuret hitherto made:

	Klaproth[*]	Vauquelin.[†]	Berzelius.[‡]
Silver	100	100	100
Sulphur	17·64	14·59	14·9

It is obvious from these analyses that sulphuret of silver is a compound of 1 atom silver + 1 atom sulphur. The correct composition according to that supposition is

Silver	13·75	100
Sulphur	2	14·544

From this it appears that Vauquelin's analysis is the most correct.

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*.[§]

VIII. Melted silver takes up $\frac{1}{14}$th of arsenic.[‖] The alloy is brittle, yellow-coloured, and useless.

IX. 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 remains 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.[††]

X. Silver does not unite with nickel by fusion.

XI. When 2 parts of cobalt and 1 of silver are melted together, the two metals are obtained separately after the process: the silver at the bottom of the crucible, and the cobalt above it. Each of them, however, has absorbed a small portion of the other metal: for the silver is brittle and dark coloured, while the cobalt is whiter than usual.[‡‡]

XII. We are ignorant of the alloys of silver with manganese, cerium, and uranium.

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[*] Beitrage, i. 162.

[†] Ann. du Musc. d'Hist. Nat. xvii. 16.

[‡] Ann. de Chim. lxxix. 131.

[§] Ann. de Chim. i. 142.

[‖] Bergman, ii. 281.

[¶] Wasserberg, i. 156.

[**] Jour. de Phys. 1788.

[††] Ann. de Chim. xliii. 47.

[‡‡] Gellert, p. 137.

XIII. 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 1 silver is sublimed in open vessels, the whole of the silver arises along with the flowers of zinc.*

XIV. 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.†

XV. 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.

XVI. 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

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* Wasserberg, i. 160. † Ibid. ‡ Lewis, Neuman's Chem. p. 57.

§ 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.

‖ I find the specific gravity of our new silver (1817) 10·3121. The weight of a shilling is 87·55 grains.

¶ 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 15·5	8·5 5·5
Portuguese	11	8
Danish	12	7·3
Swiss	21	3·8
Russian	24	3·6
Hamburgh	50	1

silver coin of the ancients 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.*

XVII. 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, these metals contract in uniting.† Mr. Hatchett found that silver made standard by tin was brittle, and did not ring well.‡

XVIII. The amalgam of silver is easily formed by throwing pieces of red hot silver into mercury heated till it begins to smoke. It forms dendritical crystals, which, according to the Dijon academicians, contain 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 in 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.

FAMILY V.

This family contains the five following metallic bodies.—1. Gold—2. Platinum—3. Palladium—4. Rhodium—5. Iridium.

They all require a strong heat to fuse them; they are all insoluble in nitric acid, and their oxides are reducible to the metallic state by the application of mere heat.

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.

* [In the coin of the United States, 1485 parts of pure silver are alloyed with 179 parts of pure copper, and make 1664 parts of standard silver, of which 15 ounces are equal in value to one ounce of standard gold. So that 1 lb. or 12 oz. standard silver, containing 10 oz. 14 dwts. $4\frac{5}{13}$ gr. pure silver. The standard gold consists of eleven parts pure gold, and one part of an alloy; which consists of equal parts of silver and copper.—C.]

† Metallurgic Chem. p. 140.

‡ On the Alloys of Gold, p. 33.

§ Gellert's Metallurgic Chemistry, 142.

SECTION I.

OF GOLD.

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

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. It is rather softer than silver.

Its specific gravity is 19·3.†

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.‡

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 150.07 lbs. avoirdupois, without breaking.§

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

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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. Proust published a valuable paper on gold in the Journal de Physique. It was afterwards examined by Vauquelin; (Ann. de Chim. lxxvii. 321), Oberkamp, (Ibid. lxxx. 140), and Berzelius, (Ibid. lxxxiii. 166.)

† 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. Hatchett tried gold of 23 carats $3\frac{3}{4}$ grains, (or gold containing 1-96 of alloy); its specific gravity was 19·277.

‡ See Shaw's Boyle, i. 404, and Lewis's Phliosoph. Commerce of the Arts, p. 44.

§ Ann. de Chim. xxv. 9.

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

¶ Lewis's Philosophical Commerce, p. 67.

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 by a fire blown by oxygen gas, which produces a much greater heat than common air.¶

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

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

II. It is capable, however, of combining with oxygen, and even of undergoing combustion in particular circumstances. The resulting compound is an *oxide of gold*. Gold must be raised to a very high temperature before it is capable of abstracting oxygen from common air. It may be kept red hot almost any length of time without any such change. Homberg, however, observed, that when placed in the focus of Tschirnhaus's burning-glass, a little of it was converted into a purple-coloured oxide; and the truth of his observations was confirmed by the subsequent experiments of Macquer with the very same burning-glass.** But the portion of oxide formed in these trials is too small to admit of being examined. Electricity furnishes a method of oxidizing it in greater quantity.

If a narrow slip of gold leaf be put, with both ends hanging out a little, between two glass plates tied together, and a strong electrical explosion be passed through it, the gold leaf is missing in several places, and the glass is tinged of a purple colour by the portion of the metal which has been oxidized. This curious experiment 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

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* "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.

¶ Kirwan's Min. ii. 92.

** Dict. ii. 153.

†† Lewis's Philosoph. Commerce, p. 175. This work was published in 1763.

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 effected 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 acquainted only with two oxides of gold. The *protoxide* has a *green* colour, the *peroxide* is *reddish-brown*.

1. Of these the *peroxide* is most easily procured; it is, therefore, best known. It may be procured in the following manner: 1 part of nitric and 4 of muriatic acid are mixed together, and poured upon gold: an effervescence takes place, the gold is gradually dissolved, and the liquid assumes a yellow colour.[*] Let this solution be rendered as neutral as possible by cautiously evaporating it to dryness, and re-dissolving it in water. Into the solution pour a quantity of potash, and then heat the liquid. A voluminous precipitate gradually appears. It must be carefully washed with water and dried. In this state it is a reddish-brown powder, tasteless and insoluble in water, but readily soluble in muriatic acid. When exposed to even a moderate heat, it is deprived of its oxygen, and reduced to the metallic state. The following table exhibits the composition of this oxide, according to the most accurate experiments hitherto made:

	Bergman.[†]	Proust.[‡]	Oberkampf.[§]	Berzelius.[‖]
Gold	100	100	100	100
Oxygen	9·889	8·57	10·01	12·077

2. When the permuriate of gold is heated till it ceases to give out chlorine gas, a straw-yellow mass remains which is insoluble in cold water, and which is a *protomuriate of gold*. When this substance is treated with caustic potash a green-coloured powder is separated, which is *protoxide of gold*. In a short time this protoxide divides itself into two parts. One-third deprives the other two-thirds of the whole of their oxygen and becomes peroxide, while the two-thirds are reduced to the metallic state.[¶] From this it is obvious that the peroxide of gold contains only one-third of the oxygen which exists in the peroxide. If, therefore, we adopt Berzelius's analysis of the peroxide as most correct, it follows that protoxide of gold is composed of—Gold 100—Oxygen 4·026.

If we take the quantity of oxygen which unites with 100 gold at

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[*] [Linen rags dipt in this solution, dried and burnt to tinder, are used (moistened with a solution of common salt) to give a slight gilding to silver. The flame of the rag when burning, is a beautiful green; which is also the colour of the finest and thinnest leaf gold when held up to the light.—C.]

[†] Opusc. ii. 201.

[‡] Nicholson's Journal, xiv. 238, 324.

[§] Ann de Chim. lxxx. 155.

[‖] Ibid. lxxxiii. 166.

[¶] Berzelius, Ann. de Chim. lxxxiii. 166.

4·02; and suppose the protoxide a compound of 1 atom gold + 1 atom oxygen, then the weight of an atom of gold will be 24·875, the weight of an atom of protoxide will be 25·875, and the weight of an atom of peroxide 27·875. We have no means of verifying these numbers, as we are not in possession of accurate analyses of any of the salts of gold.[*]

3. Berzelius thinks that there exists an intermediate oxide, which constitutes a component part of the purple of Cassius. But he has not established its existence by decisive experiments.

III. We are not in possession of any accurate experiments either respecting the chloride, iodide, or fluoride of gold.

IV. Gold does not unite with azote, hydrogen, carbon, boron, or silicon.

V. Margraff failed in his attempts to unite gold with phosphorus;[†] but Pelletier was fortunate enough to succeed by melting together in a crucible half an ounce of gold and an ounce of phosphoric glass,[‡] surrounded with charcoal. The *phosphuret of gold* thus produced was brittle, whiter than gold, and had a crystallized appearance. It was composed of 23 parts of gold and one of phosphorus.[§] He formed the same compound by dropping small pieces of phosphorus into gold in fusion.[‖] By the application of a sufficient heat, the phosphorus is dissipated and the gold remains. Oberkampf formed phosphuret of gold by precipitating muriate of gold by means of water impregnated with phosphureted hydrogen gas.

VI. Sulphur, even when assisted by heat, has no action on gold 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 one: for when an *alkaline hydro-sulphuret*[¶] is dropped into a solution of gold, a *black powder* falls to the bottom, which is found to consist of gold and sulphur; and when potash, sulphur, and gold, are heated together, and the mixture boiled in water, a considerable portion of gold is dissolved, as Stahl first discovered. Three parts of sulphur, and three of potash, are sufficient to dissolve one of gold. The solution has a yellow colour. When an acid is dropped into it, the gold falls down, united to the sulphur in the state of a reddish powder, which becomes gradually black.[**] The composition of this sulphuret has been investigated by Bucholz[††] and Oberkampf.[‡‡] The following are the results which they obtained:

	Bucholz.	Oberkampf.
Gold	100	100
Sulphur	21·95	24·39

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[*] I think it probable that the equivalent number for peroxide of gold is 9·25.

[†] Opusc. i. 2.

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

[§] Ann. de Chim. i. 71.

[‖] Ibid. xiii. 104.

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

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

[††] Beitrage, iii. 171.

[‡‡] Ann. de Chim. lxxx. 144.

The analysis of Oberkampf nearly agrees with Berzelius' estimate of the composition of the peroxide of gold. The two, therefore, serve to confirm each other.

VII. There appears to be a strong affinity between gold and arsenic : but in consequence of the great volatility of the latter metal, it is difficult to unite them by fusion. 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 were 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 dropped 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.[†]

VIII. Potassium and sodium may readily be combined with gold by heat, as Davy ascertained. The alloys are destroyed in the open air, or when put into water.

IX. We are not acquainted with the action of gold on the metallic bases of the alkaline earths or earths proper.

X. 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 1 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 1014·7.[‡] 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.

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[*] Opusc. ii. 281.

[†] On the Alloys of Gold, p. 7.

[‡] Ibid. p. 37.

[§] Phil. Com. p. 85.

[||] Wasserberg, i. 115.

XI. Mr. Hatchett melted a mixture of 11 gold and 1 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.*

XII. Mr. Hatchett melted together 11 parts of gold and 1 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 below that proportion, the gold becomes somewhat ductile.†

XIII. 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 $\frac{1}{5}$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.‡

XIV. The alloys of gold with uranium and cerium are unknown.

XV. Zinc 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 1 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

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* Hatchett on the Alloys of Gold, p. 21.

† Ibid. p. 19.

‡ Ibid. p. 22.

§ Mem. Acad. Par. 1735.

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 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 1 part of gold is alloyed with 7 of zinc, if the zinc be elevated in the state of flowers, the whole of the gold rises along with it.

XVI. Gold combines very readily with bismuth by fusion. An alloy composed of 11 gold and 1 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.†

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	17·495	1000	1027	+27

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* Hatchett on the Alloys of Gold, p. 17.

† 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.

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.*

XVII. 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 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 1 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	442	18·080	1000	1005	5
Lead	38				
Gold	442	17·765	1000	1005	6
Lead	19				
Copper	19				
Gold	442	17·312	1000	1022	22
Copper	30				
Lead	8				
Gold	442	17·032	1000	1035	35
Copper	34				
Lead	4				
Gold	442	16·627	1000	1057	57
Copper	37·5				
Lead	0·5				
Gold	442	17·039	1000	1031	31†
Copper	37·75				
Lead	0·25				

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* See Hatchett on the Alloys of Gold, p. 26.

† Ibid. p. 29 and 67.

XVIII. Tin 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 1 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 ductility 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 day-light, 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.‡

XIX. 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 7 parts of gold and 1 of copper.|| Gold alloyed with $\frac{1}{22}$d 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,

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* Hatchett, on the Alloys of Gold, p. 32.

† Hatchett, Ibid.

‡ Ibid.

§ Wasserberg, i. 112.

|| Ibid.

instead of occupying the space of 1000, as would happen were there no expansion, become 1024.*

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 experiments 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

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* Hatchett on the Alloys of Gold, p. 66. The gold was already alloyed with 1-96th of copper; the expansion, had the gold been pure, would have been greater. For the specific gravity of an alloy of 11 gold and 1 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.

† [According to the standard regulations of the British mint, 1 lb. troy weight of gold, consists of 11 oz. of pure gold and 1 oz. of copper: it used to be coined into $44\frac{1}{2}$ guineas; it now yields $46\frac{29}{40}$ of the new gold coin, called *sovereigns*, of which 934 weigh 20 lbs. troy weight.

The lb. standard of silver, consists of 11 oz. 2 dwt. pure silver, and 18 dwt. copper, and is coined into 66 shillings sterling.

The quantity of precious metals annually raised from the mines, amounts to about $10\frac{1}{2}$ millions sterling, of which $2\frac{1}{2}$ millions are gold, and 8 millions are silver.

Of the gold, 2,300,000 is from America, and about 200,000 from Europe, Asia, and Africa. Of the silver, 7 millions come from America, and 1 million from the other parts of the globe. 8 Brande's Journal, 246.

I have good authority for stating, that the amount of gold used up and consumed in works of art in the United States, is about 40,000 dollars worth yearly: and the amount of silver so used and consumed, about 500,000 dollars worth yearly. This is independent of all European importation of gold and silver leaf, and gilt and plated goods.—C.]

‡ 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.	a one guinea	1761	17·737.
———	a one guinea	1766	17·655.
———	a one guinea	1774	17·726.
———	a one guinea	1775	17·698.
———	a one guinea	1776	17·486.
———	a one guinea	1777	17·750.
———	a one guinea	1782	17·202.
———	a one guinea	1786	17·465.
———	a one guinea	1788	17·418.

pure gold. It therefore answers better for coin. A pound of standard gold is coined into 44½ guineas.*

XX. The amalgam of gold is formed very readily, because there is a very strong affinity between the two metals. If a bit of gold be dipped into mercury, its surface, by combining with mercury, becomes as white as silver. The easiest way of forming this amalgam is to throw small pieces of red-hot gold into mercury 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 1 part of mercury to 2 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.†‡

XXI. When silver and gold are kept melted together, they combine, and form an alloy composed, as Homberg ascertained, of 1 part of silver and 5 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 2 parts of gold and 1 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; 1 part of silver produces a

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Reign.		Date.	Specific gravity.
George III.	five guineas - -	1793	17·712.
———	ten half-guineas - -	1801	17·750.
———	15 seven-shilling pieces (*a*) -	1802	17·793.

(*a*) 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.

[*] [For the standard gold of the United States, see p. 389.—C.]

[†] Gellert's Metallurgic Chemistry, 375, and Lewis, Phil. Com. p. 75.

[‡] [It is absolutely necessary, for the preservation of health, to have a chimney with a strong draught, artificially made in it, over the evaporating mercury: also, a glass screen interposed between the workmen and the fire. If these precautions be not taken, death ensues in no long time.—C.]

[§] Muschenbroek.

[‖] Hatchett.

sensible whiteness in 20 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.

SECTION II.

OF PLATINUM.

Gold, the metal just described, was known in the earliest ages, and has been always in high estimation, on account of its scarcity, beauty, ductility, and indestructibility. But platinum, though perhaps inferior in few of these qualities, and certainly far superior in others, was unknown in Europe, as a distinct metal, before the year 1749.[*]

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

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

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

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

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

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

[†] Ann. de Chim. lx. 317.

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 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 quanity 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 Margraff 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. But the experiments of Berzelius[§§] and Edmond Davy[‖‖] have added most to our knowledge of its combinations.

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. Disssolve the grains in concentrated nitro-muriatic 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 ammoniac*. 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.[¶¶][***]

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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 Margraff's Opusc. ii. 226.

[‡] Mem. Par. 1758, p. 119.

[§] Jour. de Phys. iii. 234.

[‖] Macquer's Dictionary.

[¶] Opusc, ii. 166.

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

[††] Ann. de Chim. xxiv. 205.

[‡‡] Ibid. xxv. 3.

[§§] Ibid. lxxxiii. 167.

[‖‖] Phil. Mag. xl. 27, 209, 263, 350.

[¶¶] Phil. Mag. xxi. 175.

[***] [To manufacture Platinum—Boil the ore in grains in dilute muriatic acid; wash them; dissolve in aqua regia (or nitro-muriatic acid of three-fourths muriatic and one-fourth nitric, previously freed from sulphuric acid by barytes); precipitate gradually and cautiously by means of a solution of sal ammoniac containing no iron—this must be previously ascertained. Let the orange-coloured precipitate fall at intervals; when a reddish-coloured precipitate begins to fall, stop—this is palladium. Upon which see particularly Mr. Cloud's paper on these metals, in the 6th vol. of the Am. Phil. Trans. old series.

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 intermediate between that of copper and iron. Its specific gravity when reduced from the ammonio-muriate by heat is 21·47. By hammering it may be increased $\frac{1}{350}$th; so that its maximum specific gravity is 21·5313.†

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 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.

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

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It is not necessary to wash the precipitate, for water will dissolve it. Dry it; expose it in a crucible under a muffle to a strong heat, to drive off and decompose the acids combined with the platinum; collect the metallic-grey powder; place it by a little at a time in a hollow steel mould; press it gradually by means of a powerful screw: a layer of about half an inch at a time; when the hollow of the mould is full, apply the whole force of the screw. Then take the spongy mass to a blacksmith's forge; heat it to a full white heat, and hammer it into the form you wish. When it is to be fashioned into any shape, it should be given to a skilful hammer-man, and gradually formed, annealing it every now and then to prevent its cracking, which will happen, if some skill and patience be not applied.

When all the orange-coloured precipitate has been thrown down, the solution still contains palladium, and the black undissolved powder, iridium and osmium.

If small cuttings or clippings of platinum be stratified in the mould with the grey powder, they may be made to unite by strong pressure, so as to bear welding at the forge.—C.]

* 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.

† Dr. Wollaston.

‡ Morveau, Ann. de Chim. xxv. 7.

§ Dr. Clarke, by means of his oxygen and hydrogen gas blow-pipe, melted pieces of platinum weighing 100 grains.

machine, it burnt with a faint white flame, and was dissipated into 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.

At present only two oxides of platinum are known; the *protoxide* has a *black* colour, but the *peroxide* is *dark brown* or *grey*.

1. The protoxide may be obtained by pouring a neutral solution of mercury into a dilute solution of muriate of platinum in hot water. A dense powder precipitates, varying in colour from deep brown to yellow and sometimes olive-green. It is a mixture of calomel and protoxide of platinum. It must be carefully washed and dried and then exposed to a heat just sufficient to volatilize the calomel. A deep black powder remains which is the protoxide. One hundred grains of it when heated to redness give off 12½ cubic inches of oxygen gas and are reduced to the metallic state. When heated with lamp-black it gives out the same proportion of carbonic acid and is reduced to the metallic state. Mr. Cooper to whom we are indebted for the discovery of this oxide found that it might be heated strongly when mixed with enamellers' flux without being reduced. On this account he considers it as a valuable addition to the colours of enamellers.* From the preceding experiments it follows, that protoxide of platinum is composed of—Platinum 100—Oxygen 4·423. Hence an atom of platinum must weigh 22·625, and an atom of protoxide of platinum 23·625.

2. The peroxide of platinum appears to be a compound of 1 atom metal and 3 atoms oxygen, or to be a tritoxide. No accurate account of it has been hitherto published. But Mr. Edmond Davy has ascertained that when his fulminating platinum is treated with nitric acid and heated cautiously a grey oxide remains, which he concludes from his experiments to be composed of—Platinum 100—Oxygen 11·86. Berzelius endeavoured to obtain the peroxide of platinum by the following process. He decomposed the muriate by adding an excess of sulphuric acid. This excess was distilled off and the sulphate of platinum decomposed by caustic potash added in slight excess. The peroxide separates in the form of a light yellowish-brown bulky powder. When this powder is heated it becomes dark brown, almost black, and gives out water. When the peroxide of platinum is exposed to a high temperature it is reduced to the metallic state giving out oxygen gas. It dissolves in the fixed alkalies both when caustic and when in the state of carbonates. It combines likewise with lime, strontium, and barytes. This is the oxide which constitutes the base of the platinum salts.† According to the experiments of Berzelius it contains twice as much oxygen as the protoxide. It is therefore a compound of—Platinum 100—Oxygen 16·494. The mean of Berzelius' numbers and those of Edmond Davy would give 14·177 for the oxygen in

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* Royal Institution Journal, iii. 119.

† Berzelius, Lärbok i Kemien, ii. 422.

the peroxide. Now this does not differ much from 13·269 the quantity of oxygen, which would be requisite to form a tritoxide.

III. Platinum does not take fire when introduced into chlorine gas; but it slowly imbibes the gas and is converted into a *chloride.* Mr. Edmond Davy, to whom we are indebted for all the facts respecting this combination at present known, is of opinion that there are two chlorides of platinum. The *protochloride* is soluble in water and has not been much examined. The *perchloride* is an insoluble powder. But the existence of this last only has been clearly made out.*

To obtain this chloride pure platinum is to be boiled in strong muriatic acid adding occasionally a little nitric acid. The solution is to be evaporated to dryness and then digested with a little muriatic acid which is likewise to be driven off. The dry mass is to be cautiously heated nearly to redness and boiled with a considerable quantity of water. Being now dried it is pure chloride of platinum.

Its colour is dull olive brown or green. It has rather a harsh feel; but is destitute of taste and smell. It is infusible. It does not appear to be altered by exposure to the atmosphere and it is scarcely soluble in water. When heated to redness the chlorine is driven off and pure platinum remains. It is slightly soluble in boiling muriatic acid but it is insoluble in nitric, sulphuric, phosphoric, and acetic acids. When boiled in potash ley a black powder is obtained which yields both oxygen and chlorine by heat.† When it is heated with sulphur or phosphorus, chlorides of sulphur and phosphorus are obtained and phosphorus or sulphuret of platinum. According to the experiments of Mr. Edmond Davy, the chloride of platinum is composed of

Platinum	-	100	or nearly	12·125
Chlorine	-	37·93	-	4·5

From this analysis we see that it is a compound of 1 atom platinum + 2 atoms chlorine. The soluble chloride, if it be really distinct, must be the *protochloride.*

IV. The *iodide* of platinum has not been examined.

We are ignorant of the action of fluorine on this metal. It does not combine with azote, hydrogen, carbon, boron, or silicon.

V. It unites in two proportions with phosphorus. For our knowledge of these two combinations we are indebted to Mr. Edmond Davy.‡

1. Protophosphuret of platinum may be obtained by heating phosphorus and platinum in an exhausted glass tube. At a temperature considerably below redness they combine with vivid ignition and flame. Protophosphuret of platinum has a bluish-grey colour. When it has undergone fusion its lustre is little inferior to that of lead. It crystallizes in cubes. Its specific gravity while porous is 6. It is destitute of taste and smell. It is a non-con-

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* Phil. Mag. xl. 271.

† Is not this the protoxide of Berzelius?

‡ Phil. Mag. xl. 32.

ductor of electricity. When strongly heated on platinum it unites with the metal which it perforates with holes. According to the experiments of Mr. Edmond Davy it is composed of—Platinum 100—Phosphorus 21·21.

2. Perphosphuret of platinum is obtained by heating together *ammonio-muriate of platinum* with about two-thirds of its weight of phosphorus in small bits in a retort over mercury. Towards the end of the experiment the retort should be heated to a dull red to expel every thing volatile. The perphosphuret of platinum has an iron grey colour and a slight metallic lustre. It stains the fingers or paper, but the lustre is inferior to that communicated by persulphuret of platinum. Specific gravity 5·28. It is destitute of taste and smell, and is a nonconductor of electricity. When heated it becomes ignited and diminishes in bulk without changing its colour. According to the experiments of Mr. Edmond Davy, it is composed of—Platinum 100—Phosphorus 42·85*.

VI. Platinum combines with three proportions of sulphur. For the investigation of these compounds also we are indebted to Mr. Edmond Davy.†

1. Protosulphuret of platinum was formed by mixing equal weights of sulphur and platinum in an exhausted glass tube and heating them together. Towards the end of the process the mass was heated nearly to redness to expel every thing volatile. Protosulphuret of platinum thus formed is of a dull bluish grey colour. Its lustre is earthy; but when rubbed on paper it leaves a metallic stain. Its feel is rather harsh. It has no smell or taste. Its specific gravity is 6·2. It is a nonconductor of electricity. It is decomposed when heated with zinc filings. According to the analysis of Mr. Edmond Davy, its constituents are—Platinum 100—Sulphur 19·04.

2. Deutosulphuret of platinum is obtained by precipitating platinum from its solution by sulphureted hydrogen gas, and heating the precipitate which falls in close vessels. It is a tasteless loose powder, of a bluish black colour, staining paper and the fingers like black lead. It is composed of—Platinum 100—Sulphur 28·21.‡

3. Persulphuret of platinum is obtained by heating a mixture of 3 parts of ammonio-muriate of platinum and 2 parts of sulphur in a glass retort over mercury. The mixture must be gradually heated to redness and continued for some time in that heat till every thing volatile be expelled. It has a dark iron grey colour approaching to black. When in lumps it has a slight metallic lustre. It has a soft feel and when rubbed on paper leaves a stain similar to that of black lead. Its specific gravity is 3·5. It is a nonconductor of electricity. It does not melt though exposed to a very

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* The analyses of these two phosphurets agree very well with each other, but they do not correspond with the numbers which we have adopted for the weight of an atom of phosphorus and platinum.

† Phil. Mag. xl. 27, 219.

‡ Phil. Mag. xl. 219.

strong heat. When heated with zinc filings combustion takes place and sulphuret of zinc is formed. When heated to redness in the open air the sulphur is expelled and pure platinum remains. According to the analysis of Mr. Edmond Davy, its constituents are—Platinum 100—Sulphur 38·8.

The sulphur in these three compounds is as the numbers 1, $1\frac{1}{2}$, 2. Hence the first should be a compound of 1 atom platinum and 1 atom sulphur, the second of 2 atoms platinum and 3 atoms sulphur, and the third of 1 atom platinum and 2 atoms sulphur. But the numbers do not correspond with the weight of an atom of platinum as deduced from the experiments hitherto made on the subject. Hence it is probable that this number is incorrect. We cannot venture to determine the weight of an atom of phosphorus from these experiments of Mr. Edmond Davy, because the numbers for the phosphurets and sulphurets do not accord with each other.

VII. 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.*

VIII. Platinum unites with potassium and sodium with ignition, as Sir H. Davy first ascertained. The alloy is decomposed by the action of air or water.†

IX. We are ignorant of the alloys which platinum is capable of forming with the metallic bases of the alkaline earths and earths proper.

X. 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 $\frac{3}{4}$ths of 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.‡

XI. We are unacquainted with the alloys which platinum forms with nickel, cobalt, manganese, uranium, and cerium.

XII. 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

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* Phil. Com. p. 515.

† [Platinum is acted on by the caustic alkalies in a red heat, hence it will not answer to be used as a vessel for analysis when caustic potass or soda is to be exposed in it to this heat.—C.]

‡ Phil. Com. p. 534, and 551.

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 $\frac{1}{4}$th of zinc renders platinum brittle.*

XIII. Bismuth and platinum readily melt and combine when exposed rapidly to a strong heat. Dr. Lewis fused the metals in various proportions, from 1 of bismuth to 24 with 1 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, violet, or blue colour. The bismuth can scarcely be separated by heat.†

XIV. 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.§

XV. 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 continue 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.‖

XVI. 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.**

XVII. Mr. Cooper has formed an alloy of 7 parts platinum, 16 copper, and 1 zinc, that has much the appearance of pure gold. The copper and platinum are first fused with the usual precautions

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* Phil. Com. p. 520.

† Ibid. p. 509, 573.

‡ Ibid. p. 512.

§ Ibid. p. 561.

‖ Ibid. p. 510.

¶ Ibid. p. 529.

** Nicholson's Journal, ix. 363.

of covering the metals with charcoal and adding a flux of borax. When it is in perfect fusion it is removed from the fire, the zinc is added, and the mixture stirred. This alloy is very ductile, is not oxydized by exposure to the air, and is not dissolved by nitric acid except at a boiling heat.*

XVIII. 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 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.

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

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* Journal of the Royal Institution, iii. 119.

† Lewis, Phil. Com. p. 508.

‡ 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 sonsequence 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.

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

XX. 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 $\frac{1}{42}$d part of platinum greatly injured the colour of the gold. The alloy formed by Mr. Hatchett of nearly 11 parts of gold to 1 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 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 1 part of platinum with 4 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.‡

SECTION III.

OF PALLADIUM.

THIS metal was discovered by Dr. Wollaston in 1803, and the first account of its properties circulated without any intimation of the discoverer, or the source whence the metal was obtained. It was examined by Mr. Chenevix, who endeavoured to show that it was a compound of platinum and mercury. But his attempt was unsuccessful. Soon after Dr. Wollaston announced that he was the discoverer of palladium, and that he had obtained it from crude platinum. It has been since examined by M. Vauquelin,§ and a set of experiments on its oxide has been published by Berzelius.‖

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

† Klaproth, Journal de Chimie, iv. 29.

‡ Manuel de l'Essayeur, p. 48.

§ Ann. de Chim. lxxxviii. 167.

‖ Annals of Philosophy, iii. 354.

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 yellowish-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.

1. Palladium thus obtained is a white metal, which, when polished, bears a very close rsemblance 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. Vauquelin obtained it when rolled as high as 12 and a small fraction. This nearly agrees with an experiment of Mr. Lowry who found it 12·148.

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. Vauquelin fused it on charcoal by a jet of oxygen gas. When the heat was continued the metal boiled and burnt, throwing out brilliant sparks. A portion of the metal which escaped the combustion was dissipated and condensed on the surface of the charcoal in very small grains. Platinum melted in the same way does not burn like palladium, which shows that this last metal is more volatile and more combustible.

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. Berzelius was able to obtain only 1 oxide of palladium. He formed it by heating palladium filings in a platinum crucible, along with caustic potash and a little nitre. The oxide has a chesnut-brown colour and readily dissolves in muriatic acid. According to the experiments of Berzelius it is composed of—Palladium 100—Oxygen 14·209.

Vauquelin found that when this oxide is reduced to the metallic state by being heated to redness it loses 20 per cent. of its weight. But we are not certain that it had been previously deprived of all its water. If we suppose this oxide to be a compound of 1 atom palladium and 1 atom oxygen, and to consist of 100 palladium + 14·285 oxygen, the weight of an atom of palladium will be 7, and the weight of oxide of palladium 8.

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

[†] Wollaston on the Discovery of Palladium, Phil. Trans. 1805.

III. The *chloride, iodide*, and *fluoride* of palladium are still unknown.

IV. It is not probable that palladium combines with azote, hydrogen, carbon, boron, or silicon. The phosphuret of palladium has not been examined.

V. 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. According to the experiments of Vauquelin the sulphuret of palladium is a compound of—Palladium 100—Sulphur 24.

If we suppose the analysis of the oxide of palladium by Berzelius to be correct, 100 palladium ought to combine with 28½ sulphur.

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

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.

2. " Equal parts of platinum and palladium entered 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.

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.

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.

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.

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.

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.

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."*

SECTION IV.

OF RHODIUM.

RHODIUM was discovered by Dr. Wollaston in 1804. While Mr. Smithson Tennant was engaged in the examination of the black powder that remains undissolved when crude platina is treated with nitro-muriatic acid, Dr. Wollaston produced soda-muriate of rhodium, and presented it to Mr. Tennant as containing one of the new substances of which he was in quest. Mr. Tennant soon satisfied himself that it was quite different from his new metals. Upon this, Dr. Wollaston investigated its properties, and gave it the name of *rhodium*.

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 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 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 evapo-

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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, most of the facts contained in this Section have been extracted.

ration, 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 1 part in 250 of rhodium.

1. Rhodium, thus obtained, is of a white colour, not much differing from that of platinum. Its specific gravity, according to Mr. Lowry, is 10·649. It is brittle, and requires a much higher temperature to fuse it than any other metal, unless iridium be an exception. Vauquelin was unable to fuse it on charcoal, though the combustion was increased by a jet of oxygen gas. Dr. Wollaston has never been able to fuse it so completely as to obtain it in a solid mass free from cavities. Its fracture is granular, and in hardness it appears fully equal to iron.

It has the remarkable property of being insoluble in all acids.

II. From the experiments of Berzelius upon this metal, we learn that it is capable of combining with three proportions of oxygen. The *protoxide* is *black*, the *deutoxide brown*, and the *peroxide red.*

1. The protoxide is obtained by reducing rhodium to powder, and exposing it to a moderate red heat in an open vessel. It slowly combines with oxygen, and is converted into protoxide. Its colour is black, and it is destitute of metallic lustre. When heated with tallow, or sugar, it is reduced with detonation to the metallic state. It is insoluble in acids. According to the experiments of Berzelius, this oxide is composed of—Rhodium 100—Oxygen 6·71.*

2. Deutoxide of rhodium is obtained by calcining rhodium in powder with caustic potash and a little saltpetre. The alkali is removed by water; and if any portion of metal remain it is separated by levigation. The oxide thus obtained is light and flea-coloured, and retains between 15 and 16 per cent. of potash. Sulphuric acid separates the potash, but leaves the oxide untouched. This oxide combines readily with alkaline substances, but scarcely with acids. According to the calculation of Berzelius, the deutoxide of rhodium is composed of—Rhodium 100—Oxygen 13·42.

3. The peroxide of rhodium is obtained by precipitating soda-muriate of rhodium with caustic potash. A red powder falls, which is a compound of peroxide of rhodium and water. When heated, it gives out its water, and assumes a darker colour. At a heat below redness it takes fire, gives out part of its oxygen, and is converted into protoxide. This oxide, like the protoxide, has the property of combining with acids, and forming salts. Berzelius, without having analysed it, supposes that it contains three times the quantity of oxygen in the protoxide, or that it is a compound of—Rhodium 100—Oxygen 20·13.†

If we suppose the protoxide of rhodium to be a compound of 1

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[*] This proportion is an inference from the supposed composition of the muriate of rhodium.

[†] Annals of Philosophy, iii. 252.

atom rhodium and 1 atom oxygen, and that it consists of 100 rhodium united to 6·66 oxygen, which comes sufficiently near Berzelius' calculation, then the weight of an atom of rhodium will be 15.

III. Rhodium has been too imperfectly examined to enable us to state the compounds which it forms with the other supporters of combustion.

IV. 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.

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

"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 oxidized by a high degree of heat, but become incrusted with a black oxide when very slowly cooled.

"When 4 parts of gold are united with 1 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 6 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 1 part of palladium is united to 6 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 sulphur, or when merely heated by itself, it was reduced to the same state of insolubility. But when 1 part of rhodium had been fused with 3 parts of bismuth, of copper, or of lead, each of these alloys could be dissolved completely in a mixture of 2 parts, by measure, of muriatic acid with 1 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

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

when formed from the yellow oxide precipitated from the original salt."*

SECTION V.

OF IRIDIUM.

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 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.

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*.

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* See Dr. Wollaston's paper, Phil. Trans. 1804, from which all the facts contained in this Section have been extracted.

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.

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 has lately succeeded in fusing a little of it, and found it possessed of a certain degree of ductility.* Mr. Children has succeeded in fusing it by means of his immense galvanic battery, and found its specific gravity 18·68.† As the globule was porous, it is obvious that this is considerably under the truth.

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.‡

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.

We neither know the composition nor the number of its oxides. Neither have any experiments been made on its compounds with chlorine, iodine, or fluorine.

III. It is probable that it does not combine with azote, hydrogen, carbon, boron, or silicon. Its combination with phosphorus has not been examined.

Vauquelin formed a sulphuret of iridium by heating a mixture of ammonio-muriate of iridium and sulphur. The sulphuret formed was a black powder composed of—Iridium 100—Sulphur 33·3.§

If we suppose this sulphuret a compound of 1 atom iridium and

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* Ann de Chim. lxxxix. 240.

† Phil. Trans. 1815, p. 370.

‡ Fourcroy and Vauquelin, Ann. de Chim. l. 22.

§ Ann. de Chim. lxxxix. 236.

1 atom sulphur, it will follow that the weight of an atom of iridium is 6.

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

"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, 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."[*]

Vauquelin has more lately alloyed this metal with lead, copper, and tin. All these alloys were malleable and the hardness of the different metals was greatly increased by the addition of the iridium.[†]

Thus we have finished the description of the second genus of simple combustibles. It includes 28 substances, all of which are metals, though the first ten have such a disposition to unite with oxygen, that it is with difficulty they can be preserved in the metallic state. Indeed the earths proper have not yet been reduced to metals.

The weight of an atom of each of these substances, as it has been deduced from the combinations into which they enter, is as follows:

Potassium	5	Iron	3·5	Bismuth	8·875
Sodium	3	Nickel	3·375	Mercury	25
Calcium	2·625	Cobalt	3·625	Silver	13·75
Barium	8·75	Manganese	3·5	Gold	24·875
Strontium	5·5	Cerium	5·75	Platinum	22·625
Magnesium	1·5	Uranium	15·625	Palladium	7
Yttrium	4	Zinc	4·125	Rhodium	15
Glucinum	2·25	Lead	13	Iridium	6
Aluminum	1·125	Tin	7·375		
Zirconium	4·625?	Copper	8		

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[*] See 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 obtainining it in a separate state; but he showed 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.

[†] Ann. de Chim. lxxxix. 237.

But the weights of the atoms of the last 5 metals must be considered as still imperfectly known; because the salts which their oxides form are of so peculiar a nature that it has not been hitherto possible to analyse them with sufficient exactness to determine the equivalent numbers for these oxides.

The following table exhibits the colour, specific gravity, hardness, fusibility, and tenacity of the different metals belonging to this genus as far as these properties have been ascertained.

Metals.	Colour.	Hardness.	Sp. Gravity.	Melting point.		Tenacity.
				Fahrenheit.	Wedgewood.	
Potassium	White	4	0·86507	136·5°	—	—
Sodium	White	4	0·97223	194	—	—
Calcium	White	—	—	—	—	—
Borium	White	—	—	—	—	—
Strontium	White	—	—	—	—	—
Magnesium	White	—	—	—	—	—
Yttrium	Grey?	—	—	—	—	—
Glucinum	Grey?	—	—	—	—	—
Aluminum	Grey?	—	—	—	—	—
Zirconium	—	—	—	—	—	—
Iron	Grey	9	7·8	—	158°	549·25
Nickel	White	8·5	8·82	—	160+	—
Cobalt	Grey	6	8·7	—	130	—
Manganese	Grey	8	8·013	—	160	—
Cerium	White?	—	—	—	—	—
Uranium	Grey	8	9	—	170+	—
Zinc	White	6·5	7·1908	680°	—	109·8
Bismuth	Reddish white	7	9·822	476	—	20·1
Tin	White	6	7·299	442	—	34·7
Lead	Blue	5·5	11·352	612	—	27·7
Copper	Red	7·5	8·895	—	27	302·26
Mercury	White	0	13·568	39	—	—
Silver	White	7	10·510	—	22	187·13
Gold	Yellow	6·5	19·361	—	32	150·07
Platinum	White	8	21·5313	—	170+	274·31
Palladium	White	9	12·148	—	170+	—
Rhodium	White	9	10·649	—	180+	—
Iridium	White	9	18·68+	—	180+	—

3. The following table exhibits the different combinations which these metals are capable of forming with oxygen. The oxides distinguished by the mark * are those which combine most readily with acids, and form neutral salts. The oxygen is the quantity by weight which combines with 100 metal.

Metals.	Oxides.	Colour.	Oxygen.	Weight of an atom of oxide.
Potassium	1*	White	20	6
	2	Yellow	60	8
Sodium	1*	White	33·3	4
	2	Yellow	50	9
Calcium	1*	White	38·39	3·625
Borium	1*	White	11·42	9·75
	2			
Strontium	1*	White	18·18	6·5
Magnesium	1*	White	66·6	2·5
Yttrium	1*	White	25	5
Glucinum	1*	White	44·4	3·25
Aluminum	1*	White	88·8	2·125
Zirconium	1*	White	23·78?	5·625?
Iron	1*	Black	28·75	4·5
	2	Red	43·12	10
Nickel	1*	Grey	29·63	4·375
	2	Black	44·445	9·75
Cobalt	1*	Blue	27·58	4·625
	2	Black	36·77	10·25
Manganese	1*	Green	28·75	4·5
	2	Black	57·5	5·5
Cerium	1*	White	17·39	6·75
	2	Reddish brown	26·04	14·5
Uranium	1*	Greyish black	6·4	16·625
	2	Yellow	9·6	34·25
Zinc	1*	White	24·24	4.125
Bismuth	1*	Yellow	11·2672	9·875
Lead	1*	Yellow	7·692	14
	2	Red	11·538	29
	3	Brown	15·384	15
Tin	1*	Black	13·55	8·375
	2	Yellow	27·1	9·375
Copper	1	Red	12·5	9
	2*	Black	25	10
Mercury	1*	Black	4	26
	2*	Red	8	27
Silver	1*	Olive	7·272	14·75
Gold	1	Green	4·02	25·875
	2*	Reddish brown	12·06	27·875
Platinum	1	Black	4·419	23·625
	2*	Brown	13·257	25·625

Metals.	Oxides.	Colour.	Oxygen.	Weight of an atom of oxide.
Palladium	1*	Brown	14·285	8
Rhodium	1	Black	6·666	16
	2	Brown	13·333	17
	3*	Red	20	18
Iridium				7?

These oxides amount to about 47 in number; but not more than 28 or 29 have the property of neutralizing acids, and forming neutral salts.

4. The *chlorides* of these metals have been but imperfectly examined. The following table exhibits such of them as we are at present acquainted with:

Metals.	Chlorides.	Colour.	Chlorine united to 100 metal.	Weight of an atom of chloride.
Potassium	1	White	90	9·5
Sodium	1	White	150	7·5
Calcium	1	White	171·42	7·125
Barium	1	White	51·42	13·25
Strontium	1	White	69·23	11
Magnesium	1	White	300	6
Yttrium	1	White		
Glucinum	1	White		
Aluminum	1	White		
Zirconium	1	White		
Iron	1	Grey	128·37	8
	2	Brown	256.74	12·5
Nickel	1	Olive		
Cobalt	1			
Manganese	1	Pink		
Cerium				
Uranium				
Zinc	1	White	112·5	8·625
Bismuth	1	Grey	50·7	13·375
Lead	1	White	34·61	17·5
Tin	1	Grey	61·01	11·875
	2	Liquid	122·02	16·375
Copper	1	White	56·25	12·5
	2	Yellow	112·5	17
Mercury	1	White	18	29.5
	2	White	36	34
Silver	1	Grey	32·73	18·25
Platinum	1	Green	19·88	27·125

The chlorides of the 5th family of metals, with the exception of that of platinum, have not hitherto been examined.

5. The *iodides* are still more imperfectly known than the chlorides. The following table exhibits the composition of such of them as we are acquainted with:

Metals.	Iodides.	Colour.	Iodine combining with 100 metal.	Weight of an atom of iodide.
Potassium	1	White	312·5	20·625
Sodium	1	White		18·625
Calcium	1	White		18·250
Barium	1	White		24·375
Strontium	1	White		21·125
Iron	1	Brown		19·125
Zinc	1	White	390·6	19·625
Bismuth	1	Orange		24·5
Lead	1	Yellow		28·625
Tin	1	Orange		
Copper	1	Brown		23·625
Mercury	1	Yellow	62·5	40·625
	2	Red	125	56·25
Silver	1	Greenish-yellow		29·375

6. Of the acidifiable combustibles there are four which seem capable of uniting with most of the metals belonging to this genus; I mean phosphorus, sulphur, arsenic, and tellurium. Carbon is known to combine with three metals only; namely,—Iron—Nickel—Manganese.

The phosphurets have been too imperfectly examined to warrant any general statements respecting their composition.

The following table exhibits the sulphurets, as far as we are acquainted with them:

Metals.	Sulphurets.	Colour.	Sp. gravity.	Sulphur united to 100 metal.	Weight of an atom of sulphuret.
Potassium	1	Grey		40	7
Sodium	1	Grey		66·6	5
Iron	1	Yellow	4·518	57·1	5·5
	2	Yellow	4·83	114·2	7·5
Cobalt	1	Yellow		55·16	5·625
Manganese	1	Green		28·57?	9?
Uranium	1	Blackish brown			
Zinc	1	Yellow	4·049	48·84	6·125

Metals.	Sulphurets.	Colour.	Sp. gravity.	Sulphur united to 100 metal.	Weight of an atom of sulphuret.
Bismuth	1	Blue		22·52	10·875
	2	Blue		45	12·875
Lead	1	White	7·602	15·384	15
	2	White		30·768	17
Tin	1	Blue		27·1	9·375
	2	Yellow		54·2	11·375
Copper	1	Black		25	10
Mercury	1	Black	8·16	8	27
	2	Red		16	29
Silver	1	Black	7·215	14·544	15·75
Gold	1	Black		24·39	11·25
Platinum	1	Bluish grey	6·2	19·04	
	2	Bluish black		28·21	
	3	Dark grey	3·5	38·8	
Palladium	1	White		28·5	9
Rhodium	1	White			
Iridium	1	Black		33·3	8?

7. 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.

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 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.

TABLE I. MALLEABLE METALS.

	Zinc	Lead	Tin	Nickel	Iron	Copper	Iridium	Potassium	Sodium	Palladium	Mercury	Silver	Platinum
Lead	M												
Tin	M	M+											
Nickel	O	O	B										
Iron	S	B+	M	M									
Copper	S—	B+	B—	B	S								
Iridium						M							
Potassium	B	B	B		S								
Sodium	B	B	B										
Palladium		B	B+		B	S—		B					
Mercury	B	B	B	O	B	B		B	B	B			
Silver	B—	B—	B—	O	M	M+	M			M--	B—		
Platinum	B	S—	S—		M--	M--	M			M+	B	M+	
Gold	B—	B+	S—	M+	M+	M+	M			M	B	M+	M+

TABLE II. BRITTLE METALS.

	Titanium	Tungsten	Chromium	Uranium	Molybdenum	Manganese	Cobalt	Arsenic	Tellurium	Antimony
Tungsten										
Chromium										
Uranium										
Molybdenum										
Manganese		B			B					
Cobalt					B					
Arsenic					B		B			
Tellurium										
Antimony			B		B	O		B		
Bismuth			B		S	O	O	B		B

TABLE III.

	Bismuth	Antimony	Arsenic	Cobalt	Manganese	Molybden.
Gold	B—	B—	B	B—	M	B
Platinum	B	B	B			B—
Silver	B—	B—	B	B		B
Mercury	B	B	B	O	O	O
Palladium	B—		B			
Rhodium						
Potassium	B	B	B			
Sodium	B	B	B			
Copper	B=	B—	M		M	S
Iron	B+	B+	B	B	S	B
Nickel	B		B+	B		S
Tin	M	M?+	B		B	
Lead	M—	M—	B	B		S
Zinc	O	B+	B	O	O	O

GENUS III. INTERMEDIATE COMBUSTIBLES.

The substances belonging to this genus may be considered as intermediate between the first and the second genus. They differ from those of the second genus, by forming compounds with oxygen which do not neutralize acids; and from those of the first genus, by not entering into any gaseous combinations. They agree with the bodies of the first genus because their oxides possess acid properties. They agree with the bodies of the second genus because these acids are but imperfectly soluble in water and act with but little energy upon animal and vegetable bodies.

The substances belonging to this genus are the following six metals.

1. Antimony.
2. Chromium.
3. Molybdenum.
4. Tungsten.
5. Columbium.
6. Titanium.

SECTION I.

OF ANTIMONY.

The ancients were acquainted with an oxide of antimony, to which they gave the names of στιμμι and *stibium*. Pliny* informs us, that it was found in silver ore; and we know that at present there are silver ores† in which it is contained. It was used as an external application to sore eyes; and Pliny gives us the method of preparing it.‡ It is probable that a dark bluish-grey mineral, of a metallic lustre, was also known to them by the same names. It certainly bore these names as early at least as the 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 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

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* Pliny, lib. xxxiii. cap. 6.

† Kirwan's Miner. ii. 110.

‡ Pliny, lib. xxxiii. cap. 6.

§ 2 Kings, ix. 30, and Ezek. 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.

¶ Analysis Antimonii Physico-chim. Rationalis.

even a list of their names. Bergman, Berthollet, Thenard, Proust, and Berzelius, are the modern chemists who have thrown the greatest light upon its 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, and sometimes assuming the appearance of imperfect crystals. Haüy 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 nearly the same as that of gold. 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 Mushenbroeck, 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.

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 coloured 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.

The oxides of antimony have been investigated with considerable care by Thenard,[¶] Proust,[**] Bucholz, and Berzelius.[††] According to Thenard this metal forms no fewer than six oxides; according to Proust and Bucholz, whose researches coincide with those

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[*] The word *alcohol*, which is still employed in chemistry, was, if we believe Homerus Poppius Thallinus, first applied to this mineral. "Hispanicis muliercculis ejus usus in ciliorum pulchritudine conciliandafuit 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 et nothus Saturni.

[†] Jour. de Min. An. v. 601.

[‡] On the Alloys of Gold, p. 68.

[§] Mortimer, Phil. Trans, for 1747, vol. 44, p. 672. In the plate attached to the paper.

[‖] Lavoisier and Meusnier, Mem. Par. 1781, p. 274.

[¶] Ann. de Chim. xxxii. 259.

[**] Jour. de Phys. lv. 328.

[††] Nicholson's Journal, xxxiv. 241, 313, and xxxv. 38.—Annals of Philosophy, iii. 248.

of Proust, it forms only two: while according to Berzelius it is capable of forming four oxides. The protoxide of Berzelius is obtained by exposing antimony to the air or to the action of the galvanic battery. It was a grey powder. When acted on by muriatic acid it was separated into the protoxide of Proust and metallic antimony. Hence it is probably merely a mixture of the two. The two oxides of Proust are easily obtained and possess specific characters. Berzelius has shown that the second of them possesses the properties of an acid. The peroxide of Berzellus is also readily obtained; though it is not easily freed from water. It likewise possesses the properties of an acid. We know therefore three oxides of antimony. The *protoxide* is *grey*, *antimonious acid* is *white*, and *antimonic acid* is *straw yellow*.

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.†

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. This oxide may be kept melted in contact with antimony any length of time without alteration.‡

According to the experiment of Proust it is composed of—Antimony 100—Oxygen 22·7—According to Berzelius, its constituents are—Antimony 100—Oxygen 18·6.

This composition is deduced from his analysis of sulphuret of antimony. If we were to consider my analysis of this sulphuret as more correct,§ it will follow from it that the protoxide of antimony is a compound of—Antimony 100—Oxygen 17·775.

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 apo-

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[*] 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.

[‡] Proust. Jour. de Phys. lv. 328.

[§] Annals of Philosophy, iv. 99.

thecaries. 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 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.

2. *Antimonious acid* or *deutoxide* of antimony may be obtained by heating the protoxide in an open vessel nearly to redness. It takes fire, absorbs oxygen, and is converted into deutoxide. It is obtained also 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 hot nitric acid to act upon antimony.

This oxide is of a fine 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 a pretty violent heat; but it is volatilized at a lower temperature, forming white prismatic crystals of a silvery lustre. When melted with a fourth part of antimony, the whole is converted into protoxide.§ It combines with bases, and forms salts to which the name of *antimonites* may be given. According to Proust it is composed of—Antimony 100—Oxygen 29·87. According to Berzelius, its constituents are,—Antimony 100—Oxygen 24·8.

It is quite clear from its conversion into protoxide when fused with one-fourth of its weight of antimony, an experiment confirmed by Berzelius, that the oxygen in the deutoxide is to that in the protoxide as 4 to 3. Hence if the composition of the protoxide as deduced from my experiments be correct, antimonious acid must be a compound of—Antimony 100—Oxygen 23·7.

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* Proust, Jour. de Phys. lv. 334.

† Bergman, iii. 166.

‡ Ann. de Chim. xxxiv. 139.

§ Proust, Jour. de Phys. lv. 328.

3. Antimonic acid or peroxide of antimony is obtained when antimony in powder is mixed with six times its weight of nitre and exposed for an hour in a silver crucible to as strong a heat as the crucible can bear. The potash and nitre are then to be washed off with water. The white powder remaining is to be digested for a long time in muriatic acid to deprive it of the potash which it contains. It is then to be dried and exposed to a heat sufficiently strong to drive off the water with which the oxide still continues united. It is now a straw-coloured powder and is considered by Berzelius as pure antimonic acid. It is obtained also when antimony is digested in nitric or nitromuriatic acid, and the white powder obtained is dried at a temperature sufficient to drive off the water without disengaging any oxygen. This oxide is insoluble in water but it reddens vegetable blues. It appears likewise to be incapable of combining with acids. When heated to redness it gives out oxygen and is converted into antimonious acid. Berzelius did not succeed in analysing it, but he concludes from analogy that it contains twice as much oxygen as exists in the protoxide, or that it is composed of—Antimony 100—Oxygen 37·2, according to his analysis of the sulphuret; or of—Antimony 100—Oxygen 35·556, according to mine.

Our knowledge of the composition of the oxides of antimony is still too imperfect to enable us to determine the weight of an atom of this metal with any great accuracy. But there seems every reason to conclude that the sulphuret of antimony, from which the composition of the protoxide has been deduced is a compound of 1 atom metal + 1 atom sulphur. On that supposition the weight of an atom of antimony will be 5·625.

The protoxide of antimony is soluble in acids, and forms salts, some of which, (*tartar emetic* for instance) are nearly neutral; but the deutoxide and peroxides of antimony possess the characters of acids. Hence antimony might have been placed under the preceding genus as well as the present. I was induced to give it the present position, because the deutoxide of antimony, which is the most intimate compound of this metal and oxygen, possesses acid characters.

III. Antimony has a strong affinity for chlorine. When introduced into chlorine gas it takes fire and is converted into *chloride of antimony*. This chloride is most easily obtained by distilling a mixture of 2 parts of corrosive sublimate and 1 part of antimony. A fatty mass of a greyish-white colour comes over, often crystallized in four-sided prisms. This substance was formerly distinguished by the name of *butter of antimony*. It melts at a moderate heat, is very volatile, and is decomposed when mixed with water, white oxide of antimony and muriatic acid being formed. According to the analysis of Dr. John Davy,* the chloride of antimony is a compound of

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* Phil. Trans. 1812, p. 189. I have corrected his numbers by my analysis of the sulphuret of antimony.

Antimony	54·88	-	100	-	5·472
Chlorine	45·12	-	82·22	-	4·5

Hence it is obvious that the chloride of antimony is a compound of 1 atom antimony and 1 atom chlorine. This analysis then serves to confirm the weight of an atom of antimony.

IV. Antimony is easily united with iodine by heat. The iodide of antimony has a dark-red colour. When digested in water, it is entirely decomposed, and converted into hydriodic acid and oxide of antimony. It has not been analysed; but it is probably a compound of 1 atom antimony + 1 atom iodine, or by weight of—Antimony 5·625—Iodine 15·625.

V. We are ignorant of the action of fluorine on antimony. This metal does not combine with azote nor hydrogen. We are acquainted with no compound that it forms with carbon, boron, or silicon.

VI. 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 phosphoric glass, or by dropping phosphorus into melted antimony.[*]

VII. 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. This sulphuret occurs native, and constitutes almost the only ore of antimony. It has a light leaden-grey colour, and the metallic lustre. It has usually a foliated or radiated texture, and a specific gravity of about 4·368. The following table exhibits its composition, according to the most accurate experiments hitherto made:

	Antimony.		Sulphur.		Antimony.		Sulphur.
Wenzel[†]	100	+	29·870	Bergman[¶]	100	+	35·035
Proust[‡]	100	+	33·333	Thomson[**]	100	+	35·572
Vauquelin[§]	100	+	33·333	Berzelius[††]	100	+	37·000
John Davy[‖]	100	+	34·960				

My own analysis having been made with great care, and being nearly a mean of all the others (leaving out that of Wenzel), I am disposed to consider it as the most correct. I consider the sulphuret as a compound of 1 atom metal + 1 atom sulphur; and, therefore, deduce from it the weight of an atom of antimony to be 5·625.

[*] Pelletier, Ann. de Chim. xiii. 132.

[†] Annals of Philosophy, iv. 96.

[‡] Jour. de Phys. lv. 325.

[§] Ann. des Mus. d'Hist. Nat. xvii. 133.

[‖] Phil. Trans. 1812, p. 231.

[¶] Opusc. iii. 167.

[**] Annals of Philosophy, iv. 99.

[††] Nicholson's Journal, xxxiv. 244.

VIII. Antimony forms with arsenic an alloy which is very brittle, very hard, and very fusible: and composed, according to Bergman, of 7 parts of antimony and 1 part of arsenic.

IX. Antimony combines with potassium with great energy when heated with it; the alloy becoming red-hot at the moment of union. This alloy is brittle, not so white as tin, and not very fusible. In the air, or under water, it is speedily destroyed.*

It may be alloyed nearly in the same way with sodium. The alloy possesses the same properties.†

X. 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 metals.‡ This alloy may be obtained also by fusing in a crucible 2 parts of sulphuret and 1 of iron. It was formerly called *martial regulus*.

XI. The alloys which antimony forms with nickel, cobalt, manganese, cerium, and uranium, are unknown.

XII. Zinc may be readily combined with antimony by fusion. The alloy is hard and brittle, and has the colour of steel. Its specific gravity is less than intermediate.§

XIII. Antimony forms a brittle alloy with bismuth; to manganese it unites but imperfectly:‖ the compounds which it forms with nickel and cobalt have not been examined.

XIV. When equal parts of lead and antimony are fused, the alloy is porous and brittle: 3 parts of lead and 1 of antimony form a compact alloy, malleable, and much harder than lead: 12 parts of lead and 1 of antimony form an alloy very malleable, and a good deal harder than lead: 16 parts of lead and 1 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.††

XV. 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 diluted with water the whole of the two metals is precipitated.‖‖

XVI. 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.

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* Gay-Lussac and Thenard, Recherches Physico-chimiques, i. 219.

† Ibid. p. 244.

‡ Gellert, p. 136.

§ Ibid.

‖ Gmelin, Ann de Chim. xix. 367.

¶ Gmelin, Ann. de Chim. viii. 319.

** Mushenbroeck.

†† Gellert, p. 136.

‡‡ Gellert, p. 136.

§§ Fourcroy, vi. 25.

‖‖ Ann. de Chim. lv. 276.

¶¶ Gellert, p. 136.

XVII. 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 3 parts of mercury are mixed in this manner with 1 part of melted antimony, a soft amalgam is obtained, which very soon decomposes of itself.† Gellert also succeeded in forming this amalgam.‡

XVIII. 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.

XIX. 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.¶

XX. Platinum easily combines with antimony. The alloy of equal parts is brittle, and of a much duller 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.**

SECTION II.

OF CHROMIUM.

In the year 1766, Lehman, in a letter to Buffon, published the first description of a beautiful red mineral with a shade of yellow, crystallized in four-sided prisms, which is found in the mine of Beresof, near Ekaterimbourg in Siberia. This mineral, known by

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* Lewis, Neuman's Chem. p. 131.

† Wallerius.

‡ Metall. Chem. p. 141.

§ Metallurgic Chemistry, p. 136.

‖ 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.

** Lewis, Phil. Com. p. 521.

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 Klaproth,[‡] Gmelin,[§] and Moussin Pouschkin.[‖] Richter has succeeded in reducing chromium to the metallic state, and in ascertaining some of its most important properties.[¶] Vauquelin has published a second paper on chromium, in which he examines the properties of chromic acid, and described several of its combinations.[**] And Berzelius has made a set of experiments to determine the composition of the oxides of this metal.[††]

Chromium may be obtained by the following process: Two parts of the mineral called *chromate of iron* in powder are mixed with one part of nitre, and calcined for some time in a crucible. The mass is digested in water, the liquid separated, and the residue treated with muriatic acid.[‡‡] The acid solution is speedily decanted off, and the residue, which is chromate of iron undecomposed, is to be calcined a second time with the fourth part of its weight of nitre, and treated as before. When the ore is completely decomposed, the aqueous solutions, which contain the oxide of chromium, are to be collected, saturated with nitric acid, and crystallized, in order to separate some impurities. The salt is then to be dissolved in water, and mixed with a solution of nitrate of mer-

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[*] Ann. de Chim. xxv. 21, and 194.

[†] From χρωμα, because it possesses the property of giving colour to other bodies in a remarkable degree.

[‡] Crell's Annals, 1798, i. 80. Mr. Klaproth had examined the *red lead ore* in consequence of the analysis of Bindheim. His experiments led him to conclude, that the metallic acid, combined with the lead, was not the molybdic, but the acid of some new unknown metal; but his specimen was too small to enable him to decide the point. In the mean time, Vauquelin's experiments were published.

[§] Ibid. 1799, i. 275.

[‖] Ibid. 1798, i. 355, &c.

[¶] Gehlen's Jour. v. 351.

[**] Ann. de Chim. lxx. 70.

[††] Annals of Philosophy, iii. 101.

[‡‡] [Merely to separate the remains of alkali from the decomposed nitre. A better process is given by Mr. W. Hembell, jun. in the Emporium.—C.]

cury, containing as little excess of acid as possible. A red precipitate falls, consisting of the chromic acid combined with the mercury. It is to be thoroughly washed, and exposed to heat in a stoneware retort. The oxide of chromium remains in a state of purity. Richter obtained the metal by exposing a mixture of oxide of chromium and charcoal to a violent heat in a porcelain furnace. He found charcoal from sugar to answer the purpose best.

I. 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.

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*.

1. The protoxide or green oxide is obtained by the process above described. It may be procured likewise by exposing chromic acid to heat in close vessels; oxygen gas passes over, and the green oxide remains behind. When this oxide is precipitated from its solution in acids, it has a dark green colour, and contains water, from which however it is easily separated by heat. It is easily dissolved by acids. But if it be exposed to a heat rather below redness, it becomes ignited, diminishes in bulk, and assumes a fine light green colour. It is now quite insoluble in acids, yet it has lost no weight.†

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.‡ It has been since more particularly examined by Vauquelin. It may be obtained thus: Dissolve protoxide of chromium in nitric acid, evaporate the solution to dryness and expose the dry mass to heat till it ceases to give out nitrous fumes. A brown brilliant powder remains which is scarcely soluble in alkalies, and not at all in acids. When heated with muriatic acid, chlorine gas is exhaled and it is converted into protoxide. Hence we see that it contains more oxygen than the protoxide.

3. Chromic acid has a deep red colour, and a sharp and metallic

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* Gehlen's Jour. v. 394.

† Berzelius, Annals of Philosophy, iii. 105.

‡ Crell's Annals, 1798, ii. 445.

taste. It is soluble in water, and crystallizes with difficulty in small ruby red crystals, which slowly absorb moisture from the atmosphere. It is converted into green oxide by the action of sulphureted hydrogen, sulphurous acid, protoxide of iron, protoxide of copper, and protoxide of tin. It combines with the different bases, and forms salts which have been called *chromates*.

From the experiments of Berzelius it appears, that the chromates of lead and barytes are composed as follows:

Chromate of lead.		
Chromic acid	100	6·547
Protoxide of lead	213·841	14
Chromate of barytes.		
Chromic acid	100	6·541
Barytes	149·066	9·750

From these analyses we see that the equivalent number for chromic acid is 6·544. We may therefore take 6·5 as that number without any sensible error. Berzelius is of opinion that chromic acid contains twice as much oxygen as green oxide of chromium, and that 31·5 of chromic acid consist of 24·14 green oxide + 7·36 oxygen.* Hence it follows that chromic acid is composed of

Chromium	16·78	100	3·5
Oxygen	14·72	87·72	3·03
	31·50		

From the numbers in the last column we see, that on the supposition that Berzelius' experiments are correct, chromic acid must be a compound of 1 atom chromium and 3 atoms oxygen. And the weight of an atom of chromium must be 3·5. If the protoxide of chromium contain only half the oxygen in chromic oxide, it must be a compound of 2 atoms chromium and 3 atoms of oxygen, and its weight must be 10. The composition of the deutoxide is still unknown.

The remaining properties of chromium are still unknown.

SECTION III.

OF MOLYBDENUM.

1. The Greek word μολυβδαινα, and its Latin translation *plumbago*, seem to have been employed by the ancients to denote various oxides of lead; but by the moderns they were applied indiscriminately to all substances possessed of the following properties: light, friable, and soft, of a dark colour and greasy feel, and which leave a stain

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* Annals of Philosophy, iii. 102.

upon the fingers. Scheele first examined these minerals with attention. He found that two very different substances had been confounded together. To one of these, which is composed of carbon and iron, and which has been already described, he appropriated the word *plumbago;* the other he called *molybdena.*[*]

Molybdena is composed of scaly particles adhering slightly to each other. Its colour is bluish, very much resembling that of lead. Scheele analysed it in 1778, and obtained sulphur and a whitish powder, which possessed the properties of an acid, and which, therefore, he called *acid of molybdena.*[†] Bergman suspected this acid, from its properties, to be a metallic oxide; and at his request, Hjelm, 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 were 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 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.[‡‡]

The simplest method of procuring molybdenum in a state of purity seems to be that put in practice by Hjelm. 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 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.

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[*] [The streak of plumbago or black lead on white china, is greyish-black; that of the sulphuret of molybdena has an olive-green tinge, sufficiently marked.—C.]

[†] Scheele, i. 236.

[‡] Bergman's Sciagraphia, p. 19, Engl. transl.

[§] Crell's Annals, 1790, i. 39, &c.

[‖] Jour. de Phys. 1785, Decembre.

[¶] Crell's Annals, 1787, i. 407.

[**] Ibid. ii. 27, and 124.

[††] Phil. Trans. 1795, p. 523.

[‡‡] Gehlen's Jour. iv. 398.

[§§] Crell's Annals, iii. 338, Engl. transl.

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. Hjelm 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.

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.*

The combinations of molybdenum with oxygen have been but imperfectly investigated. From the experiments of Bucholz there seem to be three oxides very well distinguished from each other. The first is a tasteless powder, but the second and third have the properties of acids. The *protoxide* is *brown; molybdous acid*, *blue;* and *molybdic acid*, *white.*

1. The protoxide or brown oxide may be obtained by the following process. Heat molybdena in the open air till the sulphur is burnt off, and the metal converted into molybdic acid. Dissolve the acid in ammonia. Evaporate the molybdate of ammonia to dryness, put the dry mass into a crucible, cover it with charcoal powder and expose it to a white heat. The brown oxide will be found at the bottom of the crucible. It has a crystallized appearance, a copper brown colour, and a specific gravity of 5·666. It is incapable of forming salts with acids.

2. The *blue oxide* or *molybdous acid* may be obtained by the following process: Mix together 1 part of molybdenum in powder and 2 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 8 or 10 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 molybdic 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. 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.

3. The white oxide, or molybdic acid, is obtained most easily

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* Gehlen's Jour. iv. 618.

from native molybdena, by roasting it for some time, and then dissolving the grey residue in ammonia. Nitric acid dropped 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.

From the experiments of Berzelius† it appears, that molybdate of lead is composed of

Molybdic acid	100	9·023
Protoxide of lead	155·15	14

From this we see that the equivalent number for molybdic acid is 9. From the experiments of Bucholz we learn that molybdic acid is composed of 100 molybdenum, and between 49 and 50 oxygen. By dividing 9 in this proportion, we obtain the constitution of molybdic acid as follows:

Molybdenum	6	100
Oxygen	3	50

Hence we see that the weight of an atom of molybdenum is 6, and that molybdic acid is a compound of 1 atom molybdenum + 3 atoms oxygen.

According to the experiments of Bucholz, molybdous acid is composed of—Molybdenum 100—Oxygen 34.

Hence it follows that it is a compound of 1 atom molybdenum + 2 atoms oxygen, or by weight of

Molybdenum	6	100
Oxygen	2	33·3

The protoxide has not been analysed; but there can be no doubt that it is a compound of 1 atom molybdenum + 1 atom oxygen, or by weight of

Molybdenum	6	100
Oxygen	1	16·6

III. We are unacquainted with the combinations which molybdenum may be capable of making with chlorine, iodine, and fluorine.

We know nothing about the compounds which it may be capable of forming with any of the acidifiable combustibles, excepting with sulphur and arsenic. Pelletier indeed ascertained that molybdenum may be combined with phosphorus; but he did not examine the properties of the phosphuret.‡

IV. Molybdenum combines readily with sulphur; and the compound has exactly the properties of molybdena, the substance which Scheele decompounded.§ Molybdena is therefore *sulphuret of molybdenum*. The reason that Scheele obtained from it molybdic acid

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* Bucholz, Gehlen's Jour. iv. 604.

† Annals of Philosophy, iii. 101.

‡ Ann. de Chim. xiii. 137.

§ Pelletier, Jour. de Phys. 1785.

was, that the metal combined with oxygen during his process. Sulphuret of molybdenum may be formed also by distilling together 1 part of molybdic acid and 5 parts of sulphur. According to the experiments of Bucholz, this sulphuret is composed of—Molybdenum 100—Sulphur 66·5.

Hence it is obviously a compound of 1 atom molybdenum + 2 atoms sulphur. For this compound gives by weight,

Molybdenum	6	100
Sulphur	4	66·6

Which corresponds almost exactly with Bucholz's analysis.

V. 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.*

VI. Nothing is known respecting the alloys of molybdenum with the metals of the fixed alkalies, alkaline earths, and earths proper.

VII. Equal quntities 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 blowpipe it melted with intumescence, but without sparks. One part of iron and two of molybdenum formed a brittle alloy of 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.†

VIII. 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 alloy becomes more difficult; in other respects, its properties continue nearly the same.‡

IX. 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.§

X. 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.‖

XI. 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.¶

XII. 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

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* Crell's Annal's, p. 368.

† Ibid. p. 370.

‡ Ibid. iii. 367.

§ Ibid. p. 371.

‖ Ibid. p. 376.

¶ Ibid. p. 375.

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 button 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.*

XIII. Ten parts of lead and one of molybdenum, when melted together form an alloy which is some what 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.†

XIV. Equal parts of tin and molybdenum melted into a blackish-grey, granular, brittle, soft mass. When 2 parts of tin and 1 of molybdenum were melted together, the alloy is 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.‡

XV. 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 1½ molybdenum formed an alloy not very different in its properties; but when the metals were mixed in the proportion of 1 part copper and 2 molybdenum, the alloy was brittle, and of a reddish-grey colour. Nitric acid dissolved the copper, and left the white oxide of molybdenum.§

XVI. Hjelm could not succeed in his attempts to unite mercury and molybdenum.‖

XVII. 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 1 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 2 of molybdenum melted into a granular, brittle, greyish lump. When heated on charcoal the molybdenum

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* Crell's Annals, p. 363.

† Ibid. p. 388.

‡ Ibid. p. 373.

§ Ibid. p. 366.

‖ Ibid. iii. 358.

evaporated and the silver remained. The molybdenum may be separated from silver by cupellation, especially if the alloy has been previously calcined.*

XVIII. 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.

None of these compounds could be brought into perfect fusion even by the assistance of borax.†

XIX. 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 Hjelm to be 20.‡

SECTION IV.

OF TUNGSTEN.

THERE is a mineral found in Sweden of an opaque white colour and great weight; from which last circumstance it got the name of *tungsten* or *ponderous stone*. Some mineralogists considered it as an ore of tin, others supposed that it contained iron. Scheele analysed it in 1781, and found that it was composed of lime and a peculiar earthy-like substance, which he called from its properties *tungstic acid*.§ Bergman 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

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* Crell's Annals, p. 361.

† Hjelm, Crell's Annals, iii. 356, Eng. Trans.

‡ Hjelm, Crell's Annals, p. 52, and Ann. de Chim. iv. 17.

§ Scheele, ii. 81.

‖ Scheele, ii. 91.

¶ Wolfram had been analysed in 1761 by Lehmann. He imagined it a compound of iron and tin. See his Probierkunst, p. 8.

consist of a congeries of metallic globules, some of which were as large as a pin-head. The metal thus obtained is called *tungsten.* The manner in which it 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 accomplished by Messrs. Allen and Aiken of London. They succeeded by applying a strong heat to the combination of the oxide of tungsten and ammonia.‖ Since that time a set of experiments on tungsten has been published by Bucholz,¶ and some valuable investigations on the compositions of its oxides, have been made by Berzelius.**

1. Tungsten, called by some of the German chemists *scheelium*, and by Berzelius *wolframium*, 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.†† Bucholz found it 17·4,‡‡ which being nearly a mean of the preceding results may be taken as very near the truth. It is therefore the heaviest of the metals after gold, platinum, and iridium.

3. 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.

4. It is not attracted by the magnet.

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 *brown* and the *yellow* or *tungstic acid.*

1. Brown oxide of tungsten seems to have been observed by Bucholz; but its nature was first accurately investigated by Berzelius. He obtained it by putting a quantity of tungstic acid in a glass tube, heating it to redness and passing through it while in that state a current of hydrogen gas. Water was formed and the

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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.

[¶] Schweigger's Journal, iii. 1; and Annals of Philosophy, vi. 198.

[**] Annals of Philosophy, iii. 244.

[††] Aiken's Dictionary of Chemistry, ii. 445.

[‡‡] Annals of Philosophy, vi. 205.

acid deprived of a portion of its oxygen. The oxide formed had a flea-brown colour, and when heated in the open air takes fire and burns like tinder, and is converted into tungstic acid.

2. The peroxide or yellow oxide, known also by the name of *tungstic acid*,[*] may be obtained by boiling 3 parts of muriatic acid on 1 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 *yellow oxide* in a state of purity.[†] This oxide has no taste. It is insoluble in water, but remains long suspended in that liquid, forming a kind of yellow milk, which has no action on vegetable colours. When heated in a platinum spoon it becomes green; but before the blow-pipe on charcoal it acquires a black colour. Berzelius has shown that the blue oxide of Bucholz obtained by decomposing the tungstate of ammonia by heat in a retort is the same as the yellow. Both possess the properties of an acid and form the same compounds with bases.

From the experiments of Berzelius it appears that tungstate of lime[‡] is composed of

Tungstic acid	100	15·03
Lime	24·12	3·625

From this it follows that the equivalent number for tungstic acid is 15·2, Messrs. D'Elhuyarts, Bucholz, and Berzelius[§] have shown that tungstic acid is composed of—Tungsten 100—Oxygen 25. If we divide 15 in the proportion of 100 to 25, we obtain the composition of tungstic acid as follows:

Tungsten	12	100
Oxygen	3	25

Hence it appears that tungstic acid is a compound of 1 atom tungsten and 3 atoms oxygen, and that an atom of tungsten weighs 12.

Berzelius has shown that brown oxide of tungsten contains very nearly two-thirds the quantity of oxygen that exists in tungstic acid, or that it is a compound of about—Tungsten 100—Oxygen 16·6. If we consider it as a compound of 1 atom tungsten + 2 atoms oxygen, its composition will be

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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.

[†] A more economical process for procuring this oxide has been proposed by Bucholz. His formula is as follows: Mix 1 part of wolfram in fine powder with 2 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.

[‡] Afhandlingar, iv. 407.

[§] Annals of Philosophy, iii. 245.

Tungsten	12	100
Oxygen	2	16·6

Which corresponds exactly with the analysis.

III. We are ignorant of the compounds which tungsten forms with chlorine, iodine, and fluorine.

It probably does not combine with azote nor with hydrogen. We are unacquainted with all the combinations which it may form with the simple acidifiable combustibles except the *sulphuret*. Pelletier indeed ascertained that it combines with phosphorus; but the properties of the phosphuret were not examined.*

IV. Sulphuret of tungsten was first formed by the D'Elhuyarts. Berzelius obtained it by mixing tungstic acid with four times its weight of sulphuret of mercury, putting the mixture into a crucible, covering its surface with charcoal powder, and exposing it for half an hour to a violent heat. Sulphuret of tungsten thus formed is a greyish-black powder, which when rubbed upon a polished hematite assumes a beautiful metallic lustre. Berzelius† found it a compound of—Tungsten 100—Sulphur 33·26. Thus it contains twice as much sulphur as the brown oxide does oxygen. It is therefore a compound of 1 atom tungsten + 2 atoms sulphur.

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:

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.

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* Ann. de Chim. xiii. 137.

† Annals of Philosophy, iii. 245.

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.*

SECTION V.

OF COLUMBIUM OR TANTALUM.

In the year 1801, 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 Massachusetts. 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 1 part of oxide of iron, and rather more than 3 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. 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*.

Soon after Mr. Hatchett's discovery a metallic substance was detected in Sweden by Mr. Ekeberg, differing from every other with which he was acquainted. To this metal he gave the name of *tantalum*, and to the minerals from which he obtained it the name of *tantalite* and *yttrotantalite*.† In the year 1809, Dr. Wollaston procured specimens of the Swedish minerals, and by a careful comparison of the new oxide which it contained with the new

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* Chemical Analyses of Wolfram, translated by Cullen, p. 59.

† Vetenscaps Academiens Handlingar, 1802, p. 68.

oxide in the mineral in the British Museum, analysed by Mr. Hatchett, he demonstrated that *columbium* and *tantalum* are one and the same substance.[*] In the year 1815, Assessor Gahn of Fahlun and Professor Berzelius discovered various new minerals in the neighbourhood of Fahlun containing tantalum. Berzelius analysed these minerals and took the opportunity of reducing the oxide of tantalum to the metallic state, and of ascertaining its properties.[†]

I. Perhaps the simplest method of extracting the oxide of tantalum from the mineral called *tantalite* is the method employed by Dr. Wollaston, which is as follows. Mix together 1 part of tantalite with 5 parts of carbonate of potash and 2 parts of borax, and fuse the mixture in a platinum crucible. Soften the fused mass with water, and then digest it in muriatic acid. The iron and manganese which existed in the mineral combined with the oxide of tantalum are dissolved, and nothing remains but the oxide of tantalum in the state of a white powder.[‡] Berzelius succeeded in reducing this oxide to the metallic state by putting it into a charcoal crucible and exposing it to a violent heat.

Tantalum thus reduced has a dark grey colour and when scratched with a knife or rubbed against a fine grindstone, it assumes the metallic lustre, and puts on the appearance of iron. The tantalum had not been melted, but its particles adhered firmly together, and formed a mass through which water would not penetrate, Its specific gravity, as taken by Dr. Wollaston, was 5·61. But as the mass had not been melted, there can be no doubt that the true specific gravity of tantalum is greater than this.

The grains of tantalum are hard enough to scratch glass. It may be reduced to powder by trituration, and the powder has no metallic lustre, but a dark brown colour. It is not the least acted on by muriatic acid, nitric acid, or aqua regia, though they be digested on it for several days.

II. When tantalum is heated to redness it takes fire, burns feebly without any flame, and goes out directly if it be removed from the fire. By this combustion it is reduceed to a greyish white matter. But Berzelius could not succeed by this method in his attempts to convert tantalum into an oxide. When pulverized tantalum is mixed with nitre and thrown into a red-hot crucible, a feeble detonation takes place. The mass is snow white and is a compound of white oxide of tantalum and potash. The potash may be separated by muriatic acid and the white oxide of tantalum is left behind combined with water. This hydrate, according to the experiments

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[*] Phil. Trans. 1809. p. 246.

[†] Afhandlingar, iv. 252, 262.

[‡] Berzelius found *tungsten* in some of the tantalites from the neighbourhood of Fahlun, which he examined, and he states in a letter to me, (Annals of Philosophy, iv. 467,) that Ekeberg found the columbic acid of Hatchett, which he examined, a mixture of oxides of tantalum and tungsten. But I doubt the accuracy of this statement, because Dr. Wollaston found no tungsten in columbite; nor could he detect any though he made a new trial at my request after receiving Berzelius's letters.

of Berzelius, is a compound of—Oxide of tantalum 100—Water 12·5.

Oxide of tantalum is insoluble in nitric acid and sulphuric acid, and imperfectly soluble in muriatic acid. While in the state of hydrate it dissolves in oxalic, tartaric, and citric acids; but when the water is driven off by heat none of these acids act upon it. When fused with eight times its weight of carbonate of potash, or caustic potash, it forms a compound which dissolves in water, and it may be precipitated from the solution by muriatic acid in the state of a hydrate. Neither *prussiate of potash* nor hydrosulphuret of potash throw it down from potash, but infusion of nutgalls occasions an orange precipitate, provided there be no excess either of acid or alkali in the solution.* Berzelius has shown that this oxide possesses acid properties. The name columbic acid, therefore, given it by Hatchett may be still retained. The mean of four experiments made by Berzelius in which he oxidized determinate weights of tantalum by means of nitre, give the composition of columbic acid as follows—Tantalum 100—Oxygen 5·485.

According to the statement of Berzelius, columbate of barytes is composed of

Columbic acid	100	24·4
Barytes	40	9·75

This would make the equivalent number for columbic acid 24·4. But no confidence can be put in the analysis, as we do not even know whether the compound was a neutral salt. Were we to suppose columbic acid to be a compound of 100 tantalum + 5·5 oxygen, which deviates very little from Berzelius' numbers, and were we to suppose further that it is a compound of 1 atom tantalum + 1 atom oxygen, then the weight of an atom of tantalum would be 18 and of columbic acid 19. For 100 : 5·5 : : 18 : 1 very nearly. In the present state of our knowledge we must be satisfied with that determination. Supposing it correct, then the columbate of barytes of Berzelius would be a compound 1½ acid + 1 barytes, or 3 acid + 2 barytes.

III. We are unacquainted with the compounds which tantalum is capable of forming with the other supporters of combustion and with the acidifiable combustibles and metals, with the exception of iron and tungsten, with both of which Berzelius alloyed it.

IV. When oxide of tantalum is mixed with iron filings and strongly heated in a small crucible, it is reduced to the metallic state and forms an alloy with the iron. This alloy has the appearance of white cast iron, except that it wants its crystalline texture. It is sufficiently hard to scratch glass. Aqua regia dissolves the iron with difficulty, and leaves the tantalum in the state of a grey powder.

V. The alloy of tungsten and tantalum resembled pure tantalum, but was much firmer and harder, and readily received a polish.

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* Wollaston, Nicholson's Journal, xxv. 25.

SECTION VI.

OF TITANIUM.

In the valley of Menachan, in Cornwall, there is found a black sand, bearing a strong resemblance to gunpowder. It was examined in 1791 by Mr. Gregor, who found it composed almost entirely of iron and the oxide of a new metal, to which he gave the name of *menachine*.* He attempted in vain to reduce this oxide to the metallic state; but his experiments were sufficient to demonstrate the metallic nature of the substance, and 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 *menachine* 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.‖ Lampadius made a set of experiments on it in 1803,¶ and a new set of experiments on it, by Laugier, was published in 1814.**

Oxide of titanium may be obtained by the following process: Reduce the mineral called titanite to powder, and fuse it with twice its weight of caustic potash. Digest the fused mass with water, and pour off that liquid after it has taken up every thing soluble. Dissolve the brownish-red matter that remains in muriatic acid, and into the clear solution drop a little oxalic acid, or oxalate of ammonia. A curdy white precipitate falls. When this precipitate is well washed and dried it is oxide of titanium in a state of purity.

Laugier endeavoured to reduce this oxide to the metallic state by making it up into a paste with oil, and exposing it to the highest

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* Jour. de Phys. xxxix. 72, and 152.

† Beitrage, i. 233.

‡ Ibid. ii. 226.

§ Jour. de Min. No. xv. 10.

‖ Crell's Annals, 1799. i. 183.

¶ Nicholson's Journal, vi. 62.

** Ann. de Chim. lxxxix. 306.

temperature that could be raised in a forge for six hours. The mass, after cooling, consisted of three distinct layers. The centre consisted of brilliant needles, similar in appearance to black oxide of manganese in its crystallized state. The surface consisted of a very thin brown coat, similar to the oxide of copper. Between these two layers there was a third, full of cavities, and having the yellow colour of gold. This last Laugier considered as titanium in the metallic state. It has considerable lustre. It is brittle, but in thin plates has considerable elasticity. It is highly infusible.*

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*.

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.

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 urged by a very violent fire, some of it is volatilized. When heated sufficiently along with charcoal, it is reduced to the metallic state.

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.

III. 1. Titanium does not seem to be capable of combining with sulphur.‡

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.§

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.

The other properties of this untractable metal are still unknown.

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* Nicholson's Journal, vi. 62.

† Lampadius, Nicholson's Jour. vi. 62.

‡ Gregor.

§ Nicholson's Jour. v. 134.

Such are the properties of this genus of bodies as far as they have been hitherto investigated.

1. The following table exhibits some of the most striking characters of these bodies.

Metals.	Colour.	Hardness.	Sp. Gravity.	Melting point.		Weight of an atom.
				Fahrenheit.	Wedgewood.	
Antimony	White	6·5	6·712	810°		5·625
Chromium	White	9?	5·9		170°+	3·5
Molybdenum	White		8·611		170°+	6
Tungsten	White	9	17·4		170°+	12
Columbium	Grey	8	5·61+		170°+	18
Titanium	Yellow				170°+	18?

2. The following table exhibits the compounds which these metals form with oxygen as far as they have been examined.

Metals.	Oxides.	Colour.	Oxygen united to 100 metal.	Weight of an atom of metallic oxide.
Antimony	1	Grey	17·778	
	2	White	23·7	
	3	Yellow	35·556	
Chromium	1	Green		
	2	Brown		
	3	Red	87·72	6·5
Molybdenum	1	Brown	16·6	7
	2	Blue	33·3	8
	3	White	50	9
Tungsten	1	Brown	16·6	14
	2	Yellow	25	15
Columbium	1	White	5·5	19
Titanium	1	Blue		19?
	2	Red		20?
	3	White		21?

3. Neither the *chlorides* nor *iodides* of these metals (if we except antimony) have been examined. Neither have many experiments been made on their compounds with the acidifiable and alkalifiable combustibles. The few facts which have been ascertained will be found in the preceding Sections. Any recapitulation here seems unnecessary.

SECTION VII.

OF THORINUM.

THIS metal should have been placed in the second family of the alkalifiable combustibles immediately after zirconium. But as it has only become known to the chemical world since that part of the volume was printed, I am under the necessity of placing it here.

It was discovered in 1815 by Professor Berzelius, while engaged in the analysis of the gadolinite of Korarvet. But as he obtained it only in very small quantity, and as it was detected only in one specimen, he did not mention it in his paper on gadolinite published in the fourth volume of the Afhandlingar. But in the summer of 1816, while engaged with Assessor Gahn in examining the minerals in the neighbourhood of Fahlun, he found it again in two new minerals, the *deutofluate of cerium* and the *double fluate of cerium and yttria.* But it was only occasionally present in these minerals as had been the case in the gadolinite of Korarvet; and all of it which Berzelius obtained did not amount to quite 7½ grains. He printed however in the fifth volume of the Afhandlingar a description of its properties as far as he was able to ascertain them; and from that paper I have extracted the following account.*

The oxide only of this new metal has been obtained, and as it is white and incapable of being reduced by means of charcoal, it agrees in its properties with the earths. On that account Berzelius has distinguished this oxide by the name of *thorina*, and classed it along with zirconia.

Thorina may be obtained from the minerals containing protoxide of cerium and yttria, by the following process. Precipitate the iron by means of succinate of ammonia. Thorina indeed when alone is precipitated by that salt; but this is not the case when it is mixed with the other bodies that exist in the fluates of cerium and yttria. After the iron is removed, precipitate the cerium by means of sulphate of potash. Ammonia now precipitates the thorina mixed with yttria. Dissolve them in muriatic acid. Evaporate the solution to dryness, and pour boiling water on the residue, which will dissolve the greatest part of the yttria, but not the whole. Redissolve the residue in muriatic or nitric acid, and evaporate till it

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* A translation of the paper will be found in the Annals of Philosophy, ix. 452.

becomes as exactly neutral as possible. Then pour water upon it and boil it for an instant. The thorina precipitates and the solution contains a disengaged acid. If we saturate this acid and boil a second time, an additional portion of thorina precipitates.

Thorina, when separated by the filter, has the appearance of a gelatinous, semitransparent mass. When washed and dried it becomes white, absorbs carbonic acid, and dissolves with effervescense in acids. Though calcined it retains its white colour; and when the heat to which it is exposed is only moderate, it continues readily soluble in muriatic acid. But after exposure to a violent heat, it requires to be digested in strong muriatic acid in order to obtain a solution of it. This solution has a yellowish colour; but it becomes colourless when diluted with water. If it be mixed with yttria it dissolves more readily after having been exposed to heat.

The neutral solutions of thorina have a purely astringent taste, which is neither sweet, nor saline, nor bitter, nor metallic. In this property it agrees with zirconia, and differs from all the other earths.

When dissolved in sulphuric acid with a slight excess of acid and subjected to evaporation, it yields transparent crystals, which are not altered by exposure to the air, and which have a strong styptic taste. The mother water remaining after the formation of these crystals, retains but very little thorina. When the crystals are put into water they are decomposed. A subsulphate precipitates and a supersulphate remains in solution. When this solution is boiled it lets fall no precipitate. Sulphate of potash occasions no precipitate when added to this solution or to the muriate of thorina.

Thorina dissolves readily in nitric acid, unless it has been exposed to a red heat. In that case nitric acid dissolves it only in consequence of long boiling. The solution does not crystallize, but forms a mucilaginous mass which becomes more liquid by exposure to the air, and which when evaporated by a moderate heat leaves a white, opaque mass, similar to enamel, in a great measure insoluble in water. When the neutral solution is boiled a great portion of the earth is precipitated. A slight calcination leaves the earth with its white colour, so that we discover no evidence of a higher degree of oxidizement.

Thorina dissolves in muriatic acid in the same way as in nitric. The solution does not crystallize. When evaporated by a moderate heat it is converted into a syrupy mass, which does not deliquesce in the air; but dries, becomes white like enamel, and afterwards dissolves only in very small quantity in water, leaving a subsalt undissolved. When the muriate, not too acid, is diluted with water and boiled, the greatest part of the thorina is precipitated.

When the nitrate or muriate of thorina is evaporated by a strong heat, it leaves on the edges of the vessel a white opaque film, having the appearance of enamel. It appears very distinctly when the liquid is made to pass over the inside of the glass. This is a very characteristic mark of this earth.

Thorina combines eagerly with carbonic acid. The precipitates produced by caustic ammonia, or by boiling the neutral solutions of the earth, absorb carbonic acid from the air while drying. The alkaline carbonates precipitate the earth combined with the whole of their acid.

Thorina is precipitated by oxalate of ammonia in the state of a white, bulky matter, insoluble in water and in caustic alkalies.

Tartrate of ammonia throws down a white precipitate, which redissolves at first and does not become permanent till a sufficient quantity of the salt has been added. This precipitate is redissolved by caustic ammonia. Boiling drives off the ammonia, but the earth is not precipitated till the liquid has been concentrated to a certain degree by evaporation. It then precipitates under the form of a gelatinous mass, almost transparent.

Citrate of ammonia does not occasion any precipitate, not even when caustic ammonia is added to it. But if the liquid be boiled, the earth precipitates in proportion as the ammonia evaporates.

Benzoate of ammonia produces a white bulky precipitate.

Succinate of ammonia occasions a precipitate, which is immediately redissolved. If a sufficient quantity be added to prevent the precipitate from redissolving, and if we attempt to redissolve it by pouring in water, it is decomposed and remains in a great measure undissolved, under the form of a salt with excess of base, while the liquid contains the greatest part of the acid united to a small portion of the earth.

Ferrocyanate of potash throws down a white precipitate, which is redissolved by muriatic acid.

Caustic potash and ammonia have no action on newly precipitated thorina, not even at a boiling temperature.

Liquid carbonate of potash or carbonate of ammonia dissolves a small portion of it, which precipitates again when the alkali is supersaturated with an acid, and then neutralized by caustic ammonia. But this earth is much less soluble in the alkaline carbonates than any of the other earths.

When exposed in a charcoal crucible to a heat at which tantalum is reduced, it underwent no change in its properties, excepting that it contracted in its dimensions and acquired a small degree of translucency. It does not fuse before the blow-pipe. With borax it melts into a transparent glass, which when exposed to the exterior flame becomes opaque and milky. With phosphate of soda it fuses into a transparent pearl. It is infusible with soda. When soaked with a solution of cobalt it becomes greyish-brown.

It differs from alumina by its insolubility in hydrate of potash; from yttria, by its purely astringent taste without sweetness, and by the property which its solutions possess of being precipitated by boiling when they do not contain too great an excess of acid. It differs from zirconia by the following properties. 1. After being heated to redness it is still capable of being dissolved in acids. 2. Sulphate of potash does not precipitate it from its solutions, while it precipitates zirconia from a solution, containing even a considerable excess of acid. 3. It is precipitated by oxalate of ammonia, which is not the case with zirconia. 4. Sulphate of thorina crystallizes readily, while sulphate of zirconia, supposing it free from alkali, forms, when dried, a gelatinous transparent mass, without any tendency to crystallization.

APPENDIX.

[As Dr. Thomson seems to rely greatly on Dr. Prout's calculations in 6 Ann. of Phil. 321, it seems desirable to give here, Dr. Thomson's and Dr. Prout's views of the atomic theory, that nothing may be wanting to render Dr. Thomson's calculations and the principles he has adopted, intelligible. I have, therefore, thought it right to insert in this Appendix, Dr. Thomson's view of the atomic theory, his remarks on Dr. Prout's memoir, and the memoir itself.—C.]

No. I.

On the Proportions in which Bodies Combine Chemically.—By Dr. Thomson, from 5 Ann. of Phil. p. 8.

THAT the ultimate particles of matter consist of *atoms*, incapable of farther subdivision, is an opinion which has been pretty generally received among philosophers ever since the time of the Greeks; and since the establishment of the Newtonian philosophy this opinion has become almost universal. That substances always enter into chemical combination, in determinate proportions which never vary, has been known ever since chemists acquired the art of analysing bodies. Thus carbonate of lime, wherever, or in whatever state, it occurs, is always a compound of 43·2 carbonic acid and 57·8 lime; and sulphate of barytes, of 34·5 sulphuric acid and 65·5 barytes. In like manner, the yellow oxide of lead is always a compound of 100 lead and 7·7 oxygen; and red oxide of mercury, of 100 mercury and 8 oxygen. Sulphuric acid is always composed of three parts of oxygen and two parts of sulphur; and carbonic acid, of 2000 oxygen and 751 carbon. This law is universally admitted by chemists; and, indeed, the more rigorously it has been examined the more conspicuous and decided have become the proofs in its favour. Even Berthollet, who seems to be an enemy to the atomic theory in the abstract, has admitted that all known compounds unite in determinate proportions; and has endeavoured to reconcile this fact to his own opinions by several highly ingenious, and some rather whimsical, arguments. The few exceptions which he was able to muster up against the law have all disappeared before the more rigid and exact examination of modern analyses.

Mr. Dalton was the first person who ventured to account for this fixedness in chemical proportions. According to him, it is the atoms of bodies that unite together.* One atom of a body, *a*,

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* [The atomic theory was first stated and explained by Dr. Bryan Higgins, in 1789, as Sir H. Davy acknowledges, Elem. of Chem. Phil. p. 60.—C.]

unites with one atom of a body, *b*, or with two atoms of it, or with three, four, &c. atoms of it. The union of one atom of *a* with one atom of *b* produces one compound, the union of one atom of *a* with two atoms of *b* produces another compound, and so on. Each of these compounds, of course, must consist of the same proportions, because the weight of every atom of the same body must of necessity be the same.

We have no means of demonstrating the number of atoms which unite together in this manner in every compound; we must, therefore, have recourse to conjecture. If two bodies unite only in one proportion, it is reasonable to conclude that they unite atom to atom. Hence it is most likely that water is composed of one atom of oxygen and one atom of hydrogen; oxide of silver, of one atom silver and one atom oxygen; and oxide of zinc, of one atom zinc and one atom oxygen.

When a body has the property of uniting with various doses of oxygen, we can then determine the number of atoms which constitute the compounds. Thus manganese unites with four doses of oxygen; and supposing the manganese to be represented by 100, the oxygen of each respective oxide is represented by the numbers 14, 28, 42, 56; but these numbers are to each other as the numbers one, two, three, four. Hence the first oxide is composed of one atom manganese and one atom oxygen; the second, of one atom manganese and two atoms oxygen; the third, of one atom manganese and three atoms oxygen; and the fourth, of one atom manganese and four atoms oxygen. In like manner, as mercury combines with two doses of oxygen, and forms two oxides, the first composed of 100 mercury and four oxygen, and the second of 100 mercury and eight oxygen, it is obvious that the first must be a compound of one atom mercury and one atom oxygen, and the second of one atom mercury and two atoms oxygen.

Nor is there any difficulty with respect to iron. There are two oxides of that metal: the first composed of 100 iron and 28 oxygen; the second of 100 iron and 42 oxygen. Now as 28 is to 42 as two to three, it follows that the first is a compound of one atom iron and two atoms oxygen; the second, of one atom iron and three atoms oxygen. The same rule holds good with respect to the oxides of nickel and cobalt.

If we know the number of atoms of which a body is combined, and the proportion of the constituents, there is no difficulty in determining the proportional weight of the atoms of which it is composed. Thus if water be composed of one atom of oxygen and one atom of hydrogen, and if the weight of the oxygen in water is to that of the hydrogen as 7½ to one, then it follows that the weight of an atom of oxygen is to that of an atom of hydrogen as 7½ to one. If black oxide of mercury be composed of one atom of mercury and one atom of oxygen, and if it be composed of 100 mercury and four oxygen, then an atom of mercury is to the weight of an atom of oxygen as 100 to four, or as 25 to one. If black oxide of iron be composed of one atom iron and two atoms oxygen, and if it consist of 100 iron and 28 oxygen, then an atom of iron is to an atom of oxygen as 100 to 14, or as 7·142 to one. Such is the method of determining the weight of an atom of the different substances upon which experiment has hitherto been made. The advantage of such a knowledge is immense; because it gives us the proportions in which the different substances unite together, and even enables us to calculate the proportional constituents of all compound bodies, independent of experiment, and with more accuracy than would result from experiments unless conducted with uncommon precautions.

Hitherto the only persons who have written upon the subject of chemical atoms are Mr. Dalton, Sir Humphry Davy, Dr. Berzelius, Dr. Wollaston, and myself. Mr. Dalton made choice of hydrogen as his unit, because it is the lightest of all the atoms; and Sir H. Davy has followed his example. But as oxygen enters into a much greater number of compounds than any other body, it was chosen by Dr. Wollaston and Dr. Berzelius as the most convenient unit; and in the tables of atoms which I have published in the different volumes of the *Annals of Philosophy*, I have followed their example. Berzelius considers an atom of oxygen to weigh 100, Wollaston makes it weigh 10, and I myself make its weight one. The reader will perceive that these three numbers are the same, the only difference being the position of the decimal point.

The person who has hitherto made the greatest number of experiments upon this important subject is Dr. Berzelius; and he has considered himself as entitled, by the results which he has obtained, to establish two propositions which he considers as axioms or chemical first principles, and which have a prodigious influence on the whole doctrine. These axioms are the following:—

1. In all compounds of inorganic matter one of the constituents is always in the state of a single atom. According to this axiom, no inorganic compound is ever composed of two atoms of *a* united with three atoms of *b*, or of three atoms of *a* united with four atoms of *b*, &c.; but always of one atom of *a* united with one, two, three, four, &c. atoms of *b*. This axiom, if it hold good, which Berzelius thinks it will, greatly simplifies the doctrine of atomic combination, as far as inorganic bodies are concerned, and reduces the whole to a state of elementary facility.

2. When an acid unites to a base, the oxygen in the acid is always a multiple of the oxygen in the base by a whole number, and generally by the number denoting the atoms of oxygen in the acid. Thus sulphuric acid contains three atoms of oxygen: 100 parts of it contain 60 oxygen; and 100 parts of sulphuric acid combine with, and saturate, a quantity of base which contains 20 oxygen. Now 20 multiplied by three, the number of atoms of oxygen in

sulphuric acid, makes 60 the quantity of oxygen in 100 of sulphuric acid.

Such are the two axioms of Berzelius, which he has made the foundation of his whole reasoning, and from which he has deduced his rules for determining the proportion of oxygen in bodies, and the number of atoms of which they are composed. If they hold good, and hitherto they have answered wonderfully well, they must be admitted to be of the utmost importance, and to give a facility and elegance to our chemical investigations which could scarcely have been looked for.

Mr. Dalton, the founder of the atomic theory, has not adopted either of these axioms. At the same time he has not advanced any fact in opposition to them; but only that there is nothing in the atomic theory which necessarily leads to their adoption. This is doubtless true. The axioms are merely empyrical, and deductions from analyses. Yet if they hold in all the analyses hitherto made, we cannot well refuse them a good deal of generality; and the best mode of proceeding seems to be to admit them till some exception to them be discovered.

Berzelius, considering the atomic theory to labour under difficulties, which in the present state of our knowledge we are not able to surmount, has substituted in its place another, which he conceives to be easier and simpler. This may be called the theory of volumes. He conceives bodies to be all in the gaseous state, and embraces the opinion of Gay-Lussac, that gaseous bodies always unite in volumes that are aliquot parts of each other. One volume of one body always unites with one, two, three, &c. volumes of another. How this alteration, which consists merely in the substitution of the word *volume* for *atom*, simplifies the atomic theory, or removes any of the difficulties under which it labours, is, I own, beyond my comprehension. But Berzelius has deserved so well of chemistry, that he may be indulged in any innocent whim which produces no deterioration.

I should take up too much room were I here to give a table of the weights of the atoms of bodies. I must satisfy myself with referring to the different papers which I have inserted in the *Annals of Philosophy* on the subject, to the paper of Berzelius in the third volume of the *Annals*, in which will be found his table of the weights of an atom of the simple substances, and to Dr. Wollaston's scale of chemical equivalents. The weights given in these three different tables do not always coincide with each other; but in general a very near approach to coincidence will be perceived. In some cases the weights that I have assigned are half those given by Berzelius. The reason of this is obvious; and the circumstance can occasion no difficulty or ambiguity.

No. II.

On the Relation between the Specific Gravities of Bodies in their Gaseous State and the Weights of their Atoms.—Ann. Phil. 6.

The author of the following essay submits it to the public with the greatest diffidence; for though he has taken the utmost pains to arrive at the truth, yet he has not that confidence in his abilities as an experimentalist as to induce him to dictate to others far superior to himself in chemical acquirements and fame. He trusts, however, that its importance will be seen, and that some one will undertake to examine it, and thus verify or refute its conclusions. If these should be proved erroneous, still new facts may be brought to light, or old ones better established, by the investigation; but if they should be verified, a new and interesting light will be thrown upon the whole science of chemistry.

It will perhaps be necessary to premise that the observations about to be offered are chiefly founded on the doctrine of volumes as first generalized by M. Gay-Lussac; and which, as far as the author is aware at least, is now universally admitted by chemists.

On the Specific Gravities of the Elementary Gases.

1. *Oxygen and Azote.*—Chemists do not appear to have considered atmospheric air in the light of a compound formed upon chemical principles, or at least little stress has been laid upon this circumstance. It has, however, been long known to be constituted by bulk of four volumes of azote and one volume of oxygen; and if we consider the atom of oxygen as 10, and the atom of azote as 17·5, it will be found by weight to consist of one atom of oxygen* and two atoms of azote, or per cent. of—Oxygen 22·22†—Azote 77·77.

Hence, then, it must be considered in the light of a pure chemical compound; and indeed nothing but this supposition will account for its uniformity all over the world, as demonstrated by numerous experiments. From these data the specific gravities of oxygen and

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* [Two atoms of azote = 35
One atom of oxygen = 10
—
45

$\frac{100}{45} = 22{\cdot}222$

100 — 22·222 = 77·777.

The numbers 10 and 17·5 are adopted from Wollaston's table of equivalents.—C.]

† [These numbers seem substituted to make out the supposition of common air consisting of two atoms of azote and one of oxygen. The most accurate *experiments* seem to rest on 21 as the proportion of oxygen and 79 nitrogen or azote.—C.]

azote (atmospheric air being 1·000) will be found to be,*—Oxygen 1·1111—Azote ·9722.

2 *Hydrogen.*—The specific gravity of hydrogen, on account of its great levity, and the obstinacy with which it retains water, has always been considered as the most difficult to take of any other gas. These obstacles made me (to speak in the first person) despair of arriving at a more just conclusion than had been before obtained by the usual process of weighing; and it occurred to me that its specific gravity might be much more accurately obtained by calculation from the specific gravity of a denser compound into which it entered in a known proportion. Ammoniacal gas appeared to be the best suited to my purpose, as its specific gravity had been taken with great care by Sir H. Davy, and the chance of error had been much diminished from the slight difference between its sp. gr. and that of steam. Moreover, Biot and Arrago had obtained almost precisely the same result as Sir H. Davy. The sp. gr. of ammonia,

* Let x = sp. gr. of oxygen. 22·22 = a
y = sp. gr. of azote. 77·77 = b

Then $\frac{x+4y}{5} = 1.$

And $x : 4y :: a : b.$

(*)Hence $5 - 4y = \frac{4ay}{b}$

And $y = \frac{5b}{4a+4b} = \cdot 9722.$ And $x = 5 - 4y = 1\cdot 11111.$

(*) [Some intermediate steps of the equation, which Dr. Prout has abbreviated, would perhaps make the calculation easier to a young algebraist.

$x : 4y :: a : b.$

Then, the product of the extremes multiplied together, equal the product of the means, *i.e.*

$xb = 4ay$

$x = \frac{4ay}{b}$

But it has been found before, that

$\frac{x+4y}{5} = 1$, hence

$x + 4y = 5$, and

$x = 5 - 4y$, but

$5 - 4y = \frac{4ay}{b}$ because it is equal to x

$5b - 4by = 4ay$

$5b = 4ay + 4by$

$\frac{4ay + 4by}{4a + 4b} = y$, and

$\frac{5b}{4a+4b} = y$, or which is the same

$y = \frac{5b}{4a+4b}$ but

$\frac{5b}{4a+4b} = \cdot 9722$, therefore

$y = \cdot 9722$, and

$x = 5 - 4y$, or 1·1111.—C.]

according to Sir H. Davy, is ·590164, atmospheric air being 1·000. We shall consider it as ·5902; and this we are authorised in doing, as Biot and Arrago state it somewhat higher than Sir H. Davy. Now ammonia consists of three volumes of hydrogen and one volume of azote condensed into two volumes. Hence the sp. gr. of hydrogen will be found to be ·0694,[*] atmospheric air being 1·0000. It will be also observed that the sp. gr. of oxygen as obtained above is just 16 times that of hydrogen as now ascertained, and the sp. gr. of azote just 14 times.[†]

3. *Chlorine.*—The specific gravity of muriatic acid, according to Sir H. Davy's experiments, which coincide exactly with those of Biot and Arrago, is 1·278. Now if we suppose this sp. gr. to be erroneous in the same proportion that we found the sp. gr. of oxygen and azote to be above, (which, though not rigidly accurate, may yet be fairly done, since the experiments were conducted in a similar manner), the sp. gr. of this gas will come out about 1·2845;[‡] and since it is a compound of one volume chlorine and one volume hydrogen, the specific gravity of chlorine will be found by calculation to be 2·5.[§] Dr. Thomson states, that he has found 2·483 to be near the truth,[||] and Gay-Lussac almost coincides with him.[¶] Hence there is every reason for concluding that the sp. gr. of chlorine does not differ much from 2·5. On this supposition, the sp. gr. of chlorine will be found exactly 36 times that of hydrogen.

On the Specific Gravities of Elementary Substances in a Gaseous State, that do not at ordinary Temperatures exist in that State.

1. *Iodine.*—I had some reason to suspect that M. Gay-Lussac had in his excellent memoir rated the weight of an atom of this substance somewhat too high; and in order to prove this, 50 grains of iodine, which had been distilled from lime, were digested with 30 grs. of very pure lamellated zinc. The solution formed was transparent and colourless; and it was found that 12·9 grains of zinc had been dissolved. 100 parts of iodine, therefore, according to this experiment, will combine with 25·8 parts of zinc, and the weight of an atom of iodine will be 155,[**] zinc being supposed to be

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[*] Let $x =$ sp. gr. of hydrogen.

Then $\frac{3x + \cdot 9722}{2} = \cdot 5902$.

Hence $x = \frac{1 \cdot 1804 - \cdot 9722}{3} = \cdot 0694$.

[†] $1 \cdot 11111 \div \cdot 0694 = 16$. And $\cdot 9722 \div \cdot 0694 = 14$.

[‡] As 1·104 : 1·11111 :: 1·278 : 1·286.
And as ·969 : ·9722 :: 1·278 : 1·283. The mean of these is 1·2845.

[§] Let $x =$ sp. gr. of chlorine.

Then $\frac{x + \cdot 0694}{2} = 1 \cdot 2845$.

And $x = 2 \cdot 569 - \cdot 0694 = 2 \cdot 5$ very nearly.

[||] Annals of Philosophy, iv. p. 13.

[¶] Ibid. vi. p. 126.

[**] As 25·8 : 100 :: 40 : 155. According to experiment 8th, stated below, the weight of

40. From these data, the sp. gr. of iodine in a state of gas will be found by calculation to be 8·611111, or exactly 124 times that of hydrogen.[*]

2. *Carbon.*—I assume the weight of an atom of carbon at 7·5. Hence the sp. gr. of a volume of it in a state of gas will be found by calculation to be ·4166, or exactly 12 times that of hydrogen.

3. *Sulphur.*—The weight of an atom of sulphur is 20. Hence the specific gravity of its gas is the same as that of oxygen, or 1·1111, and consequently just 16 times that of hydrogen.

4. *Phosphorus.*—I have made many experiments in order to ascertain the weight of an atom of this substance; but after all, have not been able to satisfy myself, and want of leisure will not permit me to pursue the subject further at present. The results I have obtained approached nearly to those given by Dr. Wollaston, which I am therefore satisfied are correct, or nearly so, and which fix phosphorus at about 17·5, and phosphoric acid at 37·5,[†] and these numbers at present I adopt.

5. *Calcium.*—Dr. Marcet found carbonate of lime composed of 43·9 carbonic acid and 56·1 lime.[‡] Hence as 43·9 : 56·1 : : 27·5 : 35·1, or 35 very nearly; and 35 — 10 = 25, for the atom of calcium. The sp. gr. of a volume of its gas will therefore be 1·3888, or exactly 20 times that of hydrogen.

6. *Sodium.*—100 grains of dilute muriatic acid dissolved 18·6 grs. of carbonate of lime, and the same quantity of the same dilute acid dissolved only 8·2 grs. of carbonate of lime, after there had been previously added 30 grs. of a very pure crystallized subcarbonate of soda. Hence 30 grs. of crystallized subcarbonate of soda are equivalent to 10·4 grs. of carbonate of lime, and as 10·4 : 30 : : 62·5 : 180. Now 100 grs. of crystallized subcarbonate of soda were found by application of heat to lose 62·5 of water. Hence 180 grs. of the same salt contain 112·5 water, equal to 10 atoms, and 67·5 dry subcarbonate of soda, and 67·5 — 27·5 = 40 for the atom of soda, and 40 — 10 = 30 for the atom of sodium. Hence a volume of it in a gaseous state will weigh 1·6666, or exactly 24 times that of hydrogen.

7. *Iron.*—100 grs. of dilute muriatic acid dissolved as before 18·6 grs. of carbonate of lime, and the same quantity of the same

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an atom of zinc is 40. Dr. Thomson makes it 40.9, which differs very little. See Annals of Philosophy, iv. p. 94.

[*] One volume of hydrogen combines with only half a volume of oxygen, but with a whole volume of gaseous iodine, according to M. Gay-Lussac. The ratio in volume, therefore, between oxygen and iodine is as $\frac{1}{2}$ to 1, and the ratio in weight is as 1 to 15·5. Now ·5555, the density of half a volume of oxygen, multiplied by 15·5, gives 8·61111, and 8·61111 ÷ ·06944 = 124. Or, generally, to find the sp. gr. of any substance in a state of gas, we have only to multiply half the sp. gr. of oxygen by the weight of the atom of the substances with respect to oxygen. See Annals of Philosophy, v. p. 105.

[†] Some of my experiments approached nearer to 20 phosphorus and 40 phosphoric acid.

[‡] I quote on the authority of Dr. Thomson, Annals of Philosophy, iii. p. 376. Dr. Wollaston makes it somewhat different, or that carbonate of lime consists of 43·7 acid and 56·3 lime. Phil. Trans. civ. p. 8.

acid dissolved 10·45 of iron. Hence as 18·6 : 10·45 :: 62·5 : 35·1, or for the sake of analogy, 35, the weight of an atom of iron. The sp. gr. of a volume of this metal in a gaseous state will be 1·9444, or exactly 28 times that of hydrogen.

8. *Zinc.*—100 grs. of the same dilute acid dissolved, as before, 18·6 of carbonate of lime and 11·85 of zinc. Hence as 18·6 : 11·85 :: 62·5 : 39·82, the weight of the atom of zinc, considered from analogy to be 40. Hence the sp. gr. of a volume of it in a gaseous state will be 2·222, or exactly 32 times that of hydrogen.

9. *Potassium.*—100 grs. of the same dilute acid dissolved, as before, 18·6 carbonate of lime; but after the addition of 20 grs. of super-carbonate of potash, only 8·7 carbonate of lime. Hence 20 grs. of super-carbonate of potash are equivalent to 9·9 carbonate of lime; and as 9·9 : 20 :: 62·5 : 126·26, the weight of the atom of super-carbonate of potash. Now $126{\cdot}26 - \overline{55 + 11{\cdot}25} = 60$, the weight of the atom of potash, and 60 — 10 = 50, the weight of the atom of potassium. Hence a volume of it in a state of gas will weigh 2·7777, or exactly 40 times as much as hydrogen.

10. *Barytium.*—100 grs. of the same dilute acid dissolved exactly as much again of carbonate of barytes as of carbonate of lime. Hence the weight of the atom of carbonate of barytes is 125; and 125 — 27·5 = 97·5, the weight of the atom of barytes, and 97·5 — 10 = 87·5, the weight of the atom of barytium. The sp. gr. therefore, of a volume of its gas will be 4·8611, or exactly 70 times that of hydrogen.

With respect to the above experiments, I may add, that they were made with the greatest possible attention to accuracy, and most of them were many times repeated with almost precisely the same results.

The following tables exhibit a general view of the above results, and at the same time the proportions, both in volume and weight, in which they unite with oxygen and hydrogen: also the weights of other substances, which have not been rigidly examined, are here stated from analogy.

TABLE I.—*Elementary Substances.*

Name.	Sp. gr. hydro. being 1.	Wt. of atom, hydrogen being 1	Wt. of atom, oxygen being 10.	Wt. of atom, oxygen being 10, from experiment.	Sp. gr. atmospheric air being 1.	Sp. gr. atmospheric air being 1, from experiment.	Wt. in grs. of 100 cub. inches. Barom. 30. Therm. 60.	Wt. in grs. of 100 cub. inch. from exper.	Observations.
Hydrogen .	1	1	1·25	1·32	·06944	·073 *a*	2·118	2·23	*a* Dr. Thomson. See Annals of Philosophy, i. 177.
Carbon . .	6	6	7·5	7·54*b*	·4166	—	12·708	—	*b* Dr. Wollaston, from Biot and Arrago. Phil. Trans. civ. 20. Dr. Thomson makes it 7·51. Annals of Philosophy, ii. 42.
Azote . .	14	14	17·5	17·54	·9722	·969 *c*	29·652	29.56	*c* Dr. W. from Biot and Arrago.
Phosphorus	14	14	17·5	17·4 *d*	·9722	—	29·652	—	*d* Dr. W. from Berzelius and Rose.
Oxygen . .	16	8	10	10	1·1111	1·104 *e*	33·888	33,672	*e* Dr. Thomson, from a mean of several experiments.
Sulphur . .	16	16	20	20 *f*	1·1111	—	33·888	—	*f* Dr. W. from Berzelius.
Calcium . .	20	20	25	25·46*g*	1·3888	—	42·36	—	*g* Dr. W. from experiment.
Sodium . .	24	24	30	29·1 *h*	1·6666	—	50·832	—	*h* Dr. W. from Davy.
Iron . . .	28	28	35	34·5 *i*	1·9444	—	59·302	—	*i* Dr. W. from Thenard and Berzelius.
Zinc . . .	32	32	40	41 *k*	2·222	—	67·777	—	*k* Dr. W. from Gay-Lussac.
Chlorine .	36	36	45	44·1 *l*	2·5	2·483*m*	76·248	—	*l* Dr. W. from Berzelius.
									m Quoted from Dr. Thomson. Annals of Philosophy, iv. 13.
Potassium .	40	40	50	49·1 *n*	2·7777	—	84·72	—	*n* Dr. W. from Berzelius.
Barytium .	70	70	87·5	87 *o*	4·8611	—	148·26	—	*o* Dr. W. from Berzelius and Klaproth.
Iodine . .	124	124	155	156·21*p*	8·6111	—	262·632	—	*p* Gay-Lussac. Ann. de Chim. xci. 5.

TABLE II.—*Combinations with Oxygen.*

Name.	Sp. gr. hydro. being 1.	Wt. of atom, hydr. being 1.	Wt. of atom, ox. being 10.	Wt. of atom, ox. being 10, from exper.	Sp. gr. atmos. air being 1.	Sp. gr. atmos. air being 1, from exper.	Wt. of 100 cu. in. Bar. 30. Ther. 60.	Wt. of 100 cu. in. from exp.	Elements by volume.	No. of vol. after combination.	Elements by weight.	Observations.
Water . . .	9	9	11·25	11·32	·625	·6896 *a*	19·062	21·033	·5 ox + 1 hyd	1	1 ox + 1 hyd	*a* Trales, Dr. Thomson, Annals, i. 177.
Carbonic oxide	14	14	17·5	17·54	·9722	·956 *b*	29·652	29·16	·5 ox + 1 ca	1	1 ox + 1 car	*b* Cruickshancks, quoted by Thomson.
Nitrous oxide	22	22	27·5	—	1·5277	1·614 *c*	46·596	49·227	·5 ox + 1 az	1	1 ox + 1 az	*c* Sir H. Davy.
Atmospheric air	14·4	36	45	—	1·000	1·000	30·5	30·5 *d*	·5 ox + 2 az	2·5	1 ox + 2 az	*d* Sir G. S. Evelyn.
Phosphorous acid									·5 ox + 1 ph?		1 ox + 1 ph?	
Oxide of sulphur?									·5 ox + 1 sul?		1 ox + 1 sul?	
Euchlorine .	44	44	55		3·0555	2·409 *e*	93·192	73·474	·5 ox + 1 ch	1?	1 ox + 1 ch	*e* Sir H. Davy.
									·5 ox + 1 iod		1 ox + 1 iod	
Lime . . .	28	28	35	35·46	1·9444	—	59·304	—	·5 ox + 1 cal		1 ox + 1 cal	
									&c.		&c.	
									1 ox + 1 hy *f*		2 ox + 1 hyd	*f* This and all higher combinations of hydrogen with oxygen are unknown.
Carbonic acid	22	22	27·5	27·54	1·5277	1·518 *g*	46·596	46·313	1 ox + 1 car	1	2 ox + 1 car	*g* Saussure.
Nitrous gas .	15	30	37·5		1·0416	1·0388 *h*	31·77	31·684	1 ox + 1 az	2	2 ox + 1 az	*h* Berard.
Phosphoric acid	30	30	37·5	37·4	2·0832	—	63·54	—	1 ox + 1 ph		2 ox + 1 ph	
Sulphurous acid	32	32	40		2·2222	2·193 *i*	67·777	66·89	1 ox + 1 sul	1	2 ox + 1 sul	*i* Sir H. Davy.
									1 ox + 1 ch		2 ox + 1 ch	
									1 ox + 1 iod		2 ox + 1 iod	
									&c.		&c.	
									1·5 ox + 1 car		3 ox + 1 car	
Nitrous acid .	38	38	47·5		2·6388	2·427 *k*	80·484	74·0234	1·5 ox + 1 az	1	3 ox + 1 az	*k* Sir H. Davy.
									1·5 ox + 1 ph		3 ox + 1 ph	
Sulphuric acid	40	40	50	50	2·7777		84·72		1·5 ox + 1 sul	1	3 ox + 1 sul	
									1·5 ox + 1 ch		3 ox + 1 ch	
									1·5 ox + 1 iod		2 ox + 1 iod	
									&c.		&c.	
									2·5 ox + 1 car		5 ox + 1 car	See Gay-Lussac's memoir on iodine above referred to.
Nitric acid . .	54	54	67·5	67·54	3·75		114·372		2·5 ox + 1 az	1	5 ox + 1 az	
									2·5 ox + 1 ph		5 ox + 1 ph	
									2·5 ox + 1 sul		5 ox + 1 sul	
Chloric acid .	76	76	95		5·2777	—	160·968		2·5 ox + 1 ch	1	5 ox + 1 ch	
Iodic acid . .	164	164	205		11·3883		347·352		2·5 ox + 1 iod	1	5 ox + 1 iod	
									&c.		&c.	

TABLE III.—*Compounds with Hydrogen.*

Name.	Sp. gr. hydro. being 1.	Wt. of atom, hydrogen being 1.	Wt. of atom, oxygen being 10.	Wt. of atom, oxygen being 10, from experiment.	Sp. gr. atmospheric air being 1.	Sp. gr. atmospheric air being 1, from experiment.	Wt. of 100 cub. inch. Bar. 30. Ther. 60.	Wt. of 100 cub. inch. from experiment.	Elements by volume.	No. of vol. after condensation.	Elements by weight.	Observations.
Carbureted hydrogen	8	4	5·	5·09	·5555	·5555*a*	16·999	16·999	1 hyd + ·5car	·5	1 hyd + ·5car	*a* Dr. Thomson.
Olefiant gas . . .	14	7	8·75	8·86	·9722	·9740*a*	29·652	29·72	1 hyd + 1 car	·5	1 hyd + 1 car	
Sulphureted hydrogen	17	17	21·25	21·32	1·1805	1·177	36·006	35·89	1 hyd + 1 sul	1	1 hyd + 1 sul	
Muriatic acid . .	18·5	37	46·25	45·42	1·284	1·278	39·183	38·979	1 hyd + 1 chl	2	1 hyd + 1 chl	
Hydriodic acid . .	62·5	125	156·25	157·53	4·3402	4·3463*b*	132·375	—	1 hyd + 1 iod	2	1 hyd + 1 iod	*b* Gay-Lussac.
Ammonia	8·5	17	21·25	21·5 *c*	·5902*d*	·5900	18·003	18·000	3 hyd + 1 az	2	3 hyd + 1 az	*c* Dr. Wollaston. *d* Sir H. Davy.
Cyanogen	26	26	32·5	32·52	1·8055	1·8064*e*	55·068	—	2 car + 1 az	1	2 car + 1 az	*e* Gay-Lussac. Ann. de Chim. Aug. 1815.
Hydro-cyanic acid .	13·5	27	33·75	33·846	·9374	·9360*e*	28·593	—	1 cya + 1 hy	2	1 cya + 1 az	
Chloro-cyanic acid .	31	62	77·5	—	2·1527	2·1111*e*	65·659	—	1 cya + 1 chl	2	1 cya + 1 chl	

TABLE IV.—*Substances stated from Analogy, but of which we are yet uncertain.*

Name.	Sp. gr. hydro. being 1.	Wt. of atom, 2 vol. hydro. being 1.	Wt. of atom, oxygen being 10.	Wt. of atom, oxygen being 10, from exper.	Observations.
Aluminum . .	8	8	10	10·68 *a*	*a* Berzelius.
Magnesium .	12	12	15	14·6 *b*	*b* Henry. Berzelius makes it 15·77.
Chromium . .	18	18	22·5	23·6 *c*	*c* Berzelius.
Nickel . . .	28	28	35	36·5 *d*	*d* Ditto.
Cobalt . . .	28	28	35	36·6 *e*	*e* Rolhoff.
Tellurium . .	32	32	40	40·27 *f*	*f* Berzelius.
Copper . . .	32	32	40	40 *g*	*g* As deduced by Dr. Thomson.
Strontium . .	48	48	60	59 *h*	*h* Klaproth.
Arsenic . . .	48	48	60	60 *i*	*i* Berzelius.
Molybdenum .	48	48	60	60·13 *j*	*j* Bucholz and Berzelius.
Manganese . .	56	56	70	71·15 *k*	*k* Berzelius.
Tin	60	60	75	73·5 *l*	*l* Ditto.
Bismuth . . .	72	72	90	89·94 *m*	*m* Ditto.
Antimony . .	88	88	110	111·11 *n*	*n* Ditto. Dr. Thomson makes it 112·49.
Cerium . . .	92	92	115	114·87 *o*	*o* Hisinger.
Uranium . .	96	96	120	120 *p*	*p* Bucholz.
Tungsten . .	96	96	120	121·21 *q*	*q* Berzelius.
Platinum . .	96	96	120	121·66 *r*	*r* Ditto.
Mercury . .	100	100	125	125 *s*	*s* Fourcroy and Thenard.
Lead	104	104	130	129·5 *t*	*t* Berzelius.
Silver . . .	108	108	135	135 *u*	*u* Wenzel and Davy.
Rhodium . .	120	120	150	149·03 *x*	*x* Berzelius.
Titanium . .	144	144	180	180·1 *y*	*y* Ditto.
Gold	200	200	250	249·68 *z*	*z* Ditto.

Observations.[*]

Table I.—This, as well as the other tables, will be easily understood. In the first column we have the specific gravities of the different substances in a gaseous state, hydrogen being 1: and if we suppose the volume to be 47·21435 cubic inches, the numbers will at the same time represent the number of grains which this quantity of each gas will weigh. In the third column are the corrected numbers, the atom of oxygen being supposed, according to Dr. Thomson, Dr. Wollaston, &c. to be 10: and in the fourth, the same, as obtained by experiment, are stated, to show how nearly they coincide. Of the individual substances mentioned, I have no remark to make, except with respect to iodine. I made but one experiment to ascertain the weight of the atom of this substance, and therefore the results stated may be justly considered as deserv-

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[*] [The reader is referred to Dr. Prout's correction of these observations, in 7 Thom. Ann. of Phil. 111. As I do not exactly understand from Dr. Prout's directions, what sentence is to be expunged, I have permitted the observations to remain, as originally printed. —C.]

ing but little confidence; and indeed this would be the case, did not all the experiments of Gay-Lussac nearly coincide in the same.

Table II.—This table exhibits many striking instances of the near coincidence of theory and experiment. It will be seen that Gay-Lussac's views are adopted, or rather indeed anticipated, as a good deal of this table was drawn up before I had an opportunity of seeing the latter part of that chemist's memoir on iodine. That table also exhibits one or two striking examples of the errors that have arisen from not clearly understanding the relation between the doctrine of volumes and of atoms. Thus ammonia has been stated to be composed of one atom of azote and three of hydrogen, whereas it is evidently composed of one atom of azote and only 1·5 of hydrogen, which are condensed into two volumes, equal therefore to one atom; and this is the reason why this substance, like some others, apparently combine in double proportions.*

Table III.—This table likewise exhibits some striking examples of the coincidence above noticed. Indeed, I had often observed the near approach to round numbers of many of the weights of the atoms, before I was led to investigate the subject. Dr. Thomson appears also to have made the same remark. It is also worthy of observation, that the three magnetic metals, as noticed by Dr. Thomson, have the same weight, which is exactly double that of azote. Substances in general of the same weight appear to combine readily, and somewhat resemble one another in their nature.

On a general review of the tables, we may notice,

1. That all the elementary numbers, hydrogen being considered as 1, are divisible by 4, except carbon, azote, and barytium, and these are divisible by 2, appearing therefore to indicate that they are modified by a higher number than that of unity or hydrogen. Is the other number 16, or oxygen? And are all substances compounded of these two elements?

2. That oxygen does not appear to enter into a compound in the ratio of two volumes or four atoms.

3. That all the gases, after having been dried as much as possible, still contain water, the quantity of which, supposing the present views are correct, may be ascertained with the greatest accuracy.

Others might doubtless be mentioned; but I submit the matter for the present to the consideration of the chemical world.

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* See Gay-Lussac's memoir on iodine, Annals of Philosophy, vi. 189.

END OF VOL. I.